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Extraction and Purification of Inulin from Jerusalem Artichoke with Response Surface Method and Ion Exchange Resins

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ABSTRACT: Inulin is used as an important food ingredient, widely used for its fiber content. In this study the operational extraction variables to obtain higher yields of inulin from Jerusalem artichoke tubers, as well as the optimal conditions, were studied. Response surface methodology and Box−Behnken design were used for optimization of extraction steps. The optimal extraction conditions were as follows: extraction temperature 74 °C, extraction time 65 min, and ratio of liquid to solid 4 mL/g. Furthermore, series connection of ion-exchange resins were used to purify the extraction solution where the optimal resin combinations were D202 strongly alkaline anion resin, HD-8 strongly acidic cation resin, and D315 weakly alkaline resin while the decolorization rate and decreased salinity reached 99.76 and 93.68, respectively. Under these conditions, the yield of inulin was 85.4 ± 0.5%.
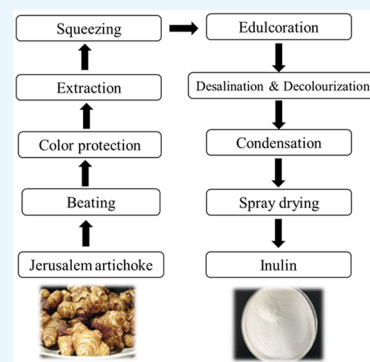
INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.) is a plant native to North America, which also called sunchoke, sunroot, topinambur, or earth apple.[1,2] Jerusalem artichoke grows well on arid saline soils land and is resistant to nutrient-poor habitats. Most importantly, it saves land that could be used for food production and can bring in large quantities of tubers for inulin extraction.[3]

Inulin is a polysaccharide linked by β-(2,1) linkages of D-fructose bonds and terminated with a glucose residue through a sucrose-type linkage at the reducing end,[4,5] which is a water-soluble storage polysaccharide with a large variety of food and pharmaceutical applications.[6] As a functional polysaccharide, inulin has been extensively applied in low calorie, low sugar, and low fat foods.[7] Moreover, the metabolites of inulin in the body could inhibit pathogen colonization in the prevention of intestinal infections and diseases.[8] Besides, inulin could also be used to delay absorption of drugs with adverse effects on the stomach.[9] Thus, inulin has already received more attention of scientists from both food and pharmaceutical applications.

Given the importance of inulin, more and more attention has been paid to the extraction of inulin from Jerusalem artichoke. Currently, inulin can be traditionally extracted by hot water.[10] However, hot water extraction generally employs a large amount of water, high energy consumption, and high liquid-to-solid ratio, which restricts the industrialization of inulin. Enzymatic extraction requires precise control of temperature and pH value according to enzyme activity, which requires strict extraction conditions.[11] In recent years, the method of microwave extraction and ultrasound-assisted extraction have been widely used with higher yield and less

time.[12,13] However, the ultrasonic would easily interrupt the polysaccharide molecules and change the physicochemical properties of inulin and limited the application in inulin extraction.[13,14] In order to make up for the shortcomings of the above methods, the middle-low temperature water method has been carried out for extracting inulin in our study. The experimental design method is used to optimize the factors and obtain cost-effective and acceptable results with the least number of test runs. Experimental design methods can be used to evaluate the interactions and relationships between variables.[15,16] Generally, response surface methodology (RSM) is an efficient statistical technique for testing complex processes factors and their reciprocal interaction. Meanwhile, RSM can be used to reduce the number of experimental trials needed to evaluate extraction conditions and their interactions. In addition, it has been widely used in optimizing many biochemical processes.[17] The Box−Behnken design (BBD) is an effective alternative (three-level factor quadratic design), where the experimental points are located at the midpoint and the central point (central point) on the edges of the cube.[18] The special arrangement of the BBD levels allows the number of design points to increase at the same rate as the number of polynomial coefficients. One advantage of BDD is that it does not contain a combination of all factors being at the highest or

lowest level at the same time. Therefore, these designs could be used to avoid unsatisfactory experimental results that may occur under extreme conditions.[19,20]

The crude extract of inulin not only contains abundant impurities such as pectin and protein but also has a tan color.[21] Consequently, in order to obtain high purity inulin products, the crude extract needs to be desalted and decolorized. Ion-exchange resin has been widely used in medicine and health, biological engineering, and industrial high purity water preparation industry with the selection, exchange, catalysis, adsorption functions.[22−24] The adsorption effect of ion-exchange resin depends on the ion-exchange ability of resin itself. During sample processing, the hydroxyl ions carried by the alkaline ion-exchange resin would be exchanged with anions in the solution and the anions in the solution would be adsorbed in the resin particles, which could result in the elution liquid exhiting alkaline properties due to the large amount of hydroxyl ions exchanged. Similarly, the cation in the solution interacts with the hydrogen ions of the acidic ion-exchange resin, and the liquid would exhibit acidic proper-ties.[25,26] As the impurity removal effect is not good with a single resin, we combine different properties of ion-exchange resin in series to achieve the required pH for industrial production. In view of the special properties of inulin, it would be degraded under the condition of an inappropriate acid−base environment, the desalting and decolorization of crude extract can be accomplished by series connection of resin.

The purpose of the present study is to optimize the process for production of high purity inulin from Jerusalem artichoke with the middle-low temperature water extraction method and desalination and decolorization process. RSM and the BBD based on a three-level and three-variable central composite is used to optimize the extraction process. The desalination and decolorization effect of Jerusalem artichol extract are studied by series connection of ion-exchange resins.

■ RESULTS AND DISCUSSION

Effects of the Extraction Temperature on the Extraction Yield of Inulin. Extraction temperature would influence the extraction efficiency and selectivity. The reaction temperature was set at 50, 60, 70, and 80 °C. The extraction time was fixed at 60 min, the ratio of liquid to solid was fixed at 2 mL/g. As shown in Figure 1a, the inulin yield increased dramatically when the temperature was below 70 °C, while the inulin yield increased slowly when the temperature was over 70 °C. With an increase of temperature, the molecular thermal movement is accelerated, as well as the polysaccharide dissolution rate. In addition, with the increase of temperature, the solubility and viscosity of inulin increased. But a higher temperature beyond 70 °C will cause degradation of inulin polysaccharide.[27,28] Consequently, 70−80 °C was considered to be the optimal extraction temperature, which was consistent with the reported optimal extraction temperature of poly-saccharides.[17]

Effects of the Extraction Time on the Extraction Yield of Inulin. As shown in Figure 1b, with the extension of extraction time, inulin yield increased.[29] The extraction time was carried out ranging from 30 to 75 min while other extraction variables were set as follows: the extraction temperature was 60 °C, the ratio of liquid to solid was 2 mL/g. The results suggested that the inulin yield reached 85.7% at 60 min. However, the inulin yield declined sharply when the time was over or below 60 min. At the initial stage,
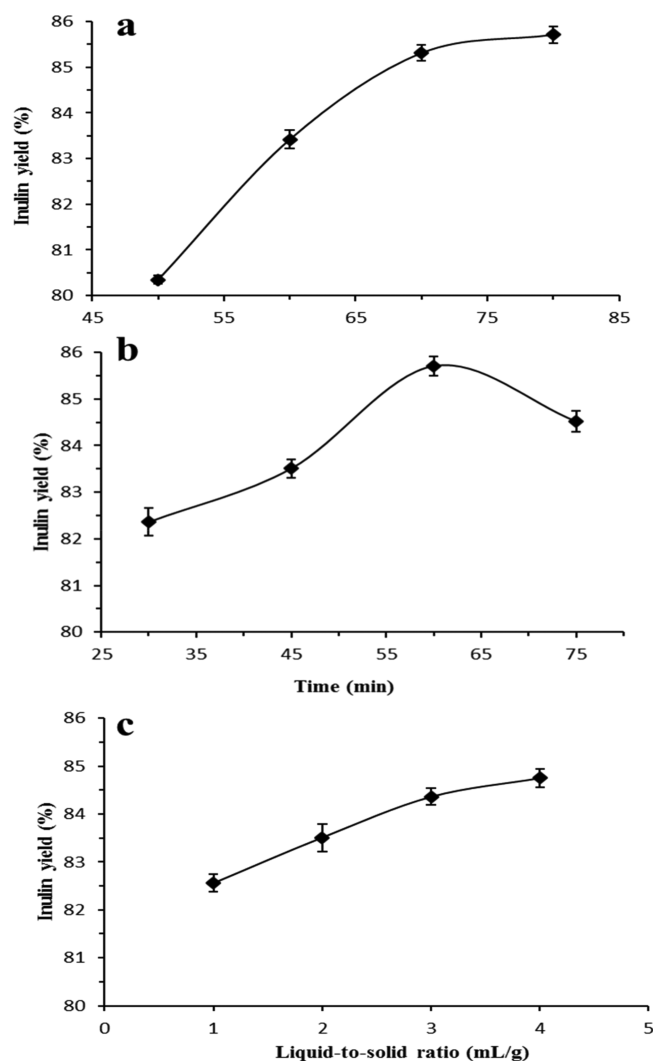
Figure 1. Effect of extraction parameters on the yield of inulin (extraction temperature, °C, extraction time, min, ratio of liquid to solid, mL/g).

the inulin yield was low, which increased the inulin leaching rate. With the increase of extraction time, the yield gradually increased and tended to reach the equilibrium state of saturation. Furthermore, inulin would be hydrolyzed after a long time extraction, which caused the inulin yield to decline. Thus, extraction of 55−65 min was favorable for producing the inulin.

Effects of the Ratio of Liquid to Solid on the Extraction Yield of inulin. Different ratios of liquid to solid on extraction of inulin were presented in Figure 1c. Inulin could not be completely extracted as the liquid to solid ratio was too small. Inversely, if the ratio was too large, it would cause high process costs.[30] In this study, extraction was carried out at different ratios ranging from 1 to 4 mL/g while other extraction conditions were as follows: the extraction time of 60 min, the extraction temperature of 60 °C. The results showed that the inulin yield increased with the increaseing ratio of liquid to solid. The maximum yield of inulin was 84.8% when the ratio of liquid to solid was 1:4. With the increase of the liquid−solid ratio, the mass transfer driving force during extraction increased, which was beneficial to improve the extraction yield. However, if the used amount of water was too

large, the energy consumption of subsequent processes would increase and the efficiency would decrease.[31]

Statistical Analysis and the Model Fitting. Compared with single parameter optimization, response surface optimization was of many merits: conserved space, time, and raw material.[32] In this study, a three-level and three-variable Box—Behnken design (BBD) was applied to determine the best combination of the three extraction variables including extraction temperature (X_1), extraction time (X_2), and the ratio of liquid to solid (X_3).[33] As shown in Table 1, a total of

Table 1. Box—Behnken Experimental Design and Results for the Extraction Yield of inulin

	independent variables			inulin yield (%)	
run	temperature (X_1)	extraction time (X_2)	ratio of liquid to solid (X_3)	experimental values (Y_1)	predicted values (Y_2)
1	−1	1	0	84.35	83.71
2	0	0	0	85.21	85.25
3	0	−1	−1	85.34	85.25
4	1	0	−1	85.75	85.82
5	0	0	0	85.39	85.25
6	0	0	0	85.23	85.25
7	0	1	1	83.98	84.07
8	0	0	0	85.82	85.25
9	−1	−1	0	84.20	84.14
10	1	0	1	84.41	84.25
11	0	−1	1	84.25	84.38
12	1	−1	0	84.63	84.66
13	0	1	−1	85.92	85.79
14	−1	0	1	84.13	84.07
15	−1	0	−1	84.93	85.09
16	1	1	0	84.65	84.71
17	0	0	0	85.20	85.25

17 experimental points were carried out in random order to evaluate the model. Considering the significant variables in Table 1, the model showed a great relationship between the predicted response of the extraction yield of inulin and the extraction parameters. After multiple regression analysis, the predicted response Y could be obtained by the following second-order polynomial equation:

$$Y = 85.21 + 0.2288X_1 + 0.1963X_2 - 0.51X_3$$
$$- 0.0325X_1X_2 - 0.0135X_1X_3 - 0.485X_2X_3$$
$$- 0.2738X_1^2 - 0.4787X_2^2 - 0.1312X_3^2 \qquad (1)$$

The analysis of variance of the experimental results for the quadratic regression model was shown in Table 2. F-test and P-value were used to check the significance of regression equation and each coefficient, respectively. The Model F-value was 19.50, indicating that the model was highly statistically significant, and there was only a 0.04% chance that a "Model F-Value" could occur because of the noise. According to the results of ANOVA of the quadratic predictive model, the determination coefficient R^2 was found to be 0.9616, which implied that only 3.84% analysis was not explained by the model. The value of R_{adj}^2 (0.9123) also indicated that the model was of high significance. In addition, R_{adj}^2 was very close to R^2, which demonstrated the sample size was large enough. The low coefficient variation value (CV%) was 0.2049, clearly indicating that the experimental value had

Table 2. Analysis of Variance (ANOVA) for the Response Surface Quadratic Model for Inulin Yield[a]

| source	sum of squares	df	mean square	F-value	P-value
model	5.29	9	0.5883	19.50	0.0004**
X_1	0.4186	1	0.4186	13.87	0.0074**
X_2	0.3081	1	0.3081	10.21	0.0152*
X_3	2.08	1	2.08	68.96	<0.0001**
X_1X_2	0.0042	1	0.0042	0.1400	0.7193
X_1X_3	0.0729	1	0.0729	2.42	0.1641
X_2X_3	0.9409	1	0.9409	31.38	0.0008**
X_1^2	0.3155	1	0.3155	10.46	0.0144*
X_2^2	0.9651	1	0.9651	31.98	0.0008**
X_3^2	0.0725	1	0.0725	2.40	0.1650
residual	0.2112	7	0.0302		
lack of fit	0.2112	3	0.0704		
pure error	0.000	4	0.0000		
cor total	5.51	16			
std dev	0.1737		R^2	0.9616	
mean	84.79		R_{adj}^2	0.9123	
CV%	0.2049				

[a]df = degree of freedom. *$P < 0.05$. **$P < 0.01$.

high accuracy and reliability. The standardized influence of independent variables and the interactions on dependent variables could be judged by the Pareto chart in Figure S1. The bars, extending beyond the line, corresponded to effects that were statistically significant at the 95% confidence level. The increase or decrease was shown with the positive or negative mark (corresponding to pink or green color), respectively.[34]

By the optimization of factors using the BBD, we understood that extraction temperature and time for the optimization had a significant and positive effect on the extraction yield. The ratio of liquid to solid and other interaction factors showed a negative effect.[35,36] The smaller the P-value was, the bigger the significance of the corresponding coefficient.[37] It can be concluded that the three independent variables (X_1, X_2, X_3), two quadratic terms (X_1^2, X_2^2), and cross product coefficients (X_2X_3) significantly affected the extraction yield of inulin, and P-values were very small ($P < 0.05$). However, other term coefficients were not significant ($P > 0.05$). The results also showed that the independent variable X_3 was the most significant factor on experimental yield of inulin ($P < 0.05$). The full model filled eq 1 and made three-dimensional and contour plots to predict the relationships between the independent variables and the dependent variables.

Optimization of Extraction Conditions of Inulin. The relationships between independent and dependent variables were presented by the three-dimensional response surfaces and two-dimensional contour plots, which obtained by the BBD. In addition, Figure 2 showed the experimental results of the effects of three variables (extraction temperature, extraction time, and the ratio of liquid to solid) on the extraction yield of inulin. In the three variables, the extraction yield of inulin was changed with two continuous variables within the experimental range, while the third variable was fixed constant at its respective zero level. The 3D response surface and 2D contour plots were the graphical representations of the regression function.[38] The effects of extraction temperature on extraction yield were illustrated in Figure 2a,b, which indicated that extraction temperature showed a quadratic effect on the inulin
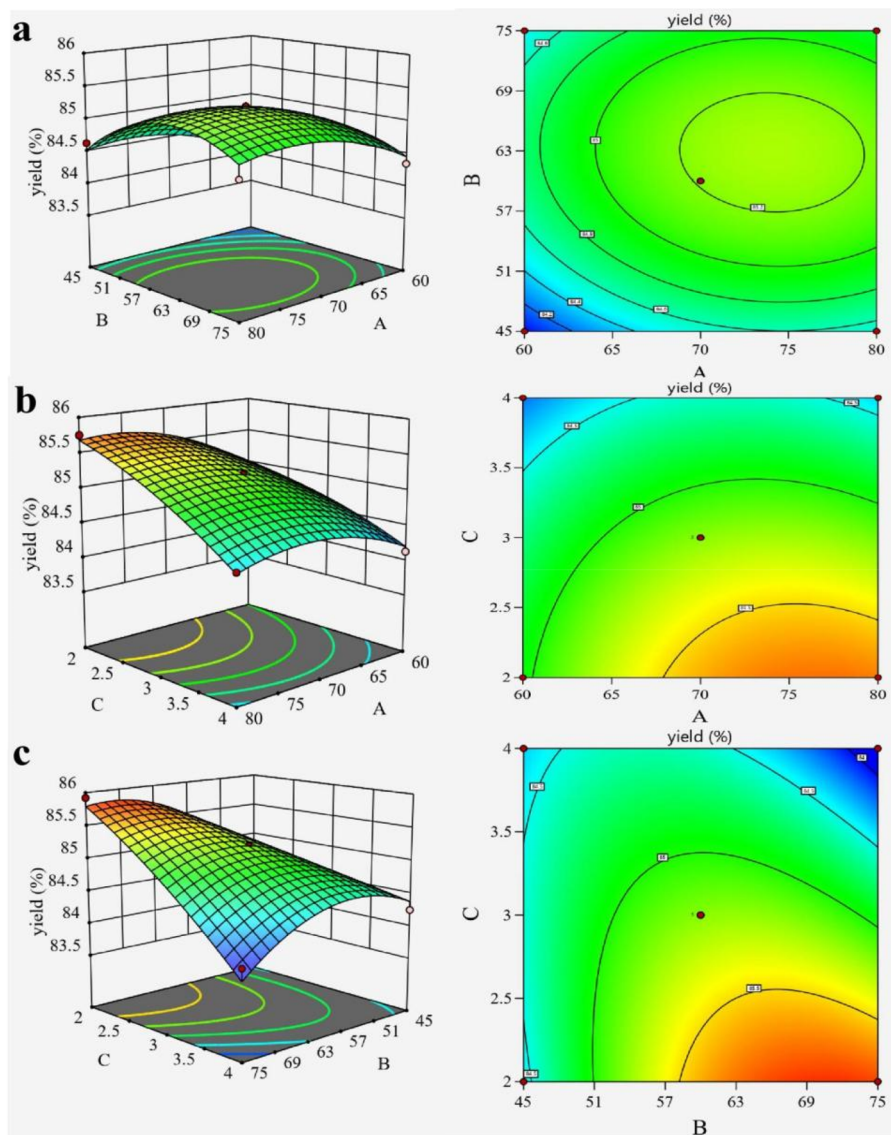
Figure 2. Response surface and contour plots showing the effect of temperature and time (a), temperature and the ratio of liquid to solid (b), and time and the ratio of liquid to solid (c) on the inulin yield.

yield. The inulin yield increased dramatically when the temperature was below 70 °C, while the inulin yield increased slowly when the temperature was beyond 70 °C. The results could be attributed to the increase of viscosity and the degradation of inulin polysaccharide with the increase of temperature.

The three-dimensional surface and contour plots constructed of the independent variables (temperature and the ratio of liquid to solid) indicted that the inulin yield increased linearly with the ratio of liquid to solid added (Figure 2b). This phenomenon indicated that with the increase of the liquid solid ratio, the mass transfer driving force in the extraction process increased, which was beneficial to inulin extraction. As presented in Figure 2c, the inulin yield increased steadily with the extension of the ratio of liquid to solid. Based on the above analysis, the optimal extraction conditions were as follows: the extraction temperature was 74.09 °C, the extraction time was 65.35 min, and the ratio of liquid to solid was 4 mL/g. Under the modified conditions, the inulin yield was up to 86.0%, which was close to the predicted value. According to gradient of slope in the 3D response surface plot (Figure 2). The effect

of various experimental factors on the extraction yield of inulin was the ratio of liquid to solid > extraction temperature > extraction time.

Verification of the Predictive Model. To verify the suitability of the model equations, a verification test was conducted under the optimal conditions and the inulin yield of $85.4 \pm 0.5\%$ was obtained, which indicated that the established model in this study was feasible for the optimization of the inulin extraction process (Table 3).

Comparative Study of Previous Research and This Work on Extraction Conditions. The extraction efficiency of the current method for inulin was compared with other published methods in the literature. As shown in Table S1, it is clear with regard to the extraction parameters such as solid–liquid ratio, extraction temperature, extraction time that the method used in this work performed relatively well compared to other reported studies.[11−13,17] Hu et al. studied the extraction and purification of inulin from Jerusalem artichoke, and a single D218 ion-exchange resin was used for decolorization, for which the inulin extraction yield was 90.76% under the extraction temperature 70 °C, extraction

Table 3. Predicted and Experimental Values of the Responses at Optimum and Modified Conditions

	temperature (°C)	extraction time (min)	ratio of liquid to solid (mL/g)	yield (%)
optimum conditions (predicted)	74.09	65.35	4	86.0
modified conditions (actual)	74	65	4	85.4 ± 0.5

time 90 min, and ratio of liquid to solid 1:15.[25] Compared with previous studies, the current method reduced the solid liquid ratio and water consumption, which reduced the energy consumption of the inulin processing process. The extraction efficiency and inulin yield were improved by effectively inhibiting the Maillard reaction.

Comparison of Desalination and Decolorization Effects Using Ion-Exchange Resin. The Jerusalem artichoke extract with ion-resin-exchange treatment results were presented in Tables 4−6, respectively. The categories of a strongly alkaline anion-exchange resin, strongly acidic cation-exchange resin, and weakly alkaline anion-exchange resin were obtained through comparing the desalination and decolorization effects.

Determination of the Best Series Resin Combination. After the preliminary screening of the series combination of the 10 ion-exchange resins, the scheme with better the desalination and decolorization effect was obtained, and the inulin adsorption effect and saturation tolerance of the best two ion-exchange resin combinations were tested. The optimal series resin combination was as follows: D202 strongly basic anion-exchange resin, 001×7 strongly acidic anion-exchange resin, D315 weakly basic anion-exchange resin, D202 strongly basic anion-exchange resin, HD-8 strongly acidic anion-exchange resin, and D315 weakly basic anion-exchange resin. The peristaltic pump was used to control the rate of 20 r/min, and the liquid was collected every 100 mL to obtain the change curve of the conductivity of the solution which the results was shown in Figure 3.[37]

As indicated in Figure 3, the conductivity of Jerusalem artichoke extract decreased significantly in the initial stage with resin treatment. In series resin combination 1, the electrical conductivity changed from 7310 to 675 μs/cm while the salinity decreased from 0.39% to 0.03%, under the experimental conditions of series combination of D202 strongly basic anion-exchange resin, 001×7 strongly acidic anion-exchange resin, and D315 weakly basic anion-exchange resin. In series resin combination 2, 001×7 strongly acidic cation-exchange resin was replaced with HD-8 strongly acidic cation-exchange resin. The conductivity changed from 8300 to 560 μs/cm while the salinity changes from 0.45% to 0.02%, and then the conductivity gradually increased. We also drew a conclusion from the variation conductivity curve that when the processing volume reached about 1600 mL, the conductivity

and salinity began to increase significantly, which indicated that the resin had gradually reached the adsorption saturation state.[39] With the desalination ability decreased, the salt concentration of eluent was gradually close to the initial sample salt concentration. Therefore, the maximum treatment volume of Jerusalem artichoke extract was about 4 times of that of the ion-exchange resin.

■ **CONCLUSIONS**

In the present study, the extraction process of inulin from Jerusalem artichoke was optimized and the desalination and decolorization effect was studied by series ion-exchange resin. The effects of independent variables (extraction temperature, extraction time, ratio of liquid to solid) on the process were determined. Under the optimum conditions, the optimal experimental yield of 86.0% could be obtained. Meanwhile, the ion-exchange resins with different properties were investigated and screened, where on the basis of the comparison and selection of salinity and conductivity, the optimal resin combination scheme was finally obtained: D202 strongly basic anion-exchange resin, HD-8 strongly acidic cation-exchange resin, and D315 weakly basic anion-exchange resin, with the decolorization rate of 99.76% and decreased salinity of 93.68%. Briefly, the technique of inulin extraction improved the efficiency and inulin yield and reduced energy consumption, which is of great significance for inulin extraction in the future

■ **MATERIALS AND METHODS**

Chemicals. Jerusalem artichokes were supplied by Dongying, Shandong province. Sulfuric acid was obtained from Sinopharm Chemical Reagent Co. Ltd., Beijing, China. Anthranone was purchased from Qiangshun Chemical Reagent Co. Ltd., Shanghai, China. Sodium hydrogen sulfite was procured from Kemiou Chemical Reagent Co. Ltd., Tianjin, China. The ion-exchange resins were supplied by Shanghai Huachen Technology Co., Ltd. All other reagents were all analytical grade and used as received.

Extraction of Inulin. After cleaning with deionized water, the raw Jerusalem artichoke tubers were grated by a crusher with a color fixative (5‰ $NaHSO_3$). Inulin was extracted with middle-low temperature water in a ratio of 2:1 of water to Jerusalem artichoke tubers, and the extracting solution was squeezed three times according to the amount of raw Jerusalem artichoke. The liquid inulin solution obtained were filtered through the gauze after being squeezed. Calcium hydroxide was added to the filtrate to adjust the pH until it reached 13 to remove the protein, and then H_3PO_4 was used to adjust to pH 8 to remove the redundant calcium hydroxide while 30% H_2O_2 (v/v) was used to bleach the solution. The series connection of resin was used for desalination and decolorization. After further concentration by a double-effect evaporator, inulin was finally obtained by spray drying.

Analysis of Inulin Content. The phenol−sulfuric acid method and the 3,5-dinitrosalicylic acid (DNS) method were

Table 4. Screening Results of a Strongly Basic Anion-Exchange Resin

resin type	initial conductivity/(μs/cm)	final conductivity/(μs/cm)	ion removal rate/%	pH	decolorization rate/%
D202	8310	649	92.19	7.35	99.61
201×7	5760	415	92.80	5.81	99.35
chloride type	5760	518	91.01	6.16	99.48

Table 5. Screening Results of a Strongly Acidic Cationic-Exchange Resin

resin type	initial conductivity/(μs/cm)	final conductivity/(μs/cm)	ion removal rate/%	pH	decolorization rate/%
001×7	5760	278	95.17	5.56	99.61
FPC11	5760	472	91.81	6.94	97.93
sodium type	5760	406	92.95	7.46	99.09
HD-8	5190	328	93.68	6.98	99.76
D001	8430	554	93.43	7.42	99.22

Table 6. Screening Results of a Weakly Basic Anion-Exchange Resin

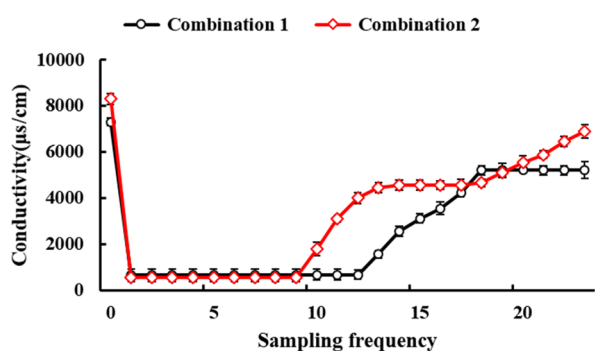| resin type	initial conductivity/ (μs/cm)	final conductivity/ (μs/cm)	ion removal rate/%	pH	decolorization rate/%
D315	5760	278	95.17	6.56	99.61
D301	5760	377	93.45	7.86	97.02

Figure 3. Conductivity change of different resin combination.

adopted to assay the total sugar content and the reducing sugar content, respectively.[17] The percentage of inulin yield was calculated as follows:

$$\text{inulin yield}(\%) = \frac{m_1}{m_2} \times 100 \tag{2}$$

The conductivity was measured with a conductivity meter where m_1 (g) is the weight of inulin in the extract and m_2 (g) is the weight of the Jerusalem artichoke tubers.

Experimental Design. Based on the preliminary experiment, inulin was extracted with middle-low temperature water. The single-factor-test was applied to ascertain the preliminary range of the main extraction variables of extraction temperature (X_1), extraction time (X_2), and ratio of liquid to solid (X_3). The BBD with three levels and three factors was used to optimize the extraction conditions. X_1, X_2, and X_3 were the independent variables while the degree of substitution (Y) was taken as the response of the design experiments. The range of independent variables and their levels was given in Table 7. The actual design of experiments was shown in Table 1, and the general form of the second-order polynomial equation was as follows:

Table 7. Independent Variables and Their Levels Used in the Response Surface Design

		levels	
independent variables	−1	0	1
temperature (°C)	60	70	80
extraction time (min)	45	60	75
ratio of liquid to solid (mL/g)	4	3	2

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ii} X_i X_j \tag{3}$$

where Y is the dependent variable, β_0 is a constant, β_i, β_{ii}, and β_{ij} are coefficients evaluated by the model, and X_i and X_j are the independent variables ($i \neq j$).

Effects of Ion-Exchange Resin on Desalination and Decolorization of Jerusalem Artichoke Extract. The newly produced resin usually contained a variety of impurities. Therefore, the resin was usually rinsed with deionized water to remove impurities for pretreatment. Cationic resin and anionic resin should be pretreated before use in inulin extraction according to the reported method with minor modification.[40,41] In order to ensure that inulin products met the food standards, it was required that the Jerusalem artichoke extract after desalination should be neutral, which could avoid the degradation of inulin. Therefore, in the process of desalination and decolorization, the ion-exchange resin was usually arranged in the order of strong alkali, strong acid, and weak alkali to ensure that the final liquid pH was close to neutral.[22,42] According to the series mode of strongly basic anion-exchange resin, strongly acidic cation-exchange resin, and weakly basic anion-exchange resin, 400 mL of the ion-exchange resin is loaded into the column to form an ion-exchange column combination.[43,44] Three kinds of resins were used to test the desalination and decolorization effect of Jerusalem artichoke extract by measuring salinity, conductivity, and absorbance. In our study, the desalination and decolorization effects of 10 kinds of ion-exchange resins were preliminarily screened. The strongly basic anion-exchange resins (D202, 201 × 7, chlorine type) were selected to form a series resin combination with 001×7 strongly acidic cation-exchange resin column and D315 weakly basic anion-exchange resin column, respectively, to process extract solution to select the optimal combination. Strongly acidic cation-exchange resins (001×7, FPC11, sodium type, HD-8, D001) were respectively combined with a D202 strongly basic anion-exchange resin column and a D315 weakly basic anion-exchange resin column. Finally, the anion-exchange resins (D301 and D315) were respectively combined in series with the strongly basic anion-exchange resin and the strongly acidic cation-exchange resin column with the best screening effect. The extract of Jerusalem artichoke was separated by three ion-exchange columns.[45,46]

According to the determination method stipulated by the National Soft Drink Association (NSDA), the absorbance of the solution was determined at the wavelength of 420 and 720 nm, respectively. The actual color value A of the solution was the difference between A_{420} and A_{720}, and the decolorization rate of solution before and after resin treatment was defined as

$$\text{decolorization rate } (\%) = \frac{A_1 - A_2}{A_1} \times 100 \tag{4}$$

where A_{420} and A_{720} represent the absorbance of the solution measured at 420 and 720 nm, respectively. A_1 represents the absorbance value of the difference between A_{420} and A_{720} before decolorization; A_2 represents the absorbance value of the difference between A_{420} and A_{720} after decolorization.

Calculation formula of decreased salinity was

$$\text{decreased salinity (\%)} = \frac{S_1 - S_2}{S_1} \times 100 \tag{5}$$

where S_1 represents the conductivity of the initial solution (μ/cm) and S_2 represents the conductivity of the solution after the column (μ/cm).

■ ASSOCIATED CONTENT

ⓢ Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.2c00302.

Table comparing inulin extraction methods and Pareto charts of the main effects in the Box-Behnken design (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

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