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Research Article

Optimization of Microwave-Assisted Extraction of Mucilage from *Ocimum basilicum* var. *album* (L.) Seed

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Microwave-assisted extraction (MAE) is an effective green extraction method of value-added and bioactive compounds. The impact of different extraction times (2-7 min), microwave power (360-760 W), and solvent-to-sample ratio (20 : 1-40 : 1 ml/g) on the extraction yield of *Ocimum basilicum* var. *album* L. using MAE was investigated. Maximum extraction yield (17.00 ± 0.14%) was obtained at optimal conditions for extraction using response surface methodology, including extraction time of 4.33 min, power of 570.32 W, and the solvent-to-sample ratio of 40 : 1 ml/g, which was very close to the model prediction (17.01%). The yield of the conventional extraction (CE) method (50°C, 100 rpm, 1 h extraction time, and solvent-to-sample ratio of 40 : 1 ml/g) was 14.53 ± 0.25%. Comparisons were made between the functional and structural characteristics of the mucilage extracted under optimal conditions and the CE method. Fourier transforms infrared (FTIR) spectroscopy was utilized to study the changes in functional groups, and scanning electron microscopy (SEM) was used to determine the morphological characteristics. Emulsion stability against heat, water absorption capacity, foaming capacity, and foaming stability of the extracted mucilage under optimal conditions were 80.73 ± 0.08%, 48.71 ± 0.32 g/g, 24.55 ± 0.42%, and 91.6 ± 0.49%, respectively, which were higher than the CE method. SEM results showed a more porous structure in mucilage obtained by the MAE method, while no changes were observed by FTIR analysis between the functional groups of extracted mucilage obtained from the utilized extraction methods. Therefore, the application of the MAE method was superior to CE in terms of yield, structural and functional characteristics, and significantly shorter extraction time. The findings show the great potential of microwave processing in commercial and laboratory extraction of mucilage without deteriorative effects on the structural and functional properties of the extracted material.

1. Introduction

Herbal mucilage is a high molecular weight viscose polysaccharide complex that is easily accessible and inexpensive. Owing to its properties, mucilage has been used in cosmetic, food, and pharma products as a thickener, binder, emulsifier, stabilizer, coating, and gelling agent [1, 2], so new sources for the production of mucilage in line with exploring novel high-efficiency extraction methods are highly demanded.

Basil is an aromatic herb that has many traditional applications in different cultures. It also has been confirmed that basil contains substantial concentrations of phenolic components. *Ocimum basilicum* var. *album* L. is one of the most important varieties among more than 60 varieties of *O. basilicum*, which is a species belonging to the genus *Ocimum* and includes 50-150 species. This plant is an annual herb that belongs to the *Lamiaceae* family [3–5] and is found in many parts of the world including Asia, Africa, and South and Central America. *Ocimum basilicum* var. *album* L. and *O. basilicum* (basil seed) are similar to each other, but the former has square legs and tiny leaves; it is odorless and shorter than the basil seed. Furthermore, *Ocimum basilicum* seeds are smaller and shinier than the basil seed [6]. In Iran, the seeds are utilized in Faloodeh (a traditional dessert) preparation and Tokhme sharbati drink. The plant's seeds are black, and when soaked in water, swelling of the outer layer

(pericarp) occurs, and a gelatin-like material or mucilage is formed. This mucilage is firmly attached to the seed shell, and the extraction process is needed for separating it from seed residues [7]. The seed mucilage is a source of fiber and is also used as a thickening agent, emulsion stabilizer, gel formation, fat substitute, and film-forming agent in different industries. The utilization of natural mucilage is preferred over synthetic agents in the industry because of enhanced biocompatibility, nontoxicity, low cost, and biodegradability [3].

Extraction is the initial stage in separating the desired natural agents from the raw products. Various approaches have been used to extract mucilage. The key factor in the selection of a suitable extraction method is preserving the inherent functional properties of the polysaccharide during the extraction procedure [8]. Conventional extraction (CE) methods have low yields, need high amounts of solvent, and are timely, increasing operating costs and leading to more environmental problems [9]. Therefore, novel extraction approaches like microwave-assisted extraction, ultrasound-assisted extraction, supercritical fluid extraction, and pressurized liquid extraction, which are also considered green extraction methods, have replaced CE methods in recent years [10–13]. Among the new extraction methodologies employed, MAE is an effective green method for the extraction of value-added and bioactive compounds from solid samples because of the advantages such as low extraction time, high yield, selectivity, and improved quality of end products with low consumption of solvent. Microwave energy is able to penetrate the inner glandular, vascular system, and trichomes of the plant and lead to a sudden temperature increment inside it. Vaporization of volatile substances would be accelerated by this high temperature which raises the intracellular pressure and cell wall rapture as a consequence. This cellular breakdown causes the enhanced release of entrapped active components [14]. This approach has been applied for the extraction of hydrocolloids from the seeds of *Ocimum basilicum* L. [15], jamun fruit [16], *Opuntia ficus-indica cladodes* [2], *Pharbitis nil* [17], and many other plants.

Effective parameters in MAE include solvent composition and volume, temperature, microwave power, time of extraction, and nature of the matrix [18]. Furthermore, the complexity of food processing operations generates different responses under different conditions. So, optimization approaches are used to improve the performance of systems and increase process efficiency besides time and cost saving. Nowadays, the utilization of response surface methodology (RSM) in optimizing various food processing operations has become common due to its advantage over conventional methods [19–23]. Already, it has been used in the optimization of the extraction process of polysaccharides successfully [17]. Choosing an experimental design is an essential step in RSM analysis. Central composite design (CCD) is the most widely used design in RSM analysis [24].

To the best of our knowledge, a few studies are available regarding the extraction of *basilicum* var. *album* L. seeds. Also, making comparisons between CE and MAE regarding the changes that occurred in functional and microstructural properties of the mucilage is useful to investigate the possible shortcomings and advantages of each process, especially when converting the current processing strategies to novel methods at the industrial scale. This comparison is rarely available in MAE studies. Therefore, this study is aimed at optimizing the extraction conditions including extraction time, microwave power, and solvent-to-sample ratio in order to achieve the optimum recovery yield of mucilage from *basilicum* var. *album* L. seeds by using RSM-based CCD. Moreover, the structural and functional characteristics of mucilage samples obtained under optimal conditions and conventional methods were also compared.

2. Materials and Methods

2.1. Materials. O. basilicum var. *album* L. seeds were purchased from a local market in Rasht City in Iran. Cleaning of the seeds was done manually, and they were stored in the refrigerator for less than 24 hours until the experiments. The chemicals used were of analytical grade.

2.2. Extraction Procedures

2.2.1. Conventional Extraction of Mucilage. The mucilage was extracted using the approach proposed by Tantiwatcharothai and Prachayawarakorn [25]. The seeds (5 g) at a ratio of 40 : 1 were soaked in distilled water and stirred using a magnetic stirrer at 50°C at 100 rpm for 1 h. A domestic mixer (Bosch, Germany) was used for 3 min to remove the mucilage from the surface of the seeds. Centrifugation of the resulting mixture was done at 12000 rpm at room temperature for 20 min to separate two phases (the mucilage and seeds). The resulting mucilage was finally freeze-dried (CHRIST, Germany) for 24 h, and the freeze-dried product was milled using an electric mill (Pars Khazar, Iran) and stored in sealed packaging at -18°C.

2.2.2. Design of Experiments and Optimization of Microwave Extraction by RSM. To determine the initial range of independent variables, the primary tests were performed, and then, according to the test results, the desired ranges were selected. Optimization of the MAE operation was performed by examining the effect of microwave power (A), extraction time (B), and solvent-to-sample ratio (C) using RSM. 20 treatments, in three levels based on CCD with six central points (coded as 0), eight factorial point runs (coded as -1 and +1), and 6 axial or star point runs (coded as $-\alpha = -1.682$ and $+\alpha = +1.682$) were designed by the Design-Expert software and were done in two repetitions (version 13.0.3.0, Stat-Ease, Inc., USA). A quadratic equation (Equation (1)) was used for fitting the experimental data by regression analysis [8]. Finally, comparisons were made between the sample extracted under optimal conditions and the sample extracted by the CE approach in terms of structural and functional characteristics. The independent variables and their level values are shown in Table 1.

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC, \quad (1)$$

Table 1: Independent variables and their levels used in the RSM.

Variable	Coded levels				
	$-\alpha$	-1	0	+1	$+\alpha$
Power (W), A	223.64	360	560	760	896.36
Time (min), B	0.2955	2	4.5	7	8.70
Solvent-to-sample ratio (ml/g), C	13.18	20	30	40	46.82

where Y is the extraction yield; β_0 is the constant term; β_1, β_2, and β_3 are linear effects; β_{11}, β_{22}, and β_{33} are quadratic effects; and β_{12}, β_{13}, and β_{23} are interaction effect coefficients.

The adequacy of the model was determined based on the coefficient of determination (R^2), predicted R^2, adjusted R^2, and coefficient of variation (CV, %). The statistically nonsignificant terms ($P > 0.05$) were dropped from the model, and a reduced model was developed.

2.2.3. Microwave-Assisted Extraction of Mucilage. The mucilage powder was extracted based on Felkai-Haddache et al. [26] with some modifications. The extraction operation was performed in a modified microwave oven (Samsung, South Korea) with the ability to adjust the power and time. Extraction was done for different levels of solvent-to-sample ratio (20 : 1-40 : 1 ml/g), microwave power (360-760 W), and extraction time (2-7 min). The seeds were cleaned first, and then, seeds (5 g) were soaked in distilled water and placed in a microwave oven under various conditions. The remaining procedure was performed similarly to the conventional extraction process (Figure 1).

Equation (2) was used to calculate the mucilage extraction yield (%).

$$Y\%(w/w) = \frac{\text{weight of extracted material (g)}}{\text{dry matter weight (g)}} \times 100. \quad (2)$$

2.3. Investigation of Functional Properties of Mucilage Powder Obtained from CE and Optimal MAE Conditions

2.3.1. Emulsion Stability against Heat. Emulsion stability (ES) was determined as reported by [27] with slight modifications. 40 ml of mucilage powder suspension with concentrations of 0.01, 0.025, and 0.05 g/ml was combined with 4 ml of sunflower oil. Then, the mixture was homogenized for 1 min by a homogenizer (SR 30, South Korea) at 10000 rpm. Next, the emulsion was heated for 30 min in an 80°C water bath and then centrifuged for 20 min at 3800 g. Equation (3) was used to calculate ES.

$$\text{ES} = \frac{\text{final emulsion volume}}{\text{initial emulsion volume}} \times 100. \quad (3)$$

2.3.2. Water Absorption Capacity (WAC). The water absorption capacity (WAC) of mucilage powder was measured by the method proposed by [28]. 0.05 g of the sample was mixed with distilled water until entirely wet, and after that, centrifugation at 1600 g for 10 min was done. The supernatant was removed, and then, the sample was weighed. Equation (4) was used to determine WAC (g/g).

$$\text{WAC} = \frac{\text{swollen sample weigh} - \text{sample weight}}{\text{sample weight}}. \quad (4)$$

2.3.3. Determination of Foaming Capacity and Stability. The foaming capacity (FC) and foaming stability (FS) were measured by the method of [29] with minor modifications. Whey protein concentrate was used to create foam. 30 ml of suspension with concentrations of 0.01, 0.025, and 0.05 g/ml was combined with 30 ml of whey protein concentrate of 0.05 g/ml and moved into a graduated cylinder. Foam volumes were recorded immediately after production. Equations (5) and (6) were used to determine FC and FS, respectively.

$$\text{FC} = \frac{\text{initial foam volume}}{\text{total suspension volume}} \times 100, \quad (5)$$

$$\text{FS} = \frac{\text{foam volume after 30 min}}{\text{initial foam volume}} \times 100. \quad (6)$$

2.4. Investigation of Structural Properties of Mucilage Powder Obtained from CE and Optimal MAE Conditions

2.4.1. Scanning Electron Microscopy (SEM). The microstructure of the freeze-dried mucilage sample powders was determined using an SEM system (VEGA TESCAN-LMU, Czech Republic). The samples were fixed on an aluminum plate, and coating was performed using gold in order to evaluate the sample at an accelerating voltage of 15 kV and high vacuum condition.

2.4.2. Fourier Transform Infrared Spectroscopy (FTIR). FTIR spectrometer (JASCO 4700 Japan) was used to detect their functional groups. A blend of 2 mg of the sample with 200 mg of potassium bromide (KBR) was prepared in the shape of a tablet. FTIR was performed in the range of 400-4000 cm^{-1}.

2.4.3. Statistical Analysis. In order to analyze the structural and functional property data, one-way analysis of variance (ANOVA) was performed using the SPSS software (version 26.0, SPSS Inc., USA). All of the experiments were conducted in 3 repetitions. Also, Duncan's test was done at a 5% significance level to compare the mean values.

3. Results and Discussion

3.1. Statistical Analysis and the Model Fitting. The experimental conditions and the yield of mucilage extraction are presented in Table 2. The mucilage extraction yield ranged from 12.75% to 16.8%. The predicted response Y (the yield

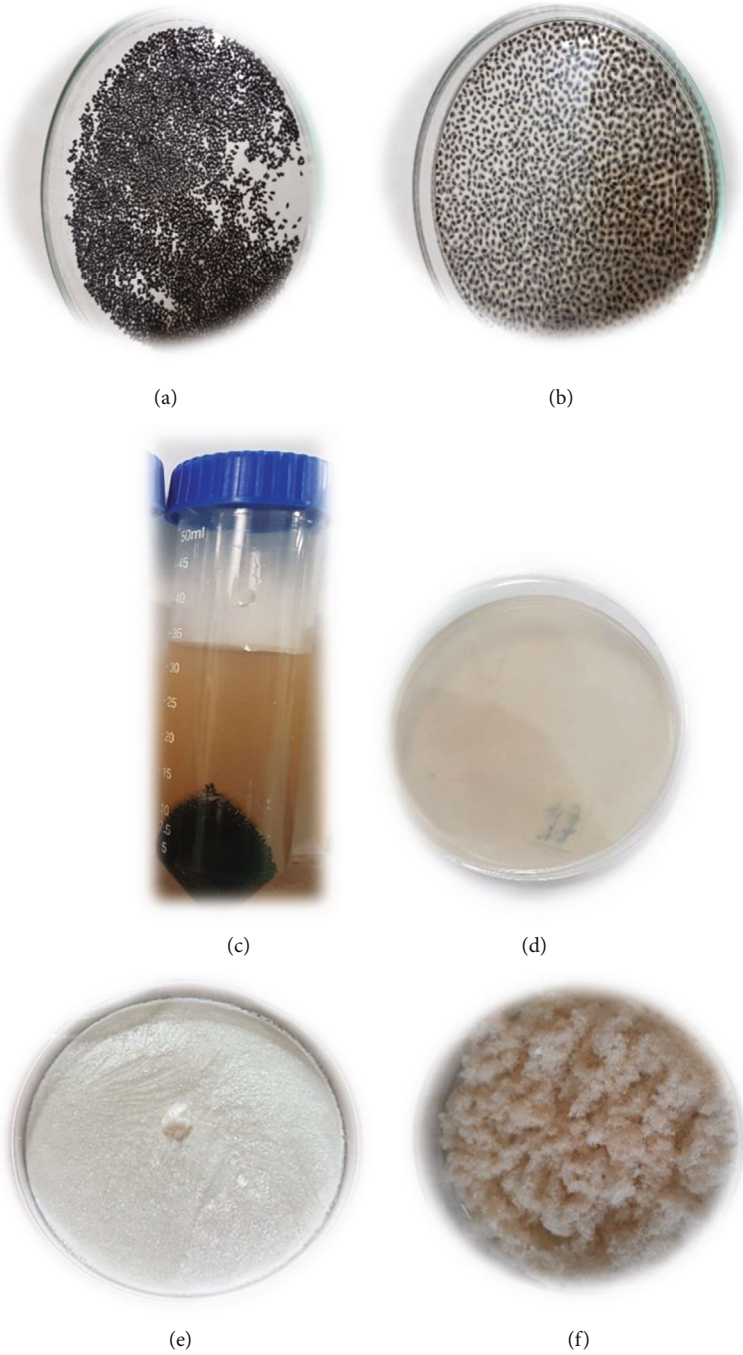


Figure 1: Extraction steps to prepare mucilage powder from plant seeds. (a) Plant seeds, (b) swollen plant seeds, (c) the mixture obtained after the centrifugation, (d) extracted mucilage, (e) mucilage dried by freeze drying, and (f) mucilage powder.

of mucilage) was obtained using Equation (7) using RSM analysis.

$$Y(\%) = 0.163032 + 0.009284A + 1.67402\,B + 0.528265C - 0.034250\mathrm{BC} - 7.30185A^2 - 0.047298B^2 - 0.004954C^2. \quad (7)$$

A quadratic model was used for the prediction of the impact of the factors on mucilage extraction yield. Model adequacy was examined by R^2, predicted R^2, and adjusted R^2. These values were 0.9428, 0.8829, and 0.9213, for the quadratic model, respectively, which indicates that the model has an acceptable validity. Also, the coefficient of variation (CV, %), an indicator for measuring the distribution of statistical data, is at a low level (2.14%) in this model, indicating low dispersion and high accuracy of statistical data.

Table 2: CCD design and extraction yield of mucilage.

Run	A (microwave power, W)	B (extraction time, min)	C (ratio of water to raw material, ml/g)	Extraction yield (%)	
				Experimental	Predicted
1	360	2	20	12.75	12.92
2	760	2	20	13.45	13.35
3	360	7	20	15.60	15.76
4	760	7	20	16.30	16.21
5	360	2	40	16.15	16.15
6	760	2	40	16.80	16.55
7	360	7	40	15.55	15.56
8	760	7	40	16.25	15.99
9	223.641	4.5	30	15.45	15.21
10	896.359	4.5	30	15.55	15.93
11	560	0.295518	30	14.53	14.60
12	560	8.70448	30	16.45	16.51
13	560	4.5	13.1821	13.85	13.73
14	560	4.5	46.8179	16.00	16.26
15	560	4.5	30	16.80	16.39
16	560	4.5	30	16.60	16.39
17	560	4.5	30	16.60	16.39
18	560	4.5	30	16.00	16.39
19	560	4.5	30	16.20	16.39
20	560	4.5	30	16.30	16.39

Table 3 presents the analysis of the variance of the experimental results. The values of F and P are used to evaluate each coefficient's significance and show the strength of the interaction between the independent variables. A lower P value ($P < 0.0001$) and higher F value ($F = 43.93$) indicated the greater significance of the respective coefficient. This model also showed nonsignificance of the lack of fit, which further confirmed the model's validity. According to the results obtained from Table 3, it is observed that the effects of power, time, solvent-to-sample ratio, and interactions of time and solvent-to-sample ratio, as well as the quadratic effect of power, time, and solvent-to-sample ratio, were significant on mucilage extraction yield ($P < 0.05$).

In order to check the model adequacy, comparisons were made between the experimental values of mucilage extraction and the model predictions (Figure 2(a)). The greater the accumulation of experimental data around the predicted model, the greater the correlation between the experimental data and the data obtained from the model. According to Figure 2(a), it can be seen that a good correlation exists between the predicted and the experimental results.

3.2. Effect of Process Parameters. To study the impact of processing conditions on the mucilage extraction yield, a diagram of minor changes in each variable around the central point (perturbation) was used. This diagram shows the impact of all independent variables at a center point in the design space. A straight line indicates the insensitivity of the response to the change of the independent variable, while the curvature in the graph of each independent variable indicates the sensitivity of the response to that independent variable. As shown in Figure 2(b), among the studied independent variables, the variables of solvent-to-sample ratio, extraction time, and microwave power, respectively, had the most significant effect on mucilage extraction yield. Details of the effect of input variables on the response are discussed in the next sections.

3.2.1. Effect of Microwave Power on the Yield of Mucilage. Microwave power is an important factor that significantly influences extraction yield. Figure 3(a) represents the effect of different microwave powers on mucilage extraction yield by keeping other extraction factors constant (time = 4.5 min and solvent-to-sample ratio = 30 ml/g). It is observed that the yield of mucilage extraction increased in the power range of 360 to 560 W. Rapid extraction of mucilage is associated with an increase in microwave power to a direct effect of microwave energy on the extracting material. The microwave energy causes the cell wall to swell and relax. The plant tissues are rapidly and extensively opened by the microwave, which increases the plant material contact with the solvent in the extraction process, as well as the penetration of the solvent into the plant matrix. As a result, mucilage is released easier during the microwave heating operation [2, 30, 31]. At powers of more than 560 W, due to the high amount of energy generated by the microwave, an irregular molecular interaction was introduced on the plant molecules, which caused thermal degradation and denaturation of the polysaccharide, thus reducing the extraction yield [16]. Samavati [32] reported that the extraction yield reached its maximum value ($13.5 \pm 0.4\%$) in the extraction of hydrocolloids from okra pods by microwave with increasing power up to 500 W. The extraction yield decreased

Table 3: Analysis of variance of the result.

Source	Sum of square	DF	Mean square	F value	P value (Prob. > F)
Model	43.68	9	4.85	43.93	<0.0001
A	1.25	1	1.25	11.29	0.0026
B	8.86	1	8.86	80.20	<0.0001
C	15.43	1	15.43	139.68	<0.0001
AB	0.0006	1	0.0006	0.0057	0.9407
AC	0.0006	1	0.0006	0.0057	0.9407
BC	11.73	1	11.73	106.16	<0.0001
A^2	1.92	1	1.92	17.41	<0.0003
B^2	1.97	1	1.97	17.83	<0.0003
C^2	5.53	1	5.53	50.07	<0.0001
Residual	2.65	24	0.1105		
Lack of fit	0.9869	5	0.1974	2.25	0.0909
Pure error	1.66	19	0.0876		
CV (%)		2.14			

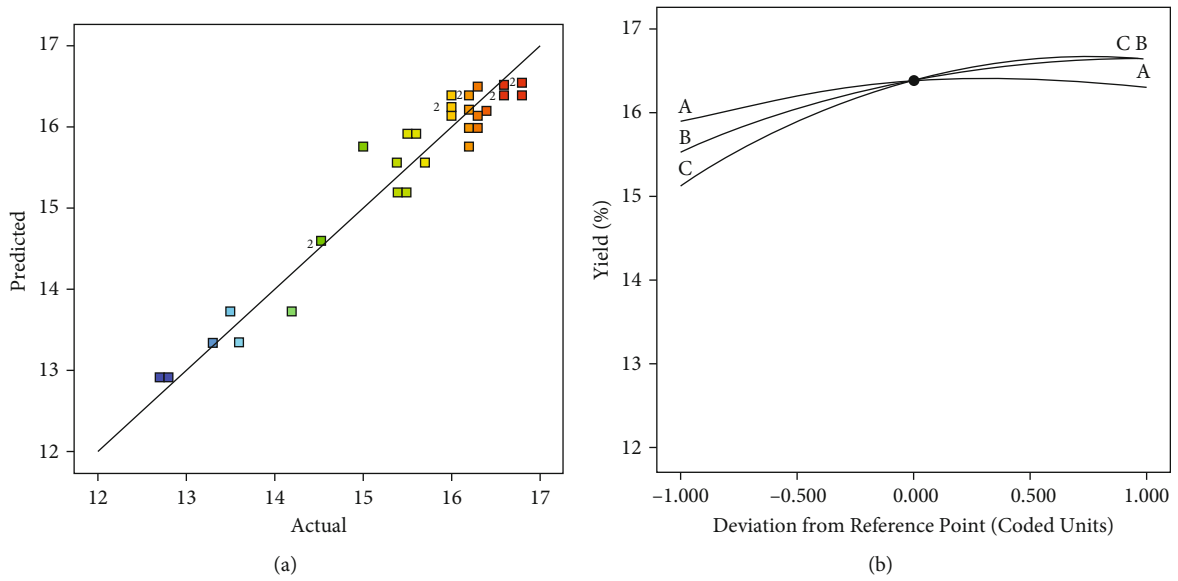


Figure 2: (a) Comparison of predicted and actual yields for mucilage, (b) perturbation plot (A: microwave power, B: extraction time, and C: solvent-to-sample ratio).

with a further increase in microwave power. Xu et al. [33] reported that a significant increase in extraction yield was observed in the extraction of polysaccharides from Meliae Toosendan, by increasing the microwave power from 500 to 700 W. At a power greater than 700 W, the extraction yield decreased quickly. Wei et al. [8] considered that the extraction yield increased with increasing microwave power up to 600 W, and further increase of microwave power reduced the extraction yield of polysaccharides from sea buckthorn. They attributed these findings to glycoside bond degradation which caused decreased polysaccharide content.

3.2.2. Effect of Microwave Time on the Yield of Mucilage. The microwave time is also one of the most critical factors influencing extraction yield. The effect of different irradiation times on mucilage extraction yield by keeping other extraction factors constant (power = 560 W and solvent-to-sample ratio = 30 ml/g) is shown in Figure 3(b). It is noticed that the mucilage extraction yield increased in the time range of 2 to 4.5 min, and the maximum extraction performance was seen in about 4.5 min. The accumulation of thermal energy in the extraction solution increases the dissolution process of the polysaccharide in the solution due to

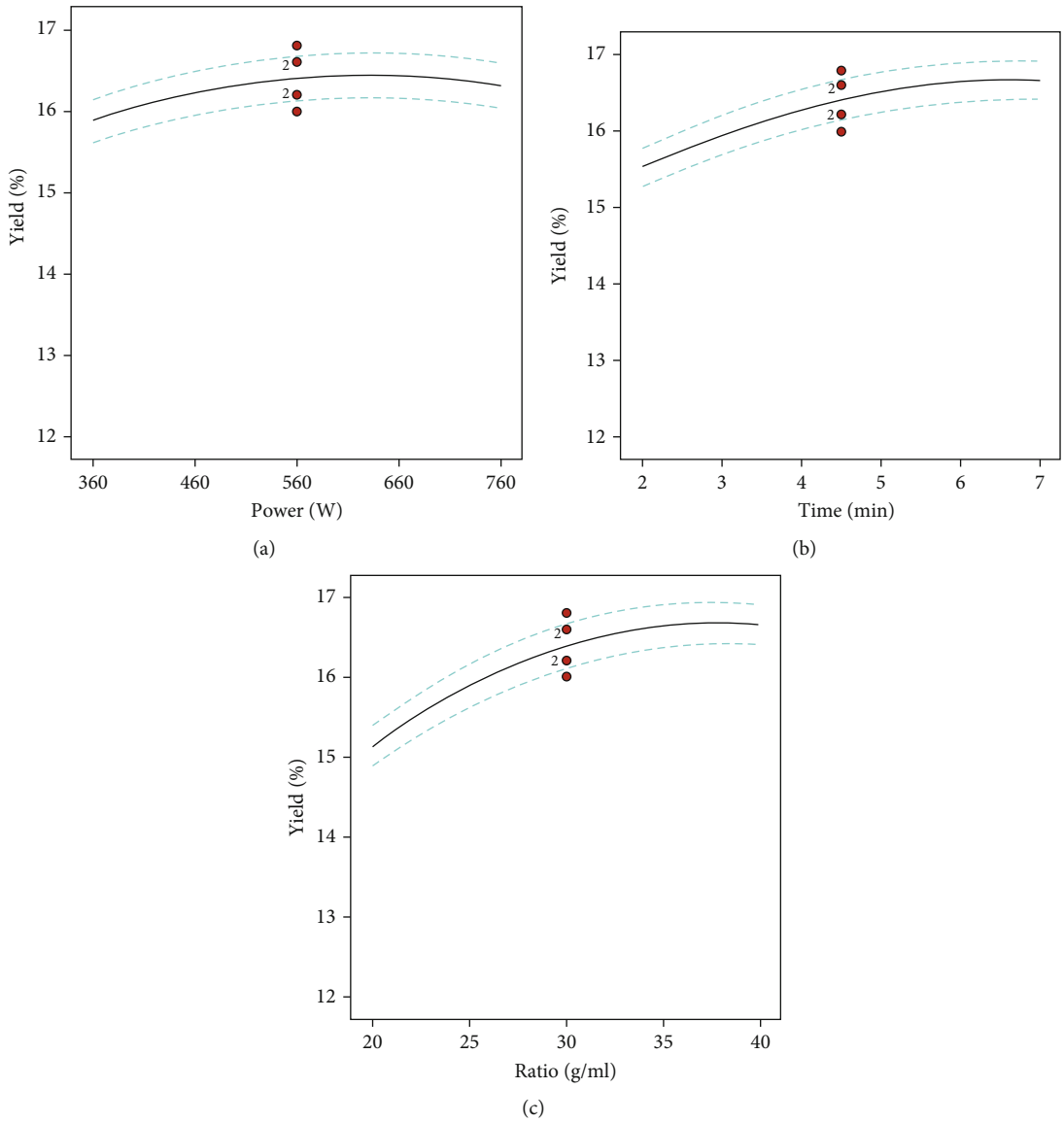


Figure 3: Effect of (a) microwave power, (b) irradiation time, and (c) solvent-to-plant material ratio on mucilage extraction yield.

microwave energy absorption [32]. As the microwave irradiation time increases, the duration of exposure of the matrix to radiation increases, which leads to the enhanced release of mucilage from the plant cell wall [34]. With more increments of extraction time, no significant change in extraction yield was seen. Al-Dhabi and Ponmurugan [16] also stated that increasing the extraction time from 1 to 4 min increases the extraction yield of the target compounds. However, the extraction yield decreases with further extraction time due to the increase in system temperature and consequent degradation of polysaccharides.

3.2.3. Effect of Solvent-to-Plant Material Ratio on the Yield of Mucilage. The amount of solvent is also an essential factor affecting the extraction yield. If the solvent-to-sample ratio is too low, the polysaccharides in the raw materials cannot be extracted entirely. If this ratio is too high, it will increase the cost of the process. Also, in microwave processing, most of the microwave energy might be absorbed by the solvent, and the material that should be extracted might receive less energy. So the proper solvent-to-sample ratio must be selected to extract the desired polysaccharides [2]. Figure 3(c) shows the effect of different solvent-to-sample ratios on mucilage extraction yield by keeping other extraction factors constant (power = 560 W and irradiation time = 4.5 min). As it is observed, the mucilage extraction yield increased with increasing solvent content up to 35 ml. The reason for the increase in yield is that the solvent used in this study (water) can easily absorb microwave energy, direct the penetration of the solvent into the plant matrix more quickly, loosen and swell the plant matrix, and increase the contact surface between solvent and matrix leading to increased mass transfer rate by tearing the plant matrix and improving mucilage extraction yield [16, 30]. Arasi et al. [35] used the ratio of solvent to sample 10 to 30 ml/g in their study and concluded that by increasing the ratio of solvent to 30 ml,

the extraction yield increased. It was reported that in pectin extraction, the yield decreased with an excessive increase in solvent-to-sample ratio because the microwave energy absorption by the plant matrix decreased due to the saturation of the solution with the solvent, which has a negative effect on the mass transfer rate and prevents the release of mucilage into the surrounding solvent [31].

3.3. Interaction between Process Variables. Figures 4(a) and 4(b) show the contour diagram and three-dimensional response surface of the interaction of microwave power and solvent-to-sample ratio on mucilage extraction yield, respectively. As shown in the figures, microwave power and solvent-to-sample ratio have positive effects on the response, and with increasing power and ratio, the extraction yield increases. However, with a further increase in the ratio, the increase in power has not had much effect on the yield. The solvent-to-sample ratio also had a more significant effect on extraction yield than microwave power. Chen et al. [36] observed that when the microwave power increased to 600 W and the solvent-to-sample ratio increased to 40 ml/g, the *Armillaria* polysaccharide extraction yield increased, and with a further increase in microwave power, the yield decreased [36].

Figures 4(c) and 4(d) show the contour diagram and three-dimensional response surface of the interaction of irradiation time and solvent-to-sample ratio on mucilage extraction yield, respectively. As shown in the figures, the extraction time and the solvent-to-sample ratio positively affected the response, indicating a significant interaction between time and ratio. The result showed that at shorter times, the yield increased significantly with the increase in the solvent-to-sample ratio, but at longer times, increasing the ratio has not significantly affected the yield. With the increasing solvent-to-sample ratio, the extraction yield increased. This is because the increase in the water ratio may increase the solvent's diffusivity into cells and as a result increase the desorption of the polysaccharides from the cells [2]. Chen et al. [36] stated that mucilage extraction yield increased with increasing extraction time and solvent-to-sample ratio, and with a further increase in extraction time, there was a slight reduction in efficiency. The interaction between microwave power and time is also presented in Figures 4(e) and 4(f).

3.4. Validation of Optimized Condition. The optimal condition achieved using RSM was as follows: microwave power, 570.32 W; extraction time, 4.33 min; and solvent-to-sample ratio, 40 ml/g with desirability of 0.989. The validation experiment was performed using the optimal condition to compare the predicted result (17.01%) with the practical value. The mean value of 17.00 ± 0.14%, obtained from the experiments, demonstrated the validity of the RSM model. The high correlation between the predicted and the real results confirmed that the response model was adequate to reflect the expected optimization. Mucilage extraction yield by CE method was 14.53 ± 0.25%. As it is observed, the yield of MAE was significantly higher than CE. Several authors reported similar findings [2, 37, 38]. The most important reason behind this observation might be the rapture of the cell wall and the enhanced release of the active compounds as a result of the generation of internal pressure and temperature in microwave-treated samples [39, 40].

3.5. Investigation of Functional Properties of Mucilage Powder Obtained from CE and Optimal MAE Conditions

3.5.1. Emulsion Stability against Heat. Emulsions are unstable and desire to separate into the two phases of which they are composed. Creaminess, flocculation, and coalescence in the presence of polysaccharides significantly affect the emulsion stability. The emulsifier stabilizes the emulsion by decreasing the interfacial tension at the oil-water interface [28, 41]. The stability of hydrocolloid emulsions is related to the correction of aqueous phase viscosity. In this way, by adding hydrocolloids to the aqueous system, the viscosity of the continuous phase increases, which decreases as a result of the collision between the suspended phase droplets. Therefore, the droplets in the solution cannot have much contact with each other. According to Stokes' law, emulsion stability (ES) can be increased by increasing the viscosity [27, 28, 42]. As shown in Figure 5(a), the ES varies from 65.26 ± 0.31% to 80.73 ± 0.08% and increases with concentration from 0.01 to 0.05 g/ml; this amount has increased for both extraction methods. Rashid et al. [27] observed that the ES against heat in flaxseed gum increased with concentration from 0.1 to 0.5% w/v, and concentrations of 0.1, 0.25, and 0.5% w/v were 86.84, 86.75, and 95.36%, respectively. ES against heat in the MAE method at concentrations of 0.01 and 0.05 g/ml was higher than that of CE, but no significant difference was observed at a concentration of 0.025 g/ml. If the tiny droplets are not able to absorb each other, the emulsion can maintain its stability. As a result, in this study, the reason for the increase in ES in the MAE method compared to the CE method is probably the decrease in droplet size as well as the uniformity of particles in the MAE compared to the CE. Shekarforoush et al. [43] concluded that the stability of the microwave-treated gum emulsion was significantly improved. Extracted mucilage due to its excellent emulsifying properties can be used as an emulsifier to increase ES in products such as sauces and frozen desserts.

3.5.2. Water Absorption Capacity. The amount of water that can be absorbed by a fiber source when put in excess water is called WAC. High WAC occurs due to water retention in the polysaccharide matrix. The higher contact surface of the hydrocolloid with water increases its WAC. One of the influencing factors of different extraction methods on WAC is the level of polar hydroxyl groups and the amount of their hydrodynamic interaction in the samples. Due to the conditions used in the extraction methods, higher amounts of water are kept in the samples, which can cause polysaccharides to break apart and increase their branching ratio [44]. According to the results, the WAC values of plant mucilage under microwave and CE conditions were 48.71 ± 0.32 and 47.36 ± 0.12 g/g, respectively. The higher WAC under optimal MAE conditions than CE is probably because microwave irradiation compared to CE causes a more open

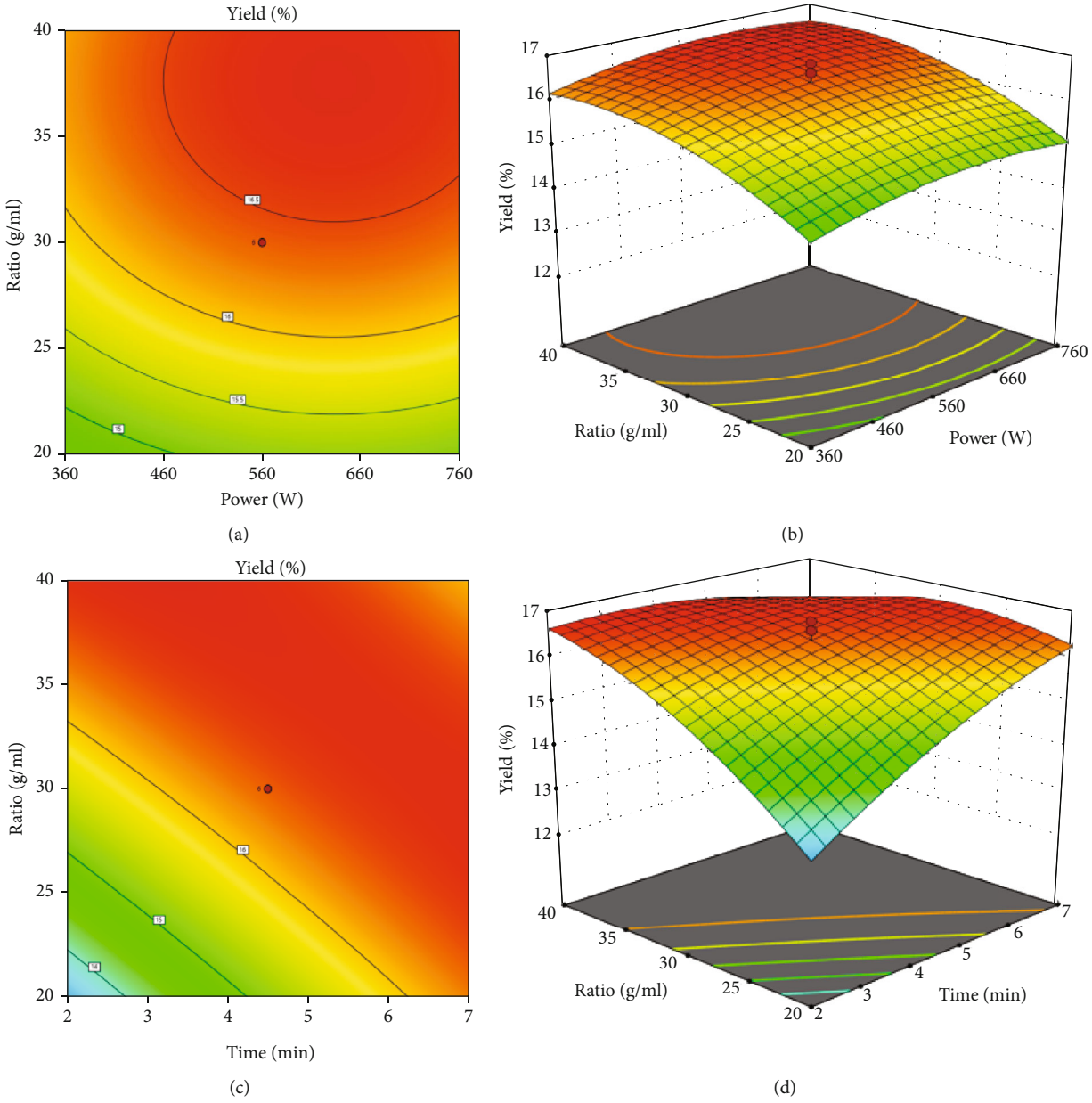
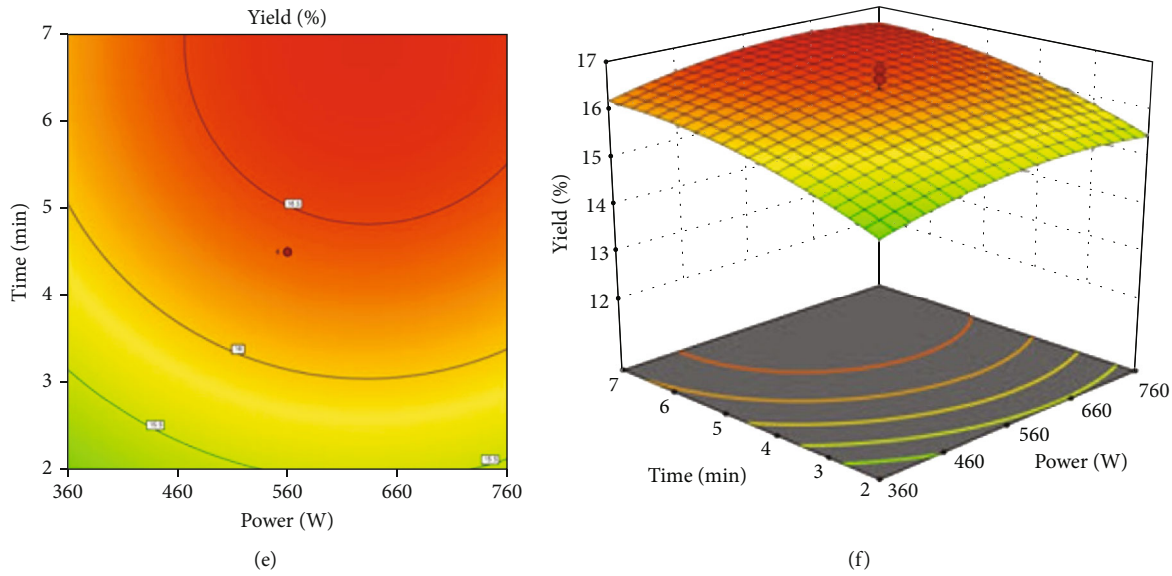
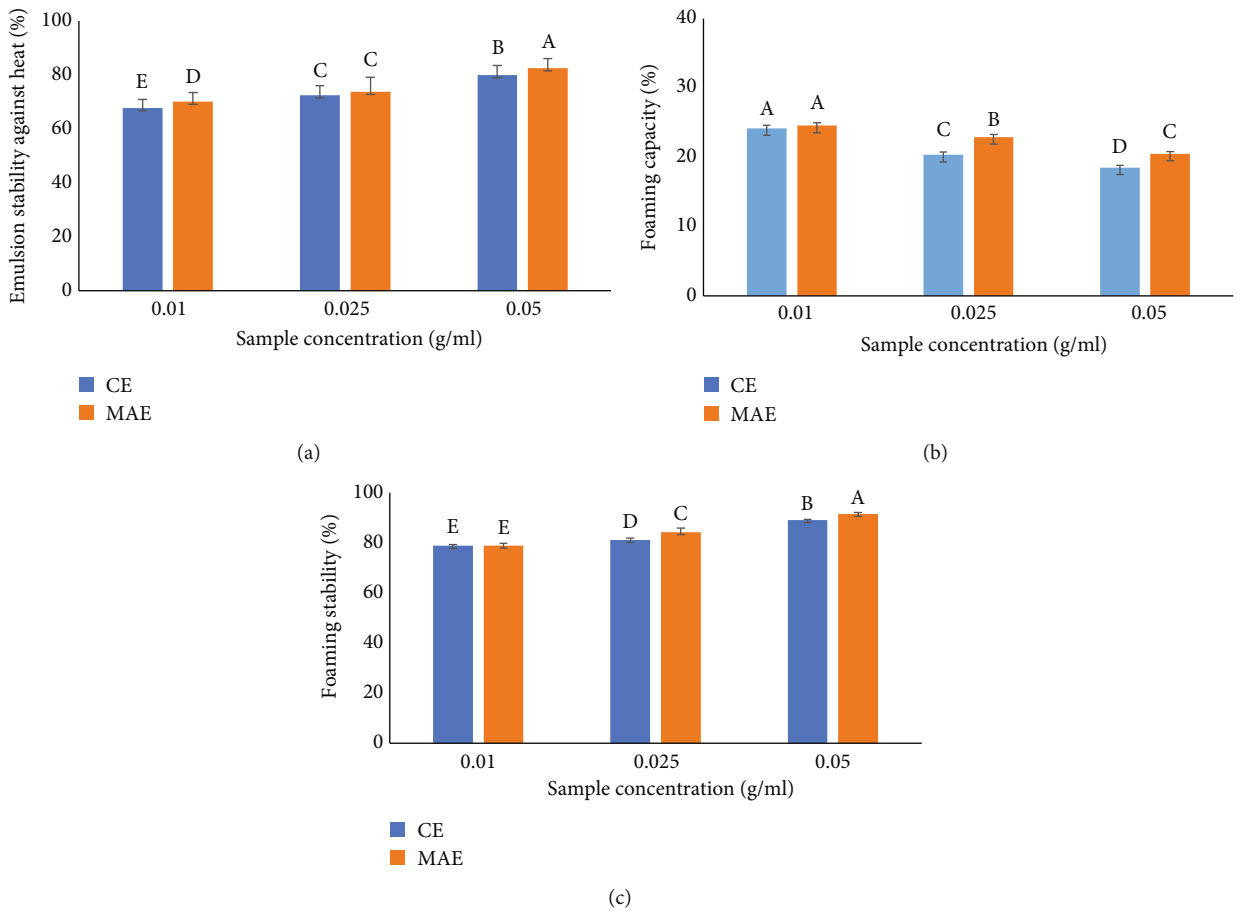


Figure 4: Continued.



(e) (f)

Figure 4: Contour plot (a, c, e) and response surface (b, d, f) illustration for the effect of water ratio and power, the effect of water ratio and irradiation time, and the effect of irradiation power and time (respectively), on extraction yield.



(a) (b) (c)

Figure 5: (a) Emulsion stability against heat, (b) foaming capacity, and (c) foaming stability under optimal MAE and CE conditions.

and porous structure that more hydrophilic groups are exposed to water. Nazir and Wani [45] reported that the WAC of basil seed mucilage was 30.75 g/g, a value of 39.2 g/g for chia seed mucilage reported elsewhere [44]. The high WAC of the extracted mucilage indicates that they can be used to prevent syneresis in products such as yogurt.

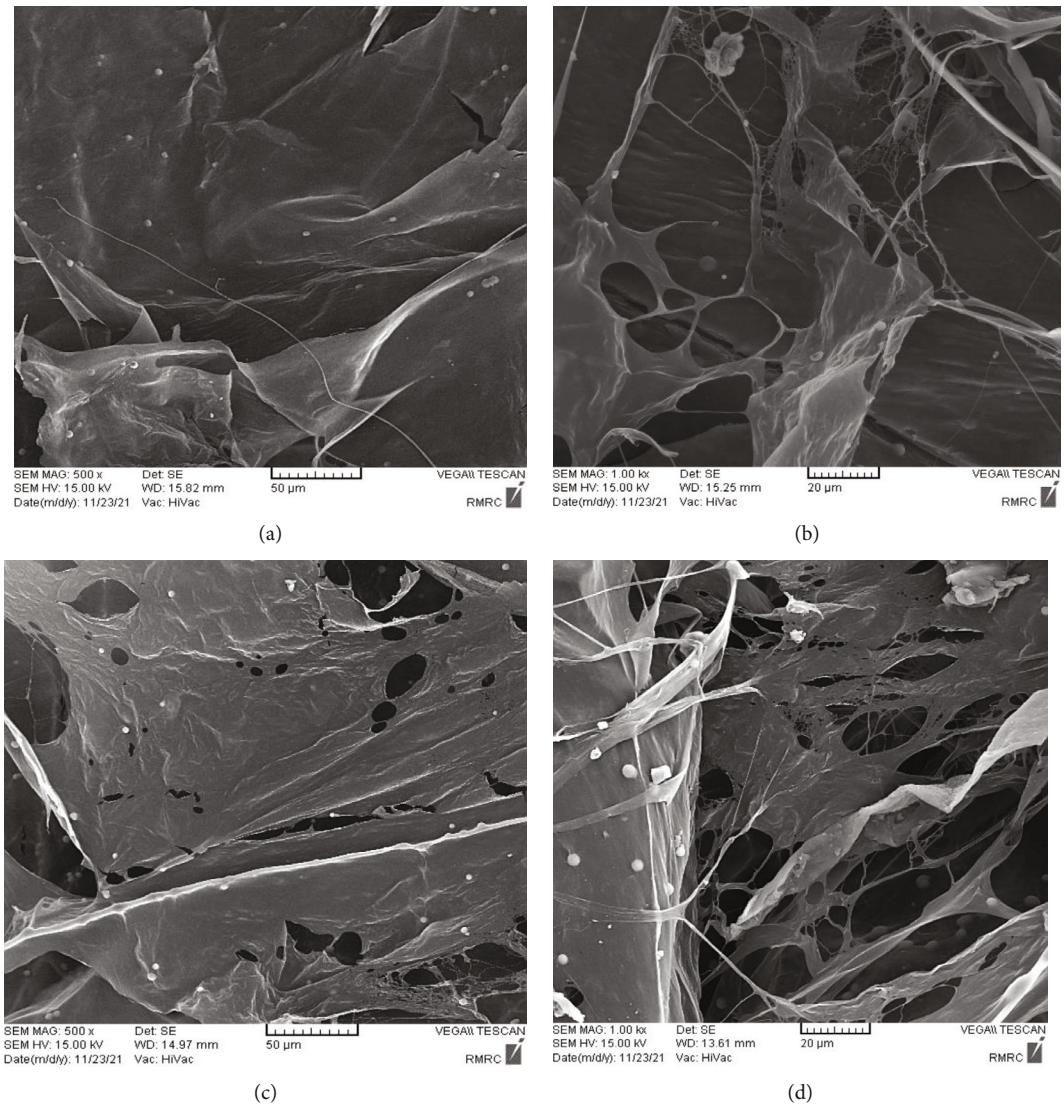


Figure 6: SEM images of *Ocimum basilicum* var. *album* L. mucilage powder. CE (a, b) and MAE (c, d) observed at the magnification of 500x and 1000x, respectively.

3.5.3. Foaming Properties. Foam is a colloidal structure and a kind of dispersion medium in which the continuous aqueous phase contains a discontinuous gas phase. The FC indicates the ability of a material to dissolve and quickly unfold, and a cohesive layer is formed around the gas [27, 46, 47]. This study used a whey protein concentrate (WPC) of 0.05 g/ml to create foam. The FC of WPC (0.05 g/ml) was 15.83 ± 0.77%, and by adding mucilage solution with different concentrations, the FC varied between 18.50 ± 0.34 and 24.55 ± 0.42%. Figure 5(b) shows the FC of different concentrations of mucilage under optimal MAE and CE conditions. The results revealed that the FC of mucilage solutions decreased with hydrocolloid concentration increment from 0.01 to 0.05 g/ml in all samples. This is because the high viscosity of the aqueous phase does not permit the entrance of air into the system [48]. Samples extracted by the MAE method showed more FC than CE, but no significant difference was observed at a concentration of 0.01 g/ml. Naji-Tabasi and Razavi also concluded in their study that the FC of basil seed gum solution decreased with increasing concentration from 0.1 to 0.3 g/ml [49].

The potential of the foam to keep its constant properties (such as foam volume, bubble size, or liquid content) over time is called FS. The significant density difference between the gas bubbles and the environment leads to the rapid separation of the system into two layers. Gas bubbles rise and may deform to form a polyhedral structure [47, 48]. Figure 5(c) shows the FS of different concentrations of mucilage solution under optimal MAE and CE conditions. The figure shows that the FS varies from 78.85 ± 0.5 to 91.6 ± 0.49%. The FS of WPC 0.05 g/ml was 52.63 ± 0.33%. The results revealed that the FS of seed mucilage solutions increased by increasing the hydrocolloid concentration from 0.01 to 0.05 g/ml in all samples. The samples extracted by the microwave method showed more FS than CE, but no significant difference was observed at a concentration of 0.01 g/ml. The main factor of FS is the correction of continuous phase viscosity. By increasing the continuous phase viscosity, hydrocolloids prevent air bubbles

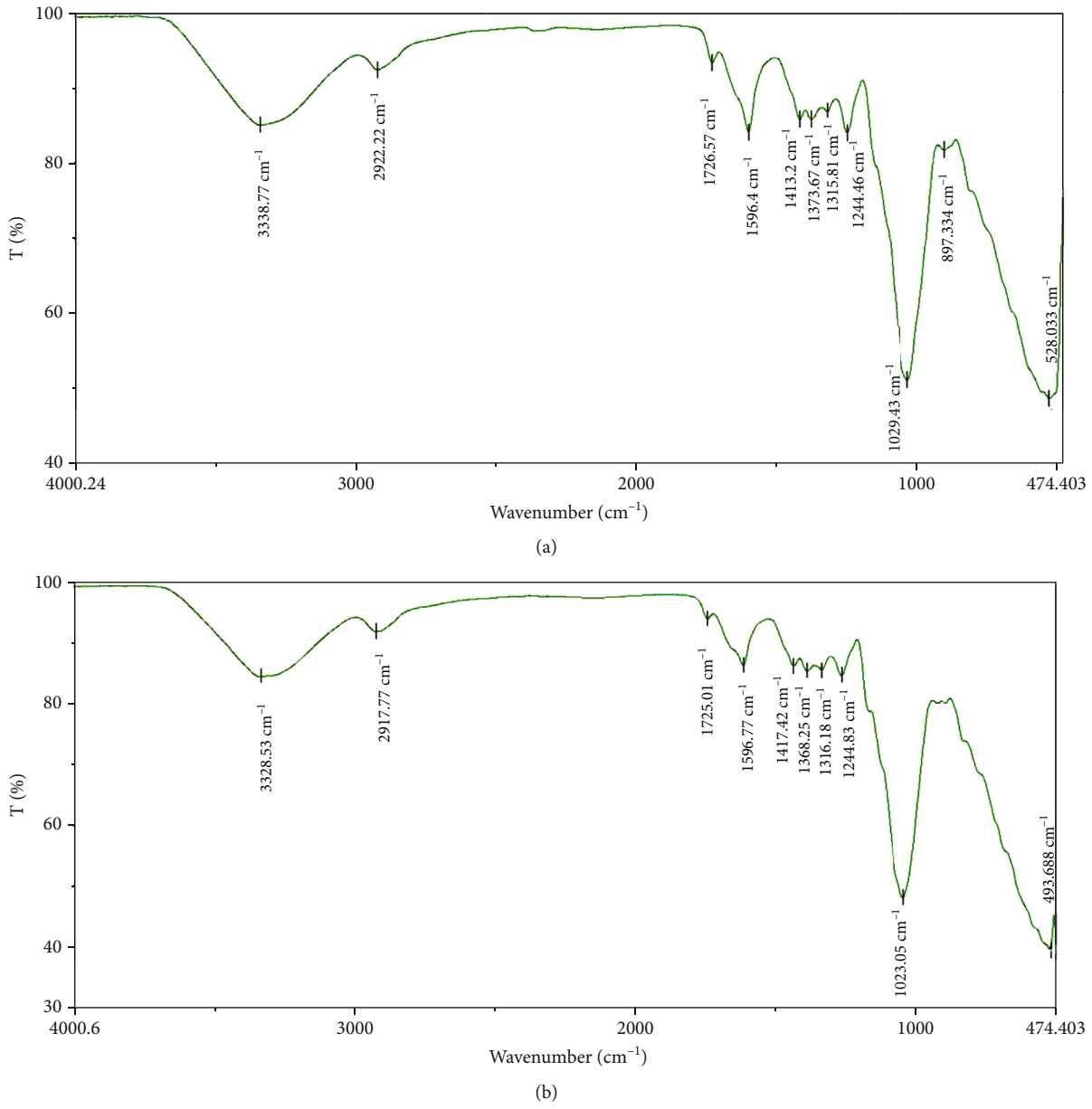


Figure 7: FTIR spectra of *Ocimum basilicum* var. *album* L. mucilage powder obtained under optimal microwave condition (a) and CE (b).

from adhering to the solid biopolymer network [49]. Naji-Tabasi and Razavi [49] concluded that the stability of the foam solution of basil seed gum increased from 65% to 96.00% by increasing the concentration from 0.1 to 0.3 g/ml.

3.6. Investigation of Structural Properties of Mucilage Powder Obtained from CE and Optimal MAE Conditions

3.6.1. SEM Observation. SEM was used to evaluate the morphological features and observe mucilage structure extracted from plant seeds. Figures 6(a)–6(d) show SEM images of mucilage powder obtained from CE and optimal microwave. The fibrillar and sheet-type structure is observed which are similar to other mucilage structures. The findings are in accordance with the findings of Silva et al. [7] and García-Salcedo et al. [50] for chia seed mucilage. Fiber strands are characteristic of such type of mucilage, and the sheet structure is also observed in freeze-dried samples [51]. MAE samples (Figures 6(c)–6(d)) demonstrate a more porous structure than CE. It was reported that such a porous structure is associated with the high water-holding capacity of the mucilage powder [52, 53]. This finding is in accordance with the result of WAC presented in section 3.5.2. Laraib et al. [54] compared the porosity of mucilage powders obtained using MAE and CE and reported that the latter is less porous. They stated that gelation time is less when microwave radiations are applied; also, more bubbles are produced and trapped in the viscus solution which results in a more porous structure. A similar porous structure was also observed in MAE-treated samples by Zhao et al. [55] when comparing MAE and CE PNIPAAm

hydrogels. A raptured structure was also reported in the pectin samples extracted using MAE compared to the commercial solutions [56].

3.6.2. FTIR Analysis. FTIR method was used to evaluate the structural characteristics of the extracted mucilage. This method is used in polysaccharides to study functional groups and the type of glycosidic bonds. FTIR spectra of mucilage extracted under optimal microwave and CE conditions are shown in Figures 7(a) and 7(b), respectively. The peak at 3338.77 cm^{-1} and 3328.53 cm^{-1} in MAE and CE corresponds to O–H stretching vibrations. Similar bands were seen in the FTIR spectrum of chia seed mucilage [7, 57]. The absorption peaks at 2922.22 cm^{-1} and 2917.77 cm^{-1} have been attributed to C–H stretching vibrations [56, 58]. The peaks at 1726.57 cm^{-1} and 1725.01 cm^{-1} are associated with C=O stretching vibrations of uronic acids in polysaccharides [59, 60]. The peaks at 1596.4 and 1596.66 and also 1413.2 and 1417.42 cm^{-1} in ME and CE powders are attributed to C=C stretching modes and CH2 or CH3, respectively [52]. The peaks at 1200-1400 cm^{-1} are representative of carboxyl groups while those at 1200-100 cm^{-1} can be attributed to ring vibrations that overlap with C–O–C stretching vibrations and C–OH side groups [60]. The band observed at 897.334 cm^{-1} in microwave extraction indicates the presence of α bonds in the pyranose form of sugars. As shown in the figures, there was no difference in the functional molecular groups of the mucilage obtained from the two extraction methods. Similar findings were reported while comparing the extraction of chia seed mucilage using different extraction methods [7], Xu et al. [60] for extraction of polysaccharides from *Eucommia ulmoides* Oliver leaf, Laraib et al. [54] for microwave and conventional extraction of *Artemisia vulgaris*, and Chen et al. [61] for ultrasonic-/microwave-assisted extraction of polysaccharides from *Inonotus obliquus*.

4. Conclusion

This study is aimed at investigating the effect of the MAE method on extraction yield and functional and structural characteristics of mucilage and compare it with the CE method. The obtained optimum conditions were microwave power of 570.32 W, extraction time of 4.33 min, and the ratio of water to raw material of 40 ml/g. Under this condition, a mucilage extraction yield of $17.00 \pm 0.14\%$ was obtained which is comparable with the predicted yield (17.01%), whereas the extraction yield of CE was measured as $14.53 \pm 0.25\%$. The higher extraction yield in the MAE method than the CE can be due to more breaking of the cell wall, reduction of particle size, more contact between solvent and material, and consequently more mucilage removal in the MAE method. Functional properties including ES against heat, WAC, FC, and FS of the extracted mucilage under optimal conditions were higher than the CE method. The results of FTIR showed no difference in the functional groups of mucilage samples obtained from the two extraction methods. SEM images showed that the MAE resulted in a more porous structure than the CE method. Therefore, considering the lower energy consumption, short extraction time, increased extraction yield, and no degradation in functional groups and also improving the functional characteristics of the microwave method compared to conventional extraction, it can be concluded that MAE can be regarded as a promising approach for the extraction of *Ocimum basilicum* var. *album* L. seed mucilage.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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