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Research Article

Effect of Sonication and Edible Coating on Total Phenolic Content, Antioxidant Capacity, and Physical Characteristics of Infrared-Dried Sweet Cherries

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This research studied the influence of combined ultrasonic (40 kHz, 150 W, for 3 min) and 0.2% xanthan gum (XG), guar gum (GG), and wild sage seed gum (WG) coating pretreatments on total phenolic content, antioxidant activity, drying time, effective water diffusivity coefficient (D_{eff}), rehydration ratio (RR), total color difference (ΔE), and surface shrinkage (SS) of infrared-dried sweet cherries. The ultrasonic pretreatment increased the water transfer rate and water diffusivity during infrared drying and decreased the drying time of fresh sweet cherries. The edible coating enhanced the total phenolic content, antioxidant activity, dehydration time, and RR and decreased the D_{eff}, ΔE, and SS values of infrared-dried sweet cherries. The highest value of total phenolic content (3469.7 μg galic acid/g dry) was recorded for pretreated sweet cherry samples by GG. The mean antioxidant activities for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 35.64, 59.88, 54.38, and 61.19%, respectively. In this study, the sweet cherry D_{eff} varied from 2.23×10^{-9} m^2/s (for untreated cherries) to 5.00×10^{-9} m^2/s (for sonicated and uncoated cherries). The experimental data for the drying curves were fitted to various single-layer equations, and the Page equation using the experimental constants best described the drying rate of sweet cherries. The mean ΔE values for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 15.11, 9.91, 8.74, and 10.69, respectively.

1. Introduction

Using ultrasonic waves to treat fruit tissue can improve mass transfer rates [1]. Wang et al. [2] used ultrasonic pretreatment to enhance the drying rate of kiwifruit slices. Their results confirmed that this pretreatment method can improve the drying process and preserve high total phenolic content. In another study, Fernandes et al. [3] used the ultrasound process to improve the mass (water and sugar) loss of papayas before drying. Their results showed that the D_{eff} was increased after treatment by ultrasound, causing a decrease of about 16% in the dehydration duration of papayas. Ali et al.'s [4] results confirmed that ultrasonic treatment significantly enhanced the availability of bioactive compounds and the antioxidant activity of food products. Yıldız et al. [5] confirmed that ultrasound-treated freshly cut kiwifruit samples showed better ascorbic acid content, antioxidant activity, and total phenolic content with highly desirable organoleptic attributes.

The gum-based edible coating is a promising pretreatment method before the drying procedure. In this procedure, thin layers of digestible material are coated on the food product [6, 7]. Allegra et al. [8] reported that edible coatings are useful in preserving breba figs fresh mass, visual score, fruit firmness, and total phenolic content. In addition, Jansrimanee and Lertworasirikul [6] confirmed that the combined sonication and gum coating pretreatment enhanced the process efficiency index and reduced osmotic dehydration duration.

Consumer demand for sweet cherries (*Prunus avium* L.) is increasing due to their sweet taste, nutritional value, attractive color, and high total phenolic content and antioxidant content [9]. To extend shelf life and add value to sweet cherries, dried sweet cherries are promising [10, 11]. The influence of refractance window drying on the color degradation of white sweet cherries was examined by Simsek and Süfer [12]. Their results demonstrated that the ΔE of the sweet cherries pretreated with citric acid and sugar is closer to the values of the control sample. In addition, this study has shown that refractance window dehydration can be an appropriate option to enhance product quality while reducing dehydration time and energy.

In terms of cost, ultrasonic is less expensive than other technologies, and the main cost of operating a sonication system is electrical energy, making it more cost-effective and environmentally friendly than other methods [13]. We found no report on the impacts of edible coating and sonication on the infrared dehydration kinetics of sweet cherries in the literature. So, the objective of this work was to study the influence of combined sonication and gum coating (XG, GG, and WG) pretreatment on the total phenolic content, antioxidant activity, dehydration time, D_{eff}, RR, ΔE, and SS of sweet cherries.

2. Materials and Methods

2.1. Sweet Cherries and Gum Solutions. Sweet cherries were obtained from a local store at an adequate stage of ripening (Bahar, Hamedan Province, Iran). The average diameter of fresh, sweet cherries was 2.0 cm. The sweet cherries were cleaned for 15 s with water. Then, they were cut in half with a kitchen knife, and their seeds were removed manually from the fruit pulp. XG and GG powders were obtained from FuFeng Co. (China) and Abdullabhai Abdul Kader Co. (India), respectively. WG powder was prepared by the procedure described by Salehi [14]. XG, GG, and WG solutions were prepared by dispersing dried XG, GG, and WG powders in distilled water at a predetermined concentration (0.2%). Gum solutions were stirred to obtain full hydration.

2.2. Sonication and Gum Coating of Fresh Sweet Cherry Halves. The sweet cherry halves were immersed in 0.2% (w/w) gum solutions (XG, GG, and WG) and passed to sonication treatment for 3 min at 25°C. The experiments were performed in an ultrasound bath (Backer vCLEAN1-L6, Iran) with a frequency of 40 kHz and an ultrasound power of 150 W.

2.3. Infrared Drying. In this study, an infrared dryer with an infrared radiation source (250 W, near-infrared (NIR), Noor Lamp Company, Iran) was used for drying sweet cherry halves. The distance of the sweet cherry halves from the radiation lamp was 7 cm. After each pretreatment (sonication and coating), the sweet cherry halves were dried until they reached a constant weight. The mass changes of sweet cherry halves were recorded using a Lutron GM-300p digital balance (Taiwan).

2.4. Determination of Total Phenolic Content and Antioxidant Activity. The extraction of phenolic compounds from sweet cherries was performed according to the technique described by Salehi et al. [10]. Also, the total phenolic content of sweet cherries was estimated according to the technique described by Salehi et al. [10]. The Folin-Ciocalteu (Folin-Ciocalteu's phenol reagent, Sigma-Aldrich, USA) technique was followed to determine the total phenolic content of dried sweet cherries. The results were reported as μg GAE/g dry matter. In addition, for the antioxidant activity analysis of sweet cherries, the 2,2-diphenyl-1-picrylhydrazyl (DPPH, Sigma-Aldrich, USA) free radical-scavenging activity (FRSA) method was used according to Salehi et al. [10].

2.5. Drying Kinetics. The experimental result of the sweet cherry drying was combined with the 10 drying models [7]. Three statistical functions were utilized to determine the good fit between the model and the experimental data (SSE, RMSE, and r). The maximum SSE and RMSE and minimum r values suggest a better fit for the model.

2.6. Determination of D_{eff} of Sweet Cherries. The formula of the slope technique, which was according to Fick's second law of diffusion, was employed to determine the D_{eff} (m^2/s) of sweet cherries during infrared drying, according to Salehi et al. [15].

2.7. Rehydration. The RR of infrared dried sweet cherries were determined according to the procedure explained by Salehi et al. [16] (process time = thirty minutes, at 50°C).

2.8. Calculation of the Total Color Difference and Surface Shrinkage. The color of the sweet cherry halves was calculated by determining the lightness (L^*) and chromaticity (redness (a^*) and yellowness (b^*)) and was measured using an iPhone 12 Megapixels camera (iPhone 12 Pro, Apple Co., USA) and ImageJ software (V.1.42e, USA). To compare and analyze the color difference between the infrared dried samples and fresh sweet cherry halves, the ΔE was estimated using the following equation [17]:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}. \quad (1)$$

The surface area of sweet cherry halves before pretreatments and after the infrared drying procedure was calculated using ImageJ software (V.1.42e, USA). The SS values of the sweet cherry halves were calculated using the following equation:

$$\text{SS} = \frac{S_i - S_f}{S_i} \times 100, \quad (2)$$

where SS is the surface shrinkage (%), and S_i and S_f (cm^2) are the surface areas of untreated and infrared-dried sweet cherry halves, respectively.

2.9. Statistical Analysis. A one-way analysis of variance (ANOVA) was carried out using SPSS 21 software (IBM).

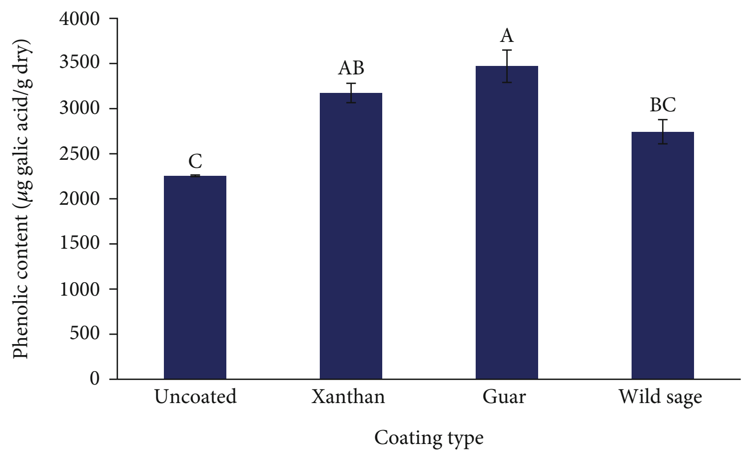

Figure 1: Impact of pretreatment on the total phenolic content of infrared-dried sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

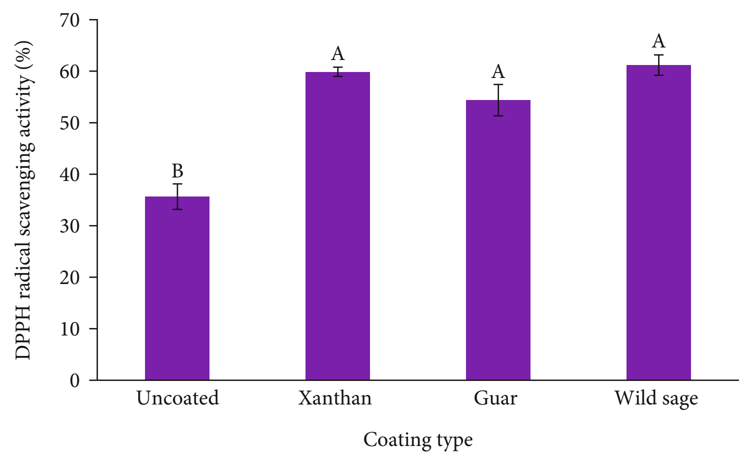

Figure 2: Impact of pretreatment on the antioxidant activity of infrared-dried sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

The difference between three times repeated data was measured at the 5% significance level (p value < 0.05).

3. Results and Discussion

3.1. Total Phenolic Content. The determination of total phenolic content is one of the main criteria for calculating the antioxidant activity of a food [18]. In this study, the total phenolic content of fresh sweet cherries was 5176.2 μg GAE/g dry. The influence of coating on the total phenolic content of sweet cherries is illustrated in Figure 1. The total phenolic content of pretreated sweet cherries was more than that of the untreated sample ($p < 0.05$). The mean total phenolic contents for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 2255.5, 3173.1, 3469.7, and 2743.9 μg GAE/g dry, respectively. The influence of refractance window drying on the total phenolic content of white sweet cherries was examined by Simsek and Süfer [12]. Their results demonstrate that a total phenolic content as low as 900 μg GAE/g was obtained in the fresh sweet cherries, and the total phenolic content was enhanced in the dried samples. Tayyab Rashid et al. [19] tested the influence of ultrasound frequency and glucose pretreatments alone or combined with the drying of sweet potato slices using a hot air dryer at 60°C to study the kinetics modeling,

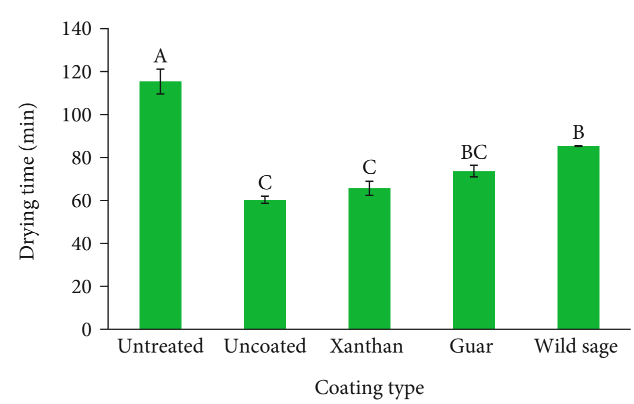

Figure 3: Impact of pretreatment on the drying time of coated sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

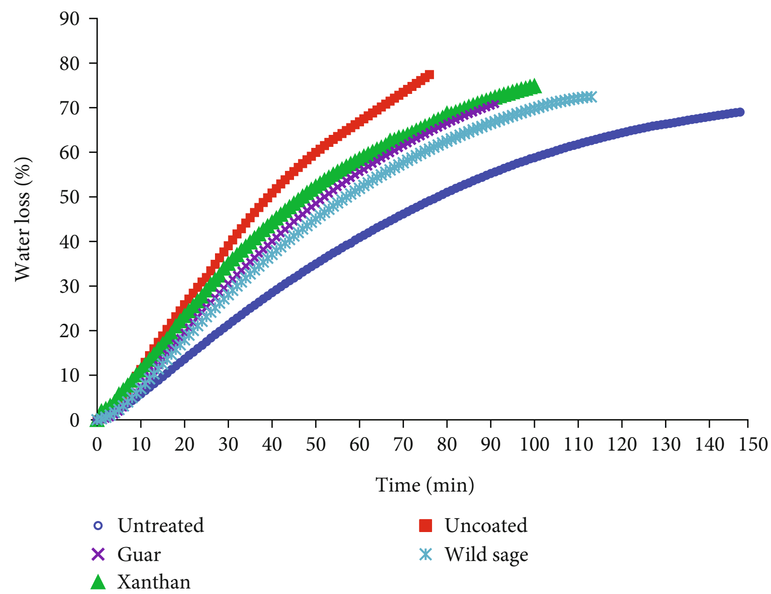

Figure 4: Water loss of untreated, uncoated, and coated sweet cherries during drying in the infrared dryer.

phytochemicals, antioxidant capacity, and functional and textural changes of the final dried product. Their results confirmed that the total phenolic content and total flavonoid content were significantly higher in glucose-pretreated samples, while antioxidant activity was higher in samples pretreated with ultrasound and glucose.

3.2. DPPH Radical Scavenging Activity. The DPPH method is a method to evaluate the antioxidant activity of foods [18, 20]. The influence of coating on the antioxidant activity of sweet cherries is illustrated in Figure 2. The antioxidant activity of the dried sweet cherries was preserved by the coating treatment. The antioxidant activity of pretreated sweet cherries was more than that of the untreated sample ($p < 0.05$). The maximum value of antioxidant activity ($61.19 \pm 3.95\%$) was observed on pretreated sweet cherry samples by WG. The antioxidant activities for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 35.64, 59.88, 54.38, and 61.19%, respectively. The effects of edible coating and sonication on the total phenolic content and antioxidant activity of sweet cherries were determined by Salehi et al. [10]. The authors reported that the antioxidant activity of uncoated and coated sweet cherries ranged from 39.75% to 61.04%. An et al. [21] examined the influence of carboxymethylcellulose (CMC)/pectin coatings combined with ultrasonic pretreatment before drying on the quality characteristics of turmeric. The CMC coating combined with ultrasonic pretreatment enhanced the quality parameters of turmeric. Furthermore, their results showed that the CMC coating preserved the bioactive compounds better than the pectin coating.

3.3. Drying Time. The moisture content of fresh, sweet cherries was 78%. The influence of coating on the dehydration duration of untreated, uncoated, and pretreated sweet cherries is illustrated in Figure 3. The ultrasonic pretreatment increased the water diffusivity during infrared drying and decreased the drying time of fresh sweet cherries. The dehydration time of the uncoated sweet cherry was lower than that of the pretreated sweet cherry. The drying times of untreated, uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 115.3, 60.3, 65.7, 73.7, and 85.3 min, respectively. The results of Rani and Tripathy's [22] study showed that ultrasound-pretreated pineapple slices provided a higher dehydration rate, increased D_{eff}, and a lighter color than that of an untreated dried sample.

Table 1: Impact of edible coatings on the effective water diffusivity coefficient (D_{eff}) of sweet cherries.

Sample	D_{eff} (m^2/s)	r
Untreated	$2.23E-09 \pm 2.40E-10^{c}$	0.997
Uncoated	$5.00E-09 \pm 7.67E-10^{a}$	0.970
Xanthan gum-coated	$4.29E-09 \pm 2.82E-10^{a}$	0.990
Guar gum-coated	$4.04E-09 \pm 8.88E-10^{ab}$	0.987
Wild sage seed gum-coated	$2.86E-09 \pm 3.58E-10^{bc}$	0.995

The values with different superscript letters in the column are significantly different ($p < 0.05$).

Table 2: The constants and coefficients of the approved model (Page).

Sample	k	n	SSE	r	RMSE
Untreated	0.0058	1.2140	0.0110	0.9994	0.0082
Uncoated	0.0065	1.3817	0.0102	0.9992	0.0111
Xanthan gum-coated	0.0092	1.2653	0.0058	0.9996	0.0080
Guar gum-coated	0.0067	1.3097	0.0071	0.9996	0.0079
Wild sage seed gum-coated	0.0050	1.3197	0.0022	0.9996	0.0054

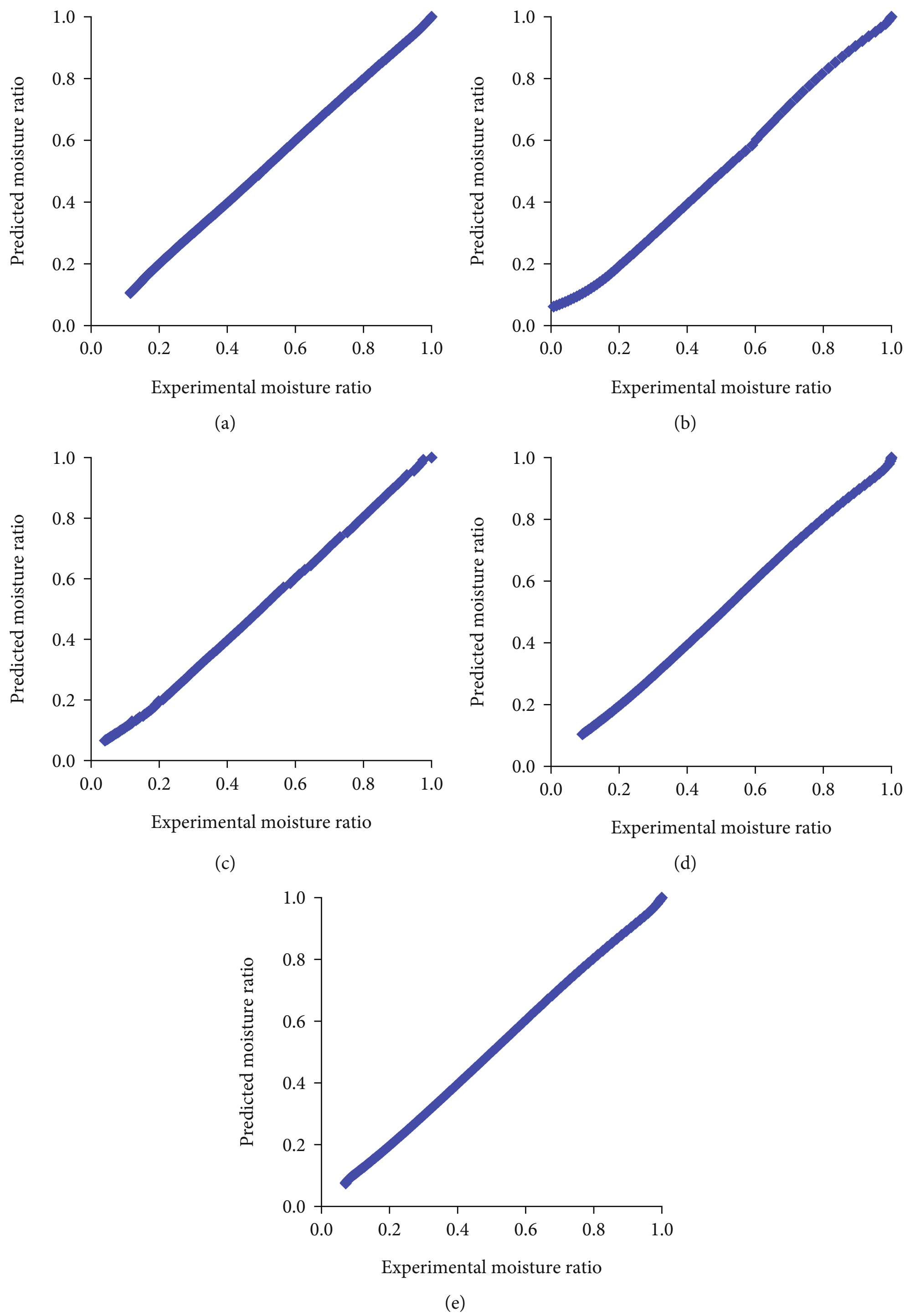

Figure 5: Comparison of fitted data by the Page model with experimental results of moisture ratio. (a) Untreated, (b) uncoated, (c) xanthan-coated, (d) Guar-coated, and (e) wild sage-coated.

They reported that the 20- and 30-minute ultrasound pretreatment reduced the drying time of pineapple slices by 19% and 14.3%, respectively.

The impact of coating on the water loss (WL) of sweet cherries during dehydration in the infrared dryer is illustrated in Figure 4. The WL rate of sonicated sweet cherries was more than that of the untreated sample. Also, the WL rate of uncoated sweet cherries was more than that of pretreated sweet cherries.

3.4. Moisture Diffusivity. The influence of pretreatment on the D_{eff} of sweet cherries is reported in Table 1. The D_{eff} of sonicated sweet cherries was more than that of the untreated sample, while the D_{eff} of pretreated sweet cherries was lower than that of the uncoated sweet cherries. The average D_{eff} values for untreated, uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 2.23×10^{-9} m^2/s, 5.00×10^{-9} m^2/s, 4.29×10^{-9} m^2/s, 4.04×10^{-9} m^2/s, and 2.86×10^{-9} m^2/s, respectively.

3.5. Kinetics Modeling. The drying behavior of sweet cherries in an infrared dryer was fitted with the Page equation (equation (3)). The Page equation illustrated an appropriate fit with the maximum r value (more than 0.9986) and the minimum SSE (sum of squared errors) and RMSE (root mean squared error) values (lower than 0.0257 and 0.0157, respectively) for all conditions compared to that of the other models. The determined constants of the Page equation including k and n are reported in Table 2 along with the respective error values for all dehydration conditions. The SSE, RMSE, and r values ranged from 0.0013-0.0257, 0.0037-0.0157, and 0.9986-0.9999, respectively. The experimental moisture ratio was satisfactorily compared with the theoretical moisture ratio. The relationship was shown in the maximum value of the coefficient of multiple determinations (closer to 1) obtained at various infrared drying durations.

$$\text{Moisture ratio} = \exp\left(-\text{kt}^{n}\right). \quad (3)$$

The results illustrated in Figure 5 compare the experimental moisture ratio with the estimated moisture ratio fitted from the Page equation for infrared-dried, pretreated sweet cherries. The results illustrated exceptional agreement between the experimental data and the predicted values, which are strongly banded around 45-degree straight lines, denoting the Page equation's fittingness in modeling the drying behavior of sweet cherries.

3.6. Rehydration Ratio (RR). The application of an edible surface coating before dehydration reduces the loss of fruit ingredients and retains the quality characteristics of the final dried product [10, 23]. The influence of edible coating on the RR of dried sweet cherries is illustrated in Figure 6. The RR of the WG-pretreated sweet cherries was significantly more than that of the uncoated sweet cherries ($p < 0.05$). The RR of uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 155.05, 159.44, 161.16, and 186.08%, respectively. The influence of edible coating and sonication on the RR of sweet cherries was determined by Salehi et al. [10]. The authors reported that the RR of uncoated and coated sweet cherries ranged from 141.8% to 176.2%. Eltoum and Babiker [23] studied the changes in antioxidant activity, RR, and browning index of tomato slices coated with gum arabic and dried in a sun dryer or a hot air dryer. Their results showed that the coating of tomato slices reduced the level of losses in antioxidants, color, and RR during drying and storage.

3.7. Color Changes and Surface Shrinkage. The average L^*, a^*, and b^* values for untreated sweet cherries were 46.15, 30.01, and 28.56, respectively. After the coating and infrared drying processes, the lightness, redness, and yellowness values of the samples decreased. The average L^*, a^*, and b^* values for treated and infrared-dried sweet cherries were 41.63, 22.80, and 26.45, respectively. The influence of coatings on the ΔE of infrared-dried sweet cherries is illustrated in Figure 7. The edible coatings play an essential role in the color change rate of sweet cherries. The gum coating reduced the color change rate of dried samples, with the lowest ΔE values in the GG-coated sweet cherries. In this study,

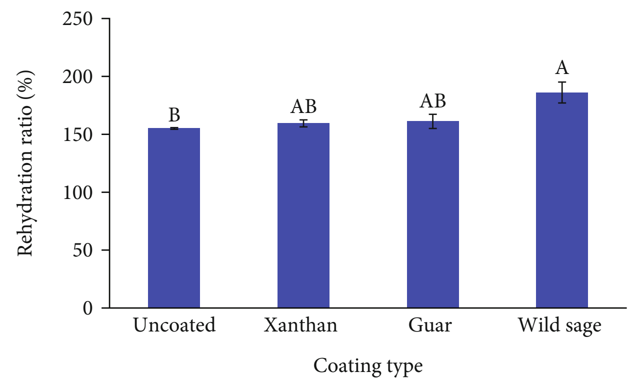

Figure 6: Impact of pretreatment on the rehydration ratio of infrared-dried sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

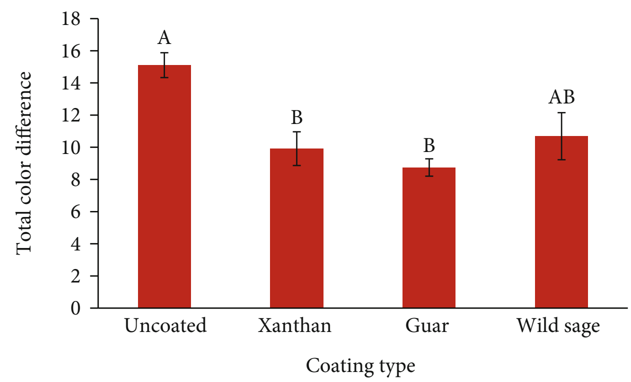

Figure 7: Impact of pretreatment on the total color difference of infrared-dried sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

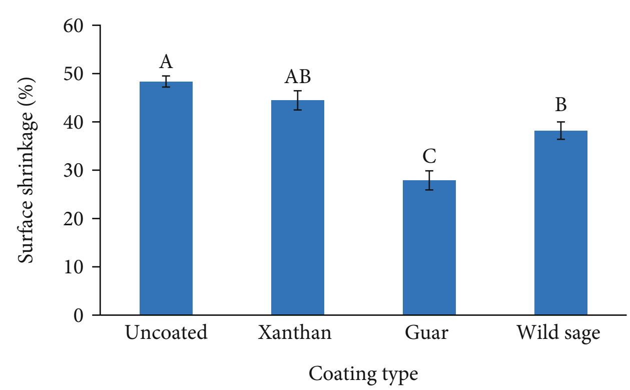

Figure 8: Impact of pretreatment on the surface shrinkage of infrared-dried sweet cherries. Different letters above the columns indicate significant differences ($p < 0.05$).

the mean ΔE values for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 15.11, 9.91, 8.74, and 10.69, respectively. Sakooei-Vayghan et al. [24] demonstrated that the edible coating preserves the quality of ultrasonic-pretreated dried apricot cubes.

The average surface area values for fresh and infrared-dried sweet cherries were 3.30 cm^2 and 2.02 cm^2, respectively. The influence of edible coatings on the SS of infrared-dried sweet cherries is illustrated in Figure 8. The gum coatings play an essential role in the SS of sweet cherries. The edible coating reduced the shrinkage rate of sweet cherries during infrared drying, with the lowest SS values in the GG-coated samples. In this study, the mean SS values for uncoated, XG-coated, GG-coated, and WG-coated sweet cherries were 48.36, 44.45, 27.89, and 38.19%, respectively.

4. Conclusion

In this context, the influence of combined ultrasonic and coating pretreatments on the total phenolic content, antioxidant activity, mass transfer rate, color changes, and surface shrinkage of sweet cherries was studied. The total phenolic content of pretreated sweet cherries was more than that of uncoated sweet cherries. In addition, the antioxidant activity of the dried sweet cherries was maintained by the coating. The drying time of sonicated sweet cherries was lower than that of the untreated sample. The D_{eff} of the pretreated sweet cherry was lower than that of the uncoated sweet cherry. The Page equation correctly explains the drying rate of the sweet cherries with the highest r among the ten models employed in this article. The RR of pretreated sweet cherries by WG was significantly more than that of uncoated sweet cherries ($p < 0.05$). The ΔE and SS values of pretreated sweet cherries by GG were considerably lower than the uncoated sample ($p < 0.05$). These results showed that the combination of edible coating (particularly GG) and ultrasonic pretreatment has significant advantages (higher total phenolic content, antioxidant activity, and RR and lower ΔE and SS values) and can be used in the food industry.

Data Availability

All data generated or analyzed during this study are included in this published article.

Ethical Approval

This study does not involve any human or animal testing.

Conflicts of Interest

The authors have declared no conflicts of interest for this article.

Authors' Contributions

Fakhreddin Salehi designed the project, analyzed the data, and wrote the main manuscript text, and Moein Inanloodoghouz and Mostafa Amiri conducted the experiment and helped with data analysis.

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