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Research Article

Ultrasound-Assisted Modification of Insoluble Dietary Fiber from Chia (*Salvia hispanica* L.) Seeds

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Modification of insoluble dietary fiber (IDF) to soluble dietary fiber (SDF) improves not only the various health benefits but also the functional properties for improved product development. This research aimed to examine the effects of sonication treatment on the functional and physicochemical properties with possible structural changes in chia seeds dietary fiber. Central composite design was applied to optimize the sonication treatment process (amplitude 55%, time 20 min, and temperature 40°C) based on the oil holding capacity (OHC) and water holding capacity (WHC) as responses. Under these optimum conditions, ultrasound-treated IDF exhibited better functional and physicochemical properties such as OHC, WHC, glucose adsorption capacity (GAC), and water retention capacity (WRC) than untreated IDF. Fourier-transform infrared spectroscopy further confirmed the structural changes in treated and untreated IDF to explain the changes in the studied parameters.

1. Introduction

Dietary fiber (DF) has intrigued researchers' interest due to its numerous health benefits [1]. Some of the potential health benefits are reducing the blood lipid and sugar level, controlling body weight, and lowering the risk of cardiovascular and colorectal cancer [2]. These effects are due to DF's physicochemical properties such as oil holding capacity, water holding capacity, water retention capacity, cation exchanges, and fermentability [3]. In humans, the activities of some bacterial enzymes (e.g., β-D-glucuronidase, β-D-glucosidase, ureases, and mucinase) in the hindgut and faeces are linked with damaged intestinal barrier function [4]. Because these bacterial enzymes are active components of intestinal bacteria that can release active metabolites, they may impair gastrointestinal function and increase the risk of colon carcinogenesis. It has been demonstrated in numerous studies that dietary fiber can successfully reduce these bacterial enzymes, while also maintaining intestinal function and health [5, 6]. In 1953, Hipsley coined the term "dietary fiber" to describe the plant cell wall as nondigestible components [7]. After several versions, the most consistent definition that is now accepted is from Trowell et al. "Dietary fiber consists of remnants of plant cells resistant to hydrolysis (digestion) by the alimentary enzymes of man [8]." Based on water solubility, dietary fiber is typically classified into two types: insoluble dietary fiber (IDF), such as cellulose, hemicellulose, and lignin, and soluble dietary fiber (SDF) such as pentosans, pectin, gums, and mucilage [9].

The contents of insoluble and soluble dietary fibers in foods, primarily in cereals, are 65–80 percent and 20–35 percent, respectively, of the total dietary fiber [10]. In terms of physiological importance, soluble dietary fibers are more significant than insoluble dietary fibers in both groups [11]. Soluble dietary fiber has better versatility than insoluble fractions due to its rapid fermentation and breakdown of short-chain fatty acids and higher intake through probiotics. Soluble dietary fiber has a hypocholesterolemic effect since it binds to cholesterol and sugar, lowering their absorption and transport in the blood [12]. Furthermore, soluble dietary fibers move with no trouble through the gastrointestinal tract due to the softness of the stools; meanwhile insoluble dietary fibers do not solubilize in water and pass quickly

through the gastrointestinal tract by adding bulk to the waste and avoiding constipation and hemorrhoids [13].

The health effects of IDF are often not as significant as those of SDF because of their distinct physicochemical and functional qualities, thus also limiting the applications in the food processing industries [14]. As a consequence, developing a modification approach that improves the uniformity and other functional qualities of IDF is highly needed [15]. DF from various food sources is currently modified using a variety of biological, chemical, and physical methods. The processing conditions alter the composition and surface morphology of DF, improving its structural and biochemical properties [16]. Biological techniques are very expensive because they require the use of isolated enzymes and different bacterial strains [17]. Chemical processes that use more quantities of strong acids and alkalis can generate a lot of waste and are bad for the environment [18]. Certain physical methods, including pressurized hot water extraction, require controlled temperature and pressure conditions [19]. Ultrasound is an innovative technique that has been very common to use in different scientific and food processing laboratories. In fact, the application of ultrasonic waves can break polysaccharide chemical bonds to improve the functional and physicochemical qualities of food by changing the surface hydrophilicity [20]. In this work, the ultrasound technique was selected instead of other techniques for the modification of IDF into SDF from chia seeds because of its advantages of low environmental impact, protection, and high performance [21]. Cavitation is the basic principle upon which ultrasound works. Ultrasound is a kind of energy generated by sound waves with frequencies that are inaudible to human ears [22]. When sound waves travel through any product, a large amount of energy is produced due to the compression and rarefaction of the medium particles [23]. Ultrasound produces various effects in the solid-fluid system that can affect resistance (internal and external) to mass transfer between solid and fluid [24]. In recent years, many researchers have used ultrasound for the modification of IDF from different fiber enriched plant sources. For instance, modification of insoluble dietary fiber using ultrasound was investigated in garlic straw [25, 26], rose pomace [27], and okara fiber [28]. Generally, the DF modification indicators include oil holding capacity (OHC) and water holding capacity (WHC), which play an important role in the food preparation process because they influence other functional and sensory characteristics. OHC values of DF reflect its polysaccharide structure, density, and surface properties [29], while WHC is important for determining storage conditions and calculating cost-effectiveness for food applications [30]. It has also been shown in several studies that DF can significantly control postprandial blood glucose levels by reducing the utilization of sugars [31], which could be analyzed through glucose adsorption capacity.

Considering all the above points, there is an imminent need to significantly transform the insoluble dietary fiber into soluble dietary fiber and, thus, to produce soluble dietary fiber enriched value-added items. The current study aimed to chemically extract dietary fiber and assess the effect of ultrasound on the modification of insoluble dietary fiber into soluble dietary fiber in chia seeds.

2. Materials and Methods

2.1. Procurement of Raw Material and Chemicals. Chia seeds (*Salvia hispanica* L.) were purchased from a local market. Megazyme International Ltd. provides ready-to-use Megazyme assay kit for carbohydrate and protein degradation (Bray, Ireland). All other chemicals were also of analytical grade and were purchased from Sigma-Aldrich Ltd. (Burlington, MA, USA).

2.2. Extraction of IDF. Chia seeds were ground through Quadrumate Senior Mill (C. W. Brabender, Duisburg, Germany) and passed through a 0.25 mm sieve and stored at 4°C. Fat was removed from ground chia powder before fiber extraction and the sample was dried overnight at 105°C in a hot air oven (Universal UF75, Memmert GmbH + Co. KG, Germany) to a constant weight. A Modified Method 991.43 of the Association of Official Analytical Chemists (AOAC) has been used for the extraction of insoluble dietary fiber [32]. Briefly, 900 ml of water was taken into a 1000 ml beaker with 30 g of chia powder, followed by adding a-amylase in the mixture. The beaker was placed into the water bath for 35 min for the incubation process of the enzyme. The incubation period started when the mixture reached 85–95°C. Once the incubation period was completed, the sample was then removed from the water bath. The temperature of the hydrolysate was cooled to 60–65°C, and then 50 mg/ml of pepsin was dissolved in the solution to hydrolyze the protein content. After that, pH was adjusted to 4.5 by adding 3 mol/l of acetic acid, and 3 ml of amyloglucosidase was added for further hydrolysis and the temperature of the solution was maintained at 60°C for 30 min. For enzyme deactivation, the solution was heated for 10 min at a high temperature and then centrifuged at $4500 \times g$ for 15 minutes (Heraeus Megafuge 8R, USA). The precipitate was collected and washed with 78 and 95 percent ethanol. The remaining portion (IDF) was dehydrated in a hot air oven overnight at 60°C and was kept safe for further use.

2.3. Ultrasonic Process. A modified method adopted by Huang et al. was used for the modification of IDF [20]. 10 g of the IDF was taken in a glass beaker and mixed in 300 ml of distilled water. A homogenizer (HQ-2475, MXBAOHENG, China) was used for obtaining a homogeneous mixture and placed in a water bath at 20–45°C for 10 min, selecting 8000 rpm. After pretreatment, the solution was placed in a sonication apparatus (VCX750, Sonics & Materials, Inc., USA) at different temperatures (20–60°C) and time intervals (10–30 min). The magnitude range of ultrasound was used between 250 and 500 W in the form of amplitude between 20 and 80%. Ultrasound treatment was run in pulse mode with 5 sec on-time and 5 sec off-time. The solution was removed from the sonicator and was stored in a freezer at −20°C for further use.

2.4. Experimental Design and Data Analysis. During this study, three independent variables have been chosen as ultrasonic process responses: ultrasonic amplitude (A), ultrasonic time (B), and temperature (C). Three levels for each factor were chosen to examine their effect and interaction of the factors. The assessment indicators were oil holding capacity (OHC) (Y_1) and water holding capacity (WHC) (Y_2). Fifteen runs were performed to improve the accuracy of the process; a complete experimental design is presented in Table 1 about the actual values of the independent response of variables. The following equation expressed the quadratic model which is commonly used.

fx1

2.5. Determination of Functional Properties

2.5.1. Oil Holding Capacity. A modified method [33] was used to measure the oil holding capacity of IDF. 1.0 g of IDF sample and 30 ml of soybean oil were taken in a centrifuge tube and the solution was mixed thoroughly and left at 25°C for 16 h. After that, the mixture was centrifuged at 4000 × g for 10 min, and oil was separated as supernatant from the solution. The following equation expressed the weight of IDF after oil absorption:

$$\mathrm{OHC\,(g/g)} = \frac{M2 - M1}{M1}, \tag{1}$$

where M_2 is the weight after oil (g) absorption by IDF and M_1 indicates the initial weight before oil absorption (g) by IDF.

2.5.2. Glucose Adsorption Capacity (GAC). The GAC was determined by Peerajit et al. with little modification [16]. Initially, a glucose solution (100 mmol/L) was prepared and was mixed with 1 g of IDF in 100 ml solution; the mixture was placed in an incubator for six hours at 37°C. After glucose adsorption achieved equilibrium, the sample was centrifuged at 4,500 × g for 20 min. The absorbed amount of glucose by IDF was calculated by using anthrone colorimetry to measure the glucose content of the supernatant.

The following equation expressed the GAC:

$$\mathrm{GAC\,(mmol/g)} = \frac{(C_0 - C_1)}{M}, \tag{2}$$

where M represents the weight of IDF in grams, C_0 shows the glucose concentration (mmol/L) in original solution, and C_1 indicates concentration of glucose (mmol/L) in supernatant when adsorption reached equilibrium position. Volume (L) of the solution is represented by V.

2.6. Determination of Physicochemical Properties

2.6.1. Water Holding Capacity. The mixture was prepared in a 100 ml beaker by taking 70 ml of distilled water and 1 g of ultrasound-treated IDF. The mixture has been properly stirred till homogenized and was stored at room temperature for 24 hours for further experiment. After that, the mixture was centrifuged for 10 min at 4000 × g; supernatant and residue were separated, and the residues were weighted. The following equation was used for the calculation of WHC as g/g water to dry sample [34]:

$$\mathrm{WHC\,(g/g)} = \frac{M2 - M1}{M1}, \tag{3}$$

where M_1 represents the weight of IDF before water absorption and M_2 shows the weight after absorption of water.

2.6.2. Water Swelling Capacity. A total of 1.0 g of the sample was hydrated in a graduated test tube with 25 mL of deionized water. After that, the solution was mixed thoroughly to eliminate any entrapped air bubbles until it was kept at ambient temperature for 4 hours and the bed volume was recorded. WSC was measured as the volume of the mixture per gram of sample weight (g) [34].

2.7. Fourier-Transform Infrared Spectroscopy. The secondary structures of protein concentrates were characterized using Fourier-transform infrared (FT-IR) spectra. The dried IDF samples spectra were recorded using a spectrophotometer with a diamond ATR (attenuated total reflectance). A Nicolet 6700 spectrophotometer was used to record the FT-IR spectra (Bruker Alpha ATIR, FT-IR, USA). Before being pelletized, KBr was used to mix properly with IDF (1 : 250, wt./wt). The spectra of FT-IR were analyzed at 2 cm resolution with 32 times of scan in the wave range 400–4,000 cm [35].

2.8. Statistical Analysis. All experiments were carried out in triplicate. Data obtained were subjected to analysis of variance (ANOVA). Each treatment of ultrasound modified fiber (UMF) was statistically analyzed for its significant values using software package (MATLAB 9.2) as described by Montgomery [36]. Optimized run was performed in triplicate and the average mean values were reported with standard deviation. Moreover, the sample analysis was done, and the significant variation was determined among means at a probability level of 5%.

3. Results and Discussion

3.1. Design Interpretation. A central composite design (CCD) was used to establish the ideal levels of each variable of ultrasonic parameter for higher response. The selected trails have been shown to approximate the entire set of experimental parameters. The ultrasonic action efficiency was demonstrated by the OHC (Y1) and WHC (Y2) of US-treated IDF reported in Table 1.

Matrix Laboratory (MATLAB) software was used to apply statistical analysis and regression line on the basis of an experimental design. For various responses, the processing conditions were analyzed and optimized. Some insignificant terms ($p > .05$) were dropped from the model (Figure 1). Regression model was designed by using the stepwise regression method, and the experimental findings were used to create the equations as shown in Table 2.

Table 1: Central composite design representing the experimental trials along with oil holding capacity (OHC) and water holding capacity (WHC) as responses.

Run	Independent variables			Dependent variables			
	Amplitude	Time	Temperature	OHC		WHC	
				Actual value	Predicted value	Actual value	Predicted value
1	−1(20)	0(20)	1(60)	2.61	2.42	4.94	4.86
2(C. P)	0(50)	0(20)	0(40)	5.36	5.21	6.91	6.89
3	0(50)	−1(10)	1(60)	3.36	3.23	5.87	5.85
4	0(50)	−1(10)	−1(20)	3.12	3.12	5.42	5.47
5(C. P)	0(50)	0(20)	0(40)	5.33	5.25	6.93	6.84
6(C. P)	0(50)	0(20)	0(40)	5.34	5.27	6.90	6.91
7	1(80)	−1(10)	0(40)	4.11	3.92	6.26	6.13
8	0(50)	1(30)	1(60)	3.42	3.42	5.93	5.88
9	−1(20)	1(30)	0(40)	3.25	3.44	5.72	5.89
10	1(80)	0(20)	1(60)	2.88	3.07	5.12	5.27
11	1(80)	0(20)	−1(20)	2.57	2.76	4.89	4.97
12	1(80)	1(30)	0(40)	4.21	4.02	6.31	6.21
13	0(50)	1(30)	−1(20)	3.22	3.23	5.65	5.67
14	−1(20)	−1(10)	0(40)	3.18	3.37	5.61	5.71
15	−1(20)	0(20)	−1(20)	2.47	2.28	4.73	4.58

Run nos. 2, 5, and 6 are the central points of US treatment.

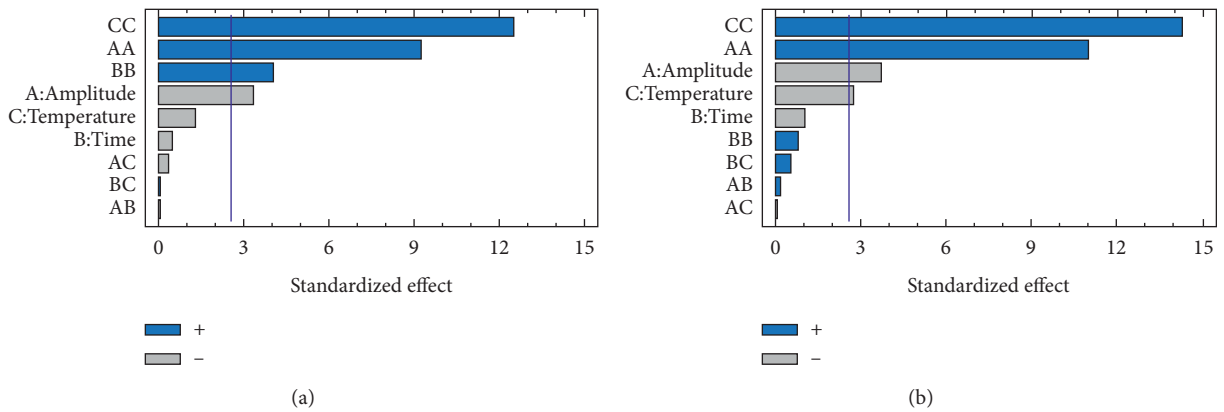

Figure 1: Pareto charts representing significant and nonsignificant factors for OHC (a) and WHC (b).

According to the statistical analysis, the proposed models were found to describe the observed significant values ($p < .05$) and ($R^2 > 98.483$), which are a satisfactory value for the response. The adjusted-R^2 value was close to R^2, indicating that the experiential and predicted data from the regression model were highly correlated. The best ultrasonic process parameters for maximum value of each response were evaluated by using equations (1) and (2) and their findings are reported in Table 2. Both responses were observed on different ultrasonic conditions and were presented as processes one and two for optimum value, as presented in Table 3. Table 4 shows the analysis of the variance representing the significant and insignificant factors. The effect of different parameters can be seen in the response surface plots showing the trend of effect in combination on OHC (Figures 2(a)–2(c)) and WHC (Figures 2(d)–2(f)). Processes one and two were considered to be the optimum ultrasonic processes for modification of IDF with higher OHC and WHC, respectively.

3.2. Optimum Ultrasonic Process. The OHC obtained using processes one and two was 5.37 g/g and 5.35 g/g, respectively, as shown in Table 4. Meanwhile, the influence coefficient of OHC is greater than WHC, as calculated by (5.37–5.35)/5.35. As a result, process one can be selected as the best ultrasonic process. Response surface plots created with MATLAB software were used to show the interaction impacts of the independent variables [37]. The optimum level of OHC occurred in the ranges of the tested variables at amplitude of 53.69%, time of 20.41 min, and 40.74°C, which were rounded to 55%, 20 min, and 40°C, respectively, according to equipment specification and feasibility of working.

3.3. Functional and Physiochemical Properties of Modified IDF. The ability to hold oil and water by chia seeds fiber is very important and plays a vital role in human health food applications. Several items are now made from or fortified

Table 2: The regression equations of the fitted model for OHC and WHC.

Response	Regression form	Regression equation
OHC (equation (1))	Actual	Oil holding capacity = 5.35 + 0.2825*amplitude + 0.04125*time + 0.11125*temperature − 1.155*amplitude^2 + 0.0075*amplitude*time + 0.0425*amplitude*temperature − 0.5075*time^2 − 0.01*time*temperature − 1.5625*temperature^2
WHC (equation (2))	Actual	Water holding capacity = 6.9 + 0.1975*amplitude + 0.05625*time + 0.14625*temperature − 0.86125*amplitude^2 − 0.015*amplitude*time + 0.005*amplitude*temperature − 0.06375*time^2 − 0.0425*time*temperature − 1.11875*temperature^2

OHC = oil holding capacity; WHC= water holding capacity; A = amplitude; B= time; C= temperature.

Table 3: Influence coefficient of ultrasonic processes based on OHC and WHC.

Ultrasonic process	OHC, Y1 (g/g)	WHC, Y2 (g/g)
Process 1 ($A = 53.69\%$, $B = 20.41$ min, $C = 40.74^{\circ}C$)	5.37	6.92
Process 2 ($A = 53.34\%$, $B = 24.09$ min, $C = 41.16^{\circ}C$)	5.35	6.9
Influence coefficient	0.0038	0.0028

Table 4: Analysis of variance (ANOVA) of the predicted quadratic model for studied parameters.

Source	DF	Oil holding capacity		Water holding capacity	
		MS	p value	MS	p value
A: amplitude	1	0.63845*	0.0209	0.31205*	0.0140
B: time	1	0.0136125^{NS}	0.6479	0.0253125^{NS}	0.3400
C: temperature	1	0.0990125^{NS}	0.2474	0.171112*	0.0407
AA	1	4.92563**	0.0003	2.73878**	0.0001
AB	1	0.000225^{NS}	0.9527	0.0009^{NS}	0.8503
AC	1	0.007225^{NS}	0.7380	0.0001^{NS}	0.9497
BB	1	0.950977**	0.0098	0.0150058^{NS}	0.4539
BC	1	0.0004^{NS}	0.9369	0.007225^{NS}	0.5976
CC	1	9.01442**	0.0001	4.6213**	0.0001
Total error	5	0.057765		0.022775	
Total (corr.)	14				
R^2		97.9951		98.483	
R^2 (adjusted for d. f.)		94.3864		95.7523	

* Significant, ** highly significant, significant at 0.05.

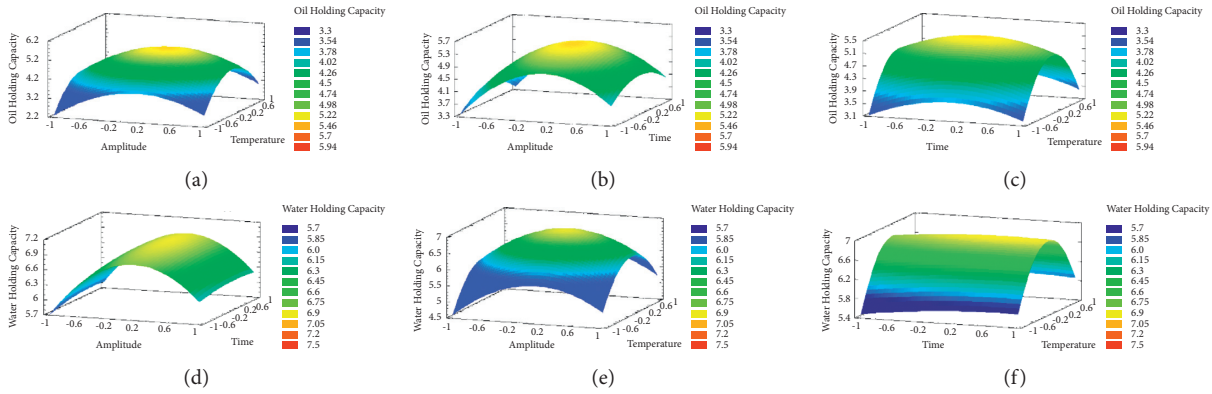

Figure 2: Response surface plots along with contour on curve showing effect of parameters on: OHC (a–c) and WHC (d–f).

with chia seeds in the food industry in various regions across the globe. These include breakfast cereals, cakes, pasta, and cookies [38]. According to Oliviera et al., flour made from chia seeds can be used to make pasta as an alternative to wheat flour. During this study, they observed that pasta made with chia flour had higher nutritive value than control pasta [39]. It contained statistically significantly higher levels of protein, minerals, and dietary fiber. Furthermore, introduction of chia to frankfurters provided a product enriched with dietary fiber, minerals, and amino acids [40]. OHC and WHC have been measured and found to be depending on the structure of chia seeds fiber. Table 5 shows the results of OHC and WHC of chia seeds fiber before and after ultrasound treatments. The best results for OHC and WHC responses (5.35 g/g and 6.92 g/g) were found in US-treated runs 2, 5, and 6, in which independent variables (amp. 50%, time 20 min, and temp. 40°C) were used to examine the response. The US-treated run no. 15 (amp. 20%, time 20 mints, and temp. 20°C) produced the lowest OHC and WHC response values of 2.47 g/g and 4.73 g/g, respectively. The results showed that the low amplitude of US resulted in little to no change in the particle size of chia seeds fiber. The reason behind this mechanism is that the large surface area of the particle size absorbed the low amplitude of US [41]. The average particle size decreased, and chia seeds fiber homogeneity increased as ultrasonic amplitude increased. This was a result that caused more cavitation and mechanical impacts due to the high amplitude of ultrasounds [42]. So, when ultrasound amplitude was 80%, there was no further reduction in the mean particle size.

The interaction between particles of fiber induced by the suspension of high viscosity was probably the reason for this mechanism [43, 44]. Temperature is another variable that affects the modification of fiber. When the temperature

Table 5: Correlation indicators of the quadratic polynomial regression analysis.

Response	R-value	Adjusted R-value	p value	Durbin–Watson	Optimum process conditions
OHC, Y_1 (g/g)	97.9951	94.3864	0.2033	1.75659	Process 1: $A = 53.69\%$, $B = 20.41$ min, $C = 40.74^{\circ}C$
WHC Y_2 (g/g)	98.483	95.7523	0.1179	1.61786	Process 2: $A = 53.34\%$, $B = 24.09$ min, $C = 41.16^{\circ}C$

A = amplitude; B = time; C=temperature; OHC = oil holding capacity; WHC = water holding capacity.

Table 6: Comparison of physicochemical properties of ultrasound-treated and untreated IDF.

IDF	OHC (g/g)	GAC (mmol/g)	WSC (ml/g)	WHC (g/g)
Untreated	2.61	2.96	5.6	3.2
Ultrasound-treated	5.35	3.72	8.4	6.92

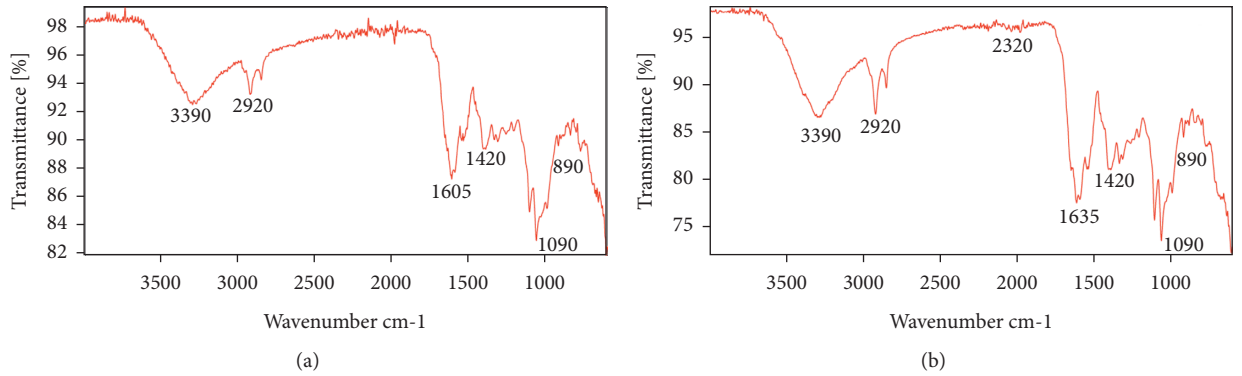

Figure 3: FT-IR spectra of chia seed IDF: untreated IDF (a) and sonicated IDF (b).

reached 40°C, the maximum change has occurred, resulting in the maximum yield. Similarly, when the temperature was at its highest (60°C), this resulted in the reduction of the yield, as shown in pictures 1 and 2.

GAC and WSC are also the functional and physicochemical properties, respectively; therefore the GAC and WSC were also examined and are shown in Table 6. This means that the values against US-treated GAC and WSC (3.72 mmol/g, 8.4 ml/g) increased as compared to the untreated ones (2.96 mmol/g and 5.6 ml/g), respectively. The improvements in functional properties and alteration of structural chemistry because of the destruction of C-H and the asymmetric vibrations of COOH and stretching of carboxyl group might also be responsible for higher GAC and WRC in ultrasound-treated IDF [45]. These results show that the IDF of chia seeds pretreated with ultrasound had a good functional and physicochemical profile, making it a useful ingredient for food products.

3.4. Structural Characterizations of US-Treated and Untreated IDF by Ultrasound. The FT-IR spectra could help to explain the functional groups and bonding information of the samples [46]. Figure 3 shows the spectrum of IDF from chia seeds, which ranges from 400 to 4,000 cm. The absorption bands about 3,390 cm^1 were caused by O-H bond stretching to hydrogen and hydroxyl groups which formed by hemicelluloses and cellulose, with absorption peaks at 3,386.44, 3,396.09, and 3,386.44 cm^1, were found in the spectra of untreated and US-treated IDF [47, 48]. The absorption peaks in different DFs were practically identical, and the band at 2,920 cm^1 was relevant to the C-H stretching of methylene and methyl group. Furthermore, asymmetric stretching vibrations of the carboxyl group COOH created the rather intense absorbance peaks at 1,633.44, 1,637.29, and 1,635.37 cm^1 in US-treated and untreated fiber. The untreated fiber sample showed a smaller peak at 775 cm^1 inside the fingerprint area. However, this peak was shifted to 833 cm^1 in the ultrasound-treated samples, showing that the long chain of $-CH_2$ groups was broken after the modification and the oligosaccharide content was boosted [49]. It seems to be that the untreated IDF has a distinctive absorption peak at 1,603 cm, which is most likely due to C5C sequence of aromatic rings [50]. In US-treated IDF, a change from 1,603 to 1,635 cm was found when compared to the two spectra, which might be attributed to the breakdown of organic molecules. Furthermore, in US-treated IDF, a new peak at 2,320 cm was observed, which is typically triple bond compounds, indicating that dehydrogenation was triggered by ultrasound. After ultrasonic treatment, the positions of the peaks changed. Ultrasound may be concluded by breaking the intramolecular chemical bonds, resulting in the demolition of organic compounds, the significant increase of carboxyl and hydrophilic groups, water binding, and the reduction of particle size, contributing to maximum OHC, WRC, and WSC [51]. After the modification, the WHC increased, and the OHC and WRC of the SDFs were significantly higher than those of the IDFs [52]. The

improvement of these properties indicated a good application prospect of modified fiber in food processing [53]. This could be due to the ultrasound treatment leading to a comparatively looser texture [54].

4. Conclusion

This study aimed to extract DF from Chia seeds (*Salvia hispanica* L.) and partially modify IDF into SDF through ultrasound, which is a nonthermal and innovative technique. The current study revealed an effective modification method to improve the compositional, structural, and functional properties of DFs. This study revealed that the physicochemical and functional properties of the IDF were increased by the pretreatment of ultrasound at amplitude 55%, time 20 min, and temperature 40°C. FT-IR results demonstrated that ultrasound treatment improved the specific surface area of IDF, correlating improved functional and physicochemical properties of modified IDF. Furthermore, chia seeds fiber has been used already in food processing of different breakfast items like pasta, cookies, and cakes. Also, this study aims to promote the use of chia seeds fiber in health and food applications by exploring its physicochemical properties.

Abbreviations

DF: Dietary fiber
IDF: Insoluble dietary fiber
SDF: Soluble dietary fiber
US: Ultrasound
PHWE: Pressurized hot water extraction
OHC: Oil holding capacity
WHC: Water holding capacity
GAC: Glucose adsorption capacity
WSC: Water swelling capacity
UD: Uniform design
FT-IR: Fourier-transform infrared spectroscopy
AOAC: Association of Official Analytical Chemists
UMF: Ultrasound modified fiber
DPS: Data processing system.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

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