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Effects of Different Osmotic Pre-Treatments on the Drying Characteristics, Modeling and Physicochemical Properties of *Momordica charantia* L. Slices

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Abstract: A significant vegetable in the *Cucurbitaceae* family, the bitter gourd (*Momordica charantia* L.) is widely recognized for its beneficial health properties, including anti-diabetic, anti-carcinogenic, anti-inflammatory, anti-ulcer, antiviral activities. With a total of three Brix values (50, 60, and 70) and three different dipping times (10, 20, and 30 h), the goal of the current study was to identify the proper sugar and grape molasses solutions (pekmez) and dipping times for osmotic pre-treatments of bitter gourd samples to make it sweet and widely consumed. In the present study, mathematical modeling of drying processes, moisture content and water activity, total color changes, total phenolic content-antioxidant activity, and carotenoid contents were assessed. As a result of 13 different mathematical modeling tests, "Diffusion Approach", "Logarithmic" and "Midilli et al." models were the best models, giving the highest R^2 and lowest X^2-RMSE values. There were samples that were dipped at 50 °Brix grape molasses, which decreased below the 10% wet basis (w.b.) limit in the shortest time with 180 min, in a 10 h dipping time. The samples were dipped in 60 °Brix sugar, which fell below the same limit in the shortest time with 135 and 165 min, respectively, at 20 and 30 h dipping times. The highest total phenolic and carotenoid contents were found in 30 h dipping time in 60 °Brix grape molasses with 8296.87 mg/kg and 10 h dipping time in 50 °Brix sugar solutions with 89.22 mg/kg, respectively. While the phenolic content was higher in all samples dipped in grape molasses, the carotenoid content was higher in all samples dipped in sugar, which was one of the most important results of the study.

Keywords: bitter gourd; osmotic pre-treatments; hot air drying; modeling; antioxidant activity; total phenolic content; carotenoid content; color change

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1. Introduction

In recent years, the eating habits and food consumption of people have been affected by social and economic developments. As a consequence, there has been an increase in demand for healthy functional foods that can offer beneficial health properties; there has also been an increase in customer demand for readily available, healthy, ready-to-eat food products with extended shelf life. Due to their high concentration of vitamins, minerals, and beneficial compounds such as polyphenols and antioxidants, fiber, and other nutrients, fruit and vegetables are essential parts of a healthy diet [1]. However, fresh vegetables are challenging to preserve because they are so sensitive to microbial deterioration, negative environmental conditions, and mechanical damage, and they are also often very perishable [2].

One of the most popular and energy-intensive methods for preserving food is drying [2]. Drying is the process of evaporating moisture in a product as a result of a heat and mass exchange between the product and the medium. The oldest, simplest, and most common technique for removing water from plant tissue is conventional hot air drying (CD) because it is affordable [3]. However, this process needs a lot of time along with elevated temperatures, which causes considerable nutritional component degradation and changes to the final product's color [4].

The osmotic pre-treatment technique relies on removing water from products via osmosis. Water from the starting material is transferred to the osmotic solution, whilst the dissolved substances from the osmotic solution are transferred to the products [5]. Products are pre-treated during osmotic pre-treatment by submersion in hypertonic solutions [3]. It is thought that partial water removal techniques like osmotic pre-treatment (OD), when used as pre-treatments before drying, can significantly decrease the negative impacts of drying while also enabling the development of novel products.

The nutritional value of the products is influenced by the osmotic solution [3]. The osmotic agent needs to be efficient, practical, non-toxic, tasty, and easily dissolvable in order to create a highly concentrated solution. Recent research has shown that functional foods might be developed via osmotic pre-treatments [3,6]. The various solutions, osmotic solution concentration, product sizes subjected to the osmotic pre-treatment, and time and temperature of the osmotic pre-treatment process are the parameters that strongly affect the osmotic pre-treatment process. Previous studies demonstrated the effects of various osmotic pre-treatment process parameters in various fruits and vegetables such as carrots [7], apricots [8], pineapples [9], peaches [10], and mangos [11]. The most often used hypertonic solution is the sucrose solution.

It is thought that molasses, syrups, and fruit juice are potential alternatives as sweeteners for the manufacture and consumption of high-nutritional food. Bchir et al. [12] used an osmotic pre-treatment dipping solution, consisting of date juice and sucrose, on pomegranate seeds. They demonstrated that the stated osmotic pre-treatment solution not only reduced the cost of the process by minimizing the quantity of sucrose added to the osmotic solution but also enhanced the dietary benefits of the product due to the high natural sugar content. Numerous nutrients, including vitamins, minerals, carbohydrates, edible fibers, and antioxidants, are abundant in grapes, which are beneficial to human health. Grape molasses (pekmez) is a type of fruit product made by heating different types of grape juices to a concentration of soluble dry matter which is around 70% without addition of sugar or other sweeteners. High concentrations of sugar, minerals, and organic acids present in this syrup make it a vital source of nourishment for children, athletes, and anybody in need of an immediate energy boost. Due to the availability of monosaccharides as a natural sweetener and acceptable sucrose substitutes in the food business, grape molasses is manufactured.

Bitter gourd (*Momordica charantia* L.), an important summer vegetable in the *Cucurbitaceae* family, is known for its beneficial health properties such as its antidiabetics, anticarcinogenic, anti-inflammatory, antiulcer, antiviral, and antiosteoporosis activities [13]. Its pharmacological effects can be attributed to its bioactive components and chemical ingredients [14]. Fresh bitter gourd fruits have a high moisture content, making them susceptible to degradation like other high-moisture horticultural agricultural products. Different preservation techniques have an impact on the phenolic contents and antioxidant components of these products. Because bitter gourd is only available during certain seasons and is perishable, preservation is absolutely necessary. Preservation should be properly and carefully carried out to prevent biological degradation, preserve the fresh produce's natural features to the fullest extent possible, and increase the likelihood of availability in different seasons [13,15]. Osmotic pre-treatment serves the purpose of not only enhancing the storage life of fruits and vegetables but also the color, aroma, nutritional constituents, and flavor compound retention value by removing acid and uptaking osmotic solutions such as sugar and grape molasses. As a consequence, fruits or vegetables have a less bitter taste

and are sweeter than non-osmotically dried products. Osmotic pre-treatment processing can optimize output while also raising the market value of pre-treated products. Therefore, dried bitter gourd has a strong chance of being used with additional value [16,17].

The present research aimed to determine the appropriate sugar and grape molasses solutions and dipping times for osmotic pre-treatment at three different Brix values (50, 60, and 70) and three different dipping times (10, 20, and 30 h). The color changes, moisture content, water activity, total phenolic content, total antioxidant activity, and carotenoid content of bitter gourd slices were evaluated. Moisture content was also presented by mathematical modeling of drying processes.

2. Materials and Methods

2.1. Sample Preparation, and Drying Tests

For the osmotic pre-treatment process, medium-sized bitter gourds that were firm, ripe, uniform in color and appearance, and free of any flaws were chosen. Bitter gourd fruits were harvested from a private garden in Antalya (36°53′10.1″ N 30°45′23.4″ E), Turkey; the fruits were then individually wrapped and packed in boxes. Bitter gourds, which were transferred to Akdeniz University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, were washed, cleaned, dried with drying towels, and sliced in 8 mm thickness (Bitter gourd is cut perpendicular to the long part in the form of a ring). The fresh weights of the sliced products were weighed, and mixtures with different °Brix (50–60–70) values were prepared for sugar and grape molasses pre-treatment applications. The fruit/mix ratio has been adjusted to 1/4. After the products were kept in 93.5 °C distilled water for 5 min, they were taken to 4 °C distilled water and the scalding process was stopped [18]. This process aims to inactivate the enzymes in the bitter gourd [19]. Afterwards, the excess water was drained, and the products were dried with the help of a drying towel and kept separately in sugar and grape molasses mixtures with different Brix values for different dipping times (10, 20, and 30 h). Bitter gourds, which were kept in the mixtures, were removed at the end of the desired time, allowed to drain for 1 h, and dried at 70 °C drying air temperature. The products were weighed manually every 15 min until they reached equilibrium moisture content (Figures 1 and 2). The products were weighed manually every 15 min until they reached equilibrium humidity. Before drying, color measurements of the fresh and pre-treated samples were also carried out after drying. Drying experiments were carried out in a 1000 Watt Dalle LT-27 cabinet convective dryer with 12 shelves, 1.5 m/s constant air velocity, operating at 30–90 °C drying air temperature values with 10 °C differences and a timer. The trial design of the trials performed in duplicate is given in Table 1. The abbreviations "S" for sugar and "G" for grape molasses are used.

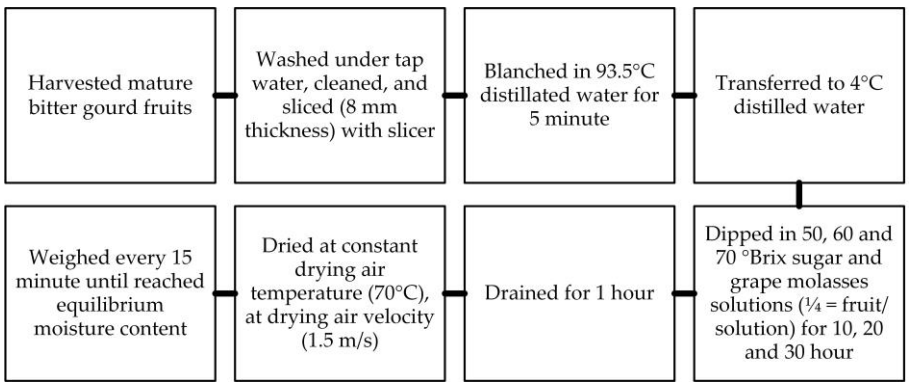

Figure 1. Flowchart of osmotic pre-treatment methods on the drying of bitter gourd.

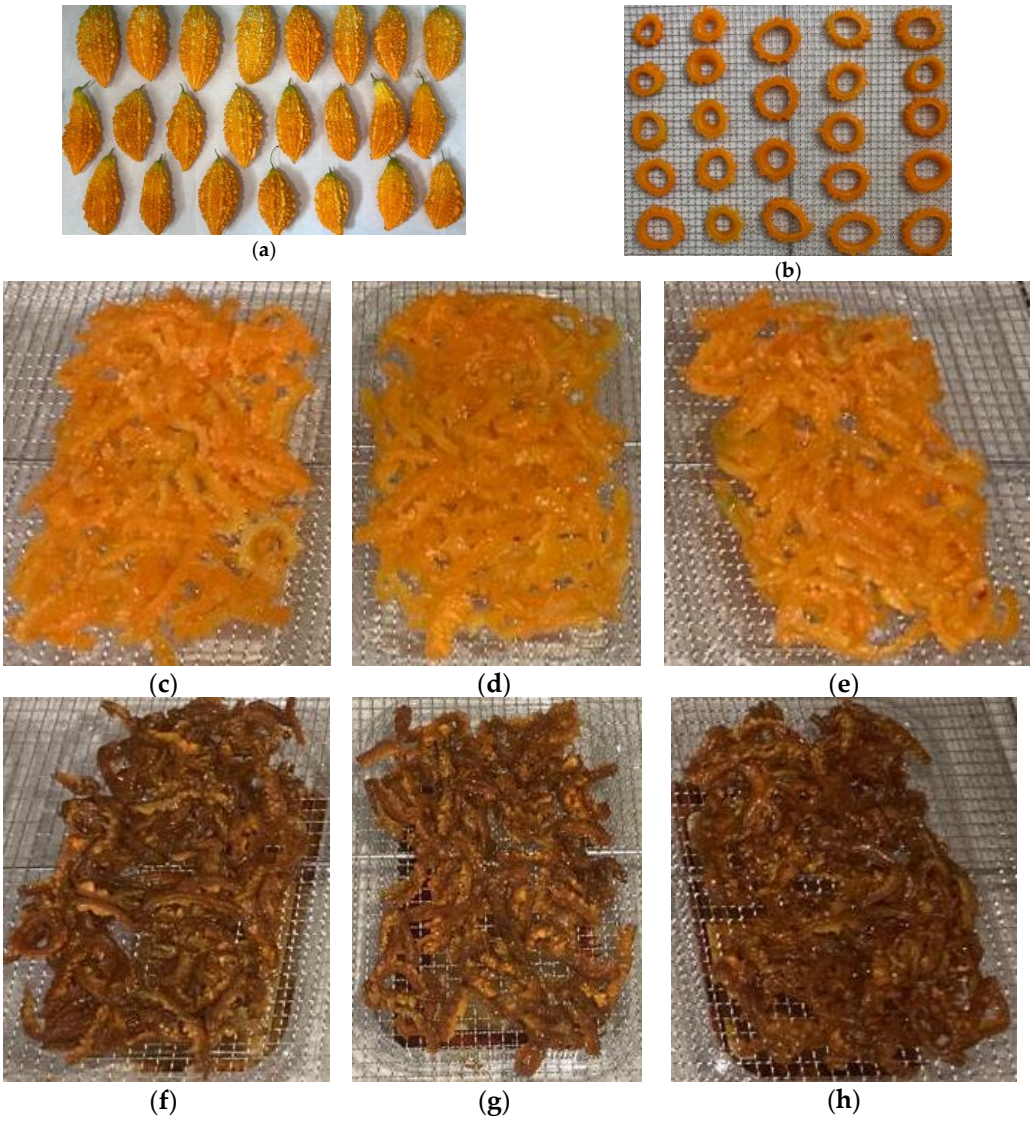

Figure 2. Fresh (**a**), 8 mm slice thickness bitter gourd samples (**b**) dipped in solutions of sugar (50 °Brix (**c**), 60 °Brix (**d**) and 70 °Brix (**e**)) and grape molasses (50 °Brix (**f**), 60 °Brix (**g**) and 70 °Brix (**h**)) for 10 h before drying.

Table 1. Trial plan for drying bitter gourd 70 °C drying air temperature, 8 mm slice thickness with sugar, and grape molasses mix solution pre-treatment.

Shelves No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
10 h dipping	S50	S50	S60	S60	S70	S70	G50	G50	G60	G60	G70	G70
20 h dipping	S50	S50	S60	S60	S70	S70	G50	G50	G60	G60	G70	G70
30 h dipping	S50	S50	S60	S60	S70	S70	G50	G50	G60	G60	G70	G70
Control Group	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP

The numbers after the abbreviations represent the Brix values. Samples that were "not pre-treated" for the control group "NP" were dried.

2.2. Moisture Content and Water Activity

Fresh samples were kept in an oven at 105 °C for 24 h to determine their moisture content [20]. Water activity was measured by using a water activity meter (AquaLab 4TE Decagon Devices, Washington, DC, USA) [21]. Water activity values of the sugar and grape molasses solutions used at different brix values are given in Table 2.

Table 2. Solutions water activity value.

		°Brix		
		50	**60**	**70**
Sugar	Average	0.9252	0.8888	0.8480
	Std. Error	0.0002	0.0006	0.0005
Grape Molasses	Average	0.8875	0.8402	0.7237
	Std. Error	0.0004	0.0001	0.0002

2.3. Mathematical Modeling of Drying Processes

The 13 different models presented in Table 3 were used to describe the drying kinetics for the moisture ratio (MR) (Equation (1)) data of the samples. Parameters in all models were decided using SigmaPlot 14.0 (Systat Software Inc., Chicago, IL, USA). Evaluation of the models was performed using the coefficient of determination (R^2) value (Equation (2)), reduced chi-squared (x^2) value (Equation (3)), and root main-square error (RMSE) (Equation (4)). These parameters were calculated using the following equations.

Table 3. Selected drying models for describing experimental drying data.

Model Name	**Model Equation**	**Reference**
Lewis	MR = exp(−k.t)	[22]
Henderson and Pabis	MR = a.exp(−k.t)	[23]
Page	MR = exp(−kt^n)	[24]
Two-term	MR = a.exp(−k_0.t) + b.exp(−k_1.t)	[23]
Two-term exponential	MR = a.exp(−k.t) + (1 − a).exp(−k.a.t)	[25]
Logarithmic	MR = a.exp(−k.t) + c	[26]
Wang and Singh	MR = 1 + a.t + b.t^2	[22]
Modified Henderson and Pabis	MR = a.exp(−kt) + b.exp(−g.t) + c.exp(−ht)	[23]
Midilli et al.	MR = a.exp(−ktn) + b.t	[27]
Verma et al.	MR = a.exp(−kt) + (1 − a).exp(−g.t)	[24]
Diffusion approach	MR = a.exp(−kt)+(1 − a) exp(−k.b.t)	[28]
Root of MR	MR = (n + k.t)2	[29]
Modified Page	MR = exp(−(kt)n)	[23]

t: drying time (min); MR: moisture ratio, k, a, b, c, g, h, n, k_0, and k_1 are model constants.

The moisture ratio (MR) of the samples during the drying processes was calculated according to Equation (1);

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_0 is the initial moisture content, M_t is the moisture content at any time (t, min), and M_e is the equilibrium moisture content during the drying process. The value of M_e was assumed as zero because it is lower than M_0 or M_t [30]. Contents of all moisture were exemplified as kg water/kg dry matter.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR_{pre}} - MR_{exp,i}\right)^2} \quad (2)$$

$$x^2 = \frac{\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{n - z} \quad (3)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2} \quad (4)$$

The predicted moisture ratio is $MR_{pre,i}$; where n is the number of observations; $MR_{exp,i}$ is the experimentally observed moisture ratio; and z is the number of constants in the

models. Lower x^2 and RMSE values, together with R^2 values close to 1, indicate a better suited model of the data.

2.4. Color Measurement

Colorimetry tests were conducted employing a highly precise measurement instrument, the PCE-CSM3 model, which offers selectable parameters including CIE L*, a*, b*, C*, h, and CIE L*, a*, b*. This device operates with an 8°/d measurement geometry, features a Ø8 mm measurement diaphragm, and incorporates a silicone photoelectric diode sensor. Notably, this advanced measurement equipment, manufactured in Turkey, was utilized for the colorimetry assessments.

The primary light source is powered by a rechargeable Li battery with 200 × 70 × 100 mm dimensions. In terms of color representation, L* signifies the brightness of the color, spanning a range from 0 to 100. Additionally, positive values of a* and b* correspond to red and yellow colors, respectively. The Hunter Lab scale establishes a correlation between color saturation and h° values, where 0, 90°, 180°, and 270° correspond to red, yellow, green, and blue, respectively.

To quantify the total color value difference (ΔE) between the samples, Equation (5) was applied. Notably, the color measurements taken from freshly sliced quince served as a reference point in this equation (L_{ref}, a_{ref}, b_{ref}) [31].

$$\Delta E = \sqrt{\left[\left(L^* - L_{ref}\right)^2 + \left(a^* - a_{ref}\right)^2 + \left(b^* - b_{ref}\right)^2\right]} \quad (5)$$

2.5. Determination of Total Phenolic Content and Antioxidant Activity

Extraction of the samples for total phenolic content and antioxidant activity analyses was performed according to the method of Dincer et al. [32] with some modifications. Two grams of the sample was weighed into a 50 mL centrifuge tube after crushing with a blender (Waring, International, New Hartford, CT, USA), and 50 mL of 80% methyl alcohol was added. The tubes were placed in an ultrasonic bath (Bandalin Sonorex Digiplus, 160/640 W, 35 kHz, Berlin, Germany) and extracted at 35 kHz constant frequency at 40 °C for 30 min. Thereafter, the extracts were filtered and kept at 4 °C until the analyses were performed.

The total phenolic content analyses were performed using the method described by Dincer et al. [32]. For this purpose, 0.5 mL of the extract was treated with 2.5 mL of 0.2 N Folin–Ciocalteu reagent and 2 mL of Na_2CO_3 (75 g/L). Then, the mixture was incubated at 50 °C for 5 min and immediately cooled. The absorbance of the final solution was recorded with a spectrophotometer (Thermo Fisher Scientific, Evaluation 160 model, UV-Vis, Madison, WI, USA) at a wavelength of 760 nm with respect to the blank solution (80% methyl alcohol). The results were expressed as gallic acid equivalents (mg GAE/kg).

The antioxidant activity of the samples was analyzed using the DPPH assay described by Fernández-León et al. [33]. From the sample extract, 50 µL was added to 950 µL of diphenylpicrylhydrazyl (DPPH) solution (6×10^{-5} M in methanol). The mixtures were shaken and kept in the dark at room temperature for 30 min. Absorbances were recorded at 515 nm (Thermo Scientific Evolution 160 UV-Vis, USA). Trolox was used as the standard of the measurement and the antioxidant activity was reported in mg Trolox/kg.

2.6. Total Carotenoid Content

The total carotenoid content of the samples was determined using the method described by Chan and Matanjun [34] with some modifications. Three grams of the sample was weighed into glass bottle after crushing with a blender (Waring, USA), and 75 mL of hexane:acetone:ethanol (2:1:1, *v*/*v*) was added. The glass bottles were placed in an ultrasonic bath (Bandalin Sonorex Digiplus, 160/640 W, 35 kHz, Germany) and extracted at 35 kHz constant frequency at 40 °C for 45 min. Thereafter, the extracts were filtered using Whatman No.1 filter paper, and the supernatant collected was made up to 100 mL with extraction solvent. Next, 25 mL of water was added and shaken vigorously. Separation

of the phase took place after 30 min. Two layers were observed: the organic (upper layer) and the aqueous layer (lower layer). The absorbance of the organic layer was measured at 470 nm, and the total carotenoid content was calculated using the following Equation (6);

$$Total\ carotenoid\ content\left(\frac{mg}{kg}\right) = \frac{[A \times V(mL) \times 10^4]}{A^{1\%} \times w(g)} \quad (6)$$

where A: absorbance; v: total extract volume; w: sample weight; and A1%: 2600 (β-carotene extinction coefficient in hexane).

3. Results and Discussion

3.1. Moisture Content and Water Activity

While "NP" started to dry with a moisture content of 93.8% wet basis (w.b.), all bitter gourds dipped at different °Brix values for 10 h started drying between 52.1% and 63.9% (w.b.) moisture content. Although "S70" started the drying process at the lowest moisture content, "G50" was the first to go below 10% moisture level after 180 min. In addition, "G50" started the drying process with the second highest moisture content. "G70" started at the highest level and reached an equilibrium moisture content with the highest moisture content as a result of drying. "S50" and "G60" started to dry at close moisture contents: "G60" lost moisture more quickly at the beginning, but after 135 min, "S50" started to lose moisture faster. While only "G50", "NP", "S70", and "S50" dropped below 10% (w.b.) moisture content, they exceeded this limit at drying times of 180, 250, 255, and 345 min, respectively (Figure 3).

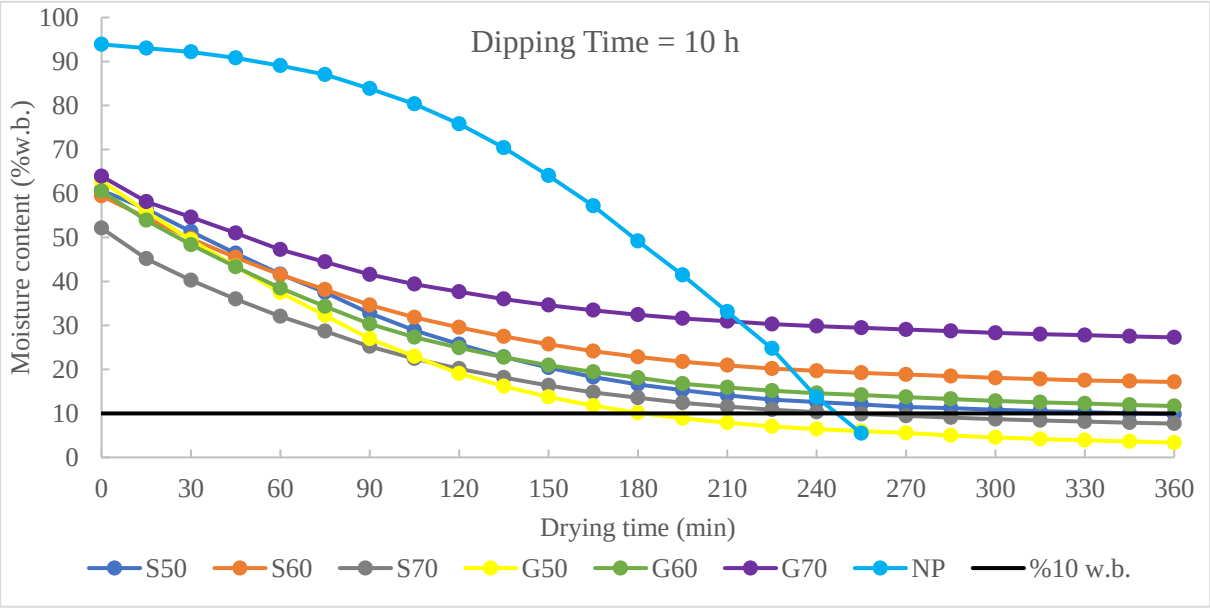

Figure 3. Drying curves of bitter gourd kept for 10 h dipping in sugar (S) and grape molasses (G) mixtures of different Brix values.

All of the bitter gourd dipped in different Brix values for 20 h remained between 41.4% and 62.4% (w.b.) moisture content at the beginning of drying. While all pre-treatment trials with "S" were below 10% (w.b.), the closest "G60" pre-treatment trial approached here in "G" application and reached this level in approximately 360 min. All samples treated with "S" reached 10% (w.b.) levels in the range of approximately 135–145 min. "S70" started the drying process from the lowest moisture content in the 20 h process, as in the 10 h dipping time pre-treatment. Then, while "S50" and "S60" caught the lowest level start, when it went below 10% level, this situation was reversed, and these two trials lost moisture faster. In "G" applications, "G50" started the drying process with the highest moisture content,

followed by "G60" and "G70", respectively. At the end of drying, while "G70" remained at the highest moisture content, "G50" did not decrease to 10% (w.b.) moisture content. Among all dipping pre-treatments, the trial in which the moisture content levels of 10% (w.b.) was decreased in the shortest time was seen as the application in which 20 h dipping time was made (Figure 4).

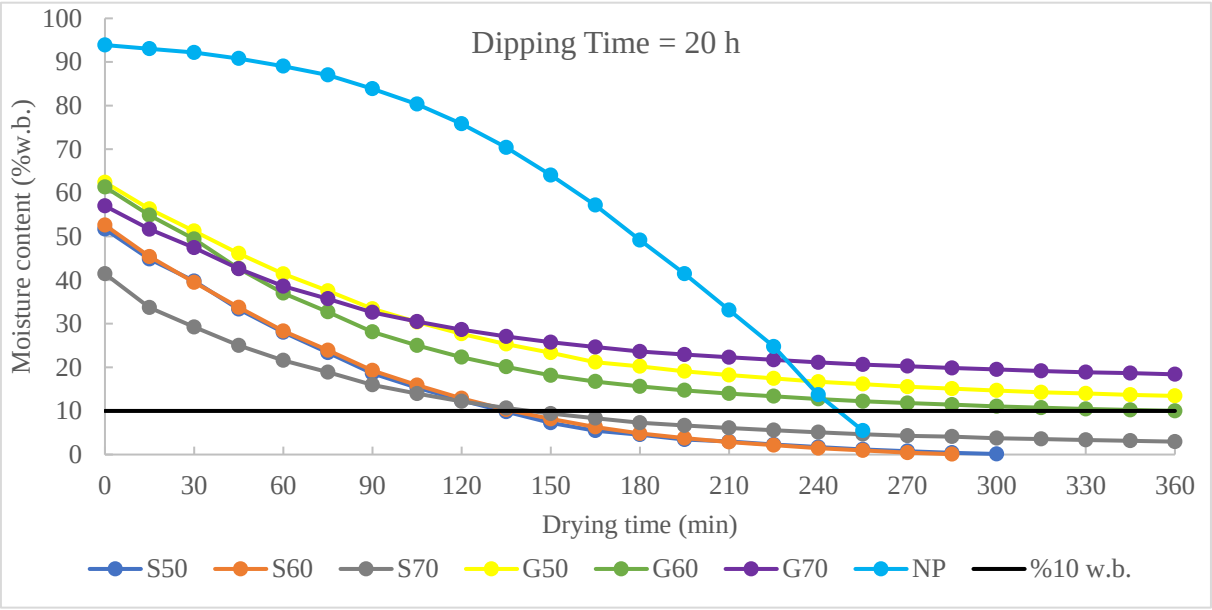

Figure 4. Drying curves of bitter gourd kept for 20 h dipping in sugar (S) and grape molasses (G) mixtures of different brix values.

All bitter gourds, which were kept at different °Brix values for 30 h, started to dry between 49.4% and 64.8% (w.b.) moisture content values. "S70" started drying with the lowest moisture content as in all other pre-treatment times. Then, "S60" was seen at the lowest level. Although "S50" and "S60" started to dry at a higher moisture content level than "S70", "S60" at the 70th minute and "S50" at the 125th minute passed "S70" and went below 10% (w.b.) moisture content at approximately 180 min. After these, the "S70" exceeded the same level in the 300th minute. While "G50" started at the highest moisture content level, the drying curve changed at the 105th minute, and "G70" completed drying at the highest moisture content level as in all other dipping times. "G50" and "G60" showed the same curve after the 255th minute. Although "S50" started to dry at the highest moisture content level after "G50", it caught a fast drying curve and decreased below 10% (w.b.) moisture content in the shortest time (Figure 5).

Due to its low molecular weight, sucrose is one of the osmotic agents. Sucrose was used as an osmotic agent in previous osmotic pre-treatment studies. Sucrose can readily diffuse and permeate into cells and tissues; thus, it may protect the quality of vegetables and fruits by inhibiting many chemical processes including enzymatic browning and oxidation [16,35]. In one of previous research work, Ispir and Togrul [8] investigated the effects of four different osmotic agents on the mass transfer of osmotically pre-treated apricots and discovered that sugar caused the water loss. Therefore, the researchers thought that sugar was one of the best osmotic agents. Regarding moisture contents of bitter gourd slices that are affected at different °Brix values of sugar and grape molasses, it is revealed that sugar is more effective than grape molasses for the bitter gourd slices that reach less than 10% (w.b.) moisture content in the shortest time. On the other hand, it is assumed that the concentration of the osmotic solution and osmotic pre-treatment duration affects the moisture content of an osmotically pre-treated vegetable and fruit sample. It was discovered that removing moisture from pineapples was successful when

using sugar syrup at 70 °Brix [16]. Pre-treatments like blanching also improve mass and heat transmission as well as enhancing qualities of fruits and vegetables.

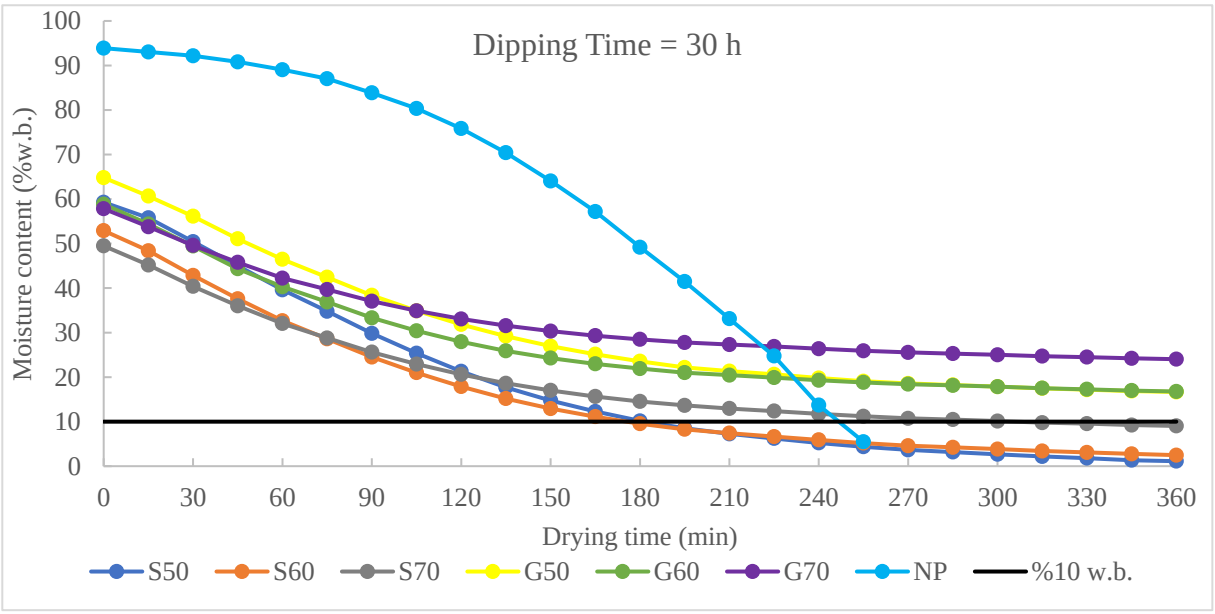

Figure 5. Drying curves of bitter gourd kept for 30 h dipping in sugar (S) and grape molasses (G) mixtures of different Brix values.

When the samples were evaluated in terms of a_w, a statistically significant difference was observed between the samples with "S" and "G" pre-treatment, and it was determined that all samples treated with "S" were higher. However, all of the "S" treated samples had lower a_w levels than the fresh sample. After the fresh trial, the highest a_w values were observed in the 50 and 70 °Brix solutions samples at 10 and 20 h dipping times. Among all the pre-treated samples, the lowest a_w value was seen in the 30h50Bx sample, while it was in this group in all samples in the 30 h group. The a_w values were higher than "NP" in all "S" trials. While all "G" samples do not show any statistical difference in themselves, this situation is different in "S" samples. In the "G" trials, "NP" and all other pre-treated samples were at a lower level than the "Fresh" sample and were statistically in the same group (Figure 6). For the stability and quality assurance of dried foods, it was reported that water activity was more crucial than moisture content [13]. As the amount of water contained in foods an increase, the water activity value also increases. The occurrence and speed of many chemical reactions, such as microbial growth, are related to water activity. To extend the shelf life of vegetables and fruits, it may be necessary to ensure they are dry. Fruits and vegetables that are osmotically air-dried become unstable when stored. In the effort to inactivate enzymes, the blanching procedure was used after osmotic treatment but before further processing [16]. Nyangena et al. [36] showed that pre-treatment before drying was a necessity to contribute to lower the water activity content of mango chips. It is thought that lower water activity slows down the activity of bacteria, enzymes, yeasts, and molds [37].

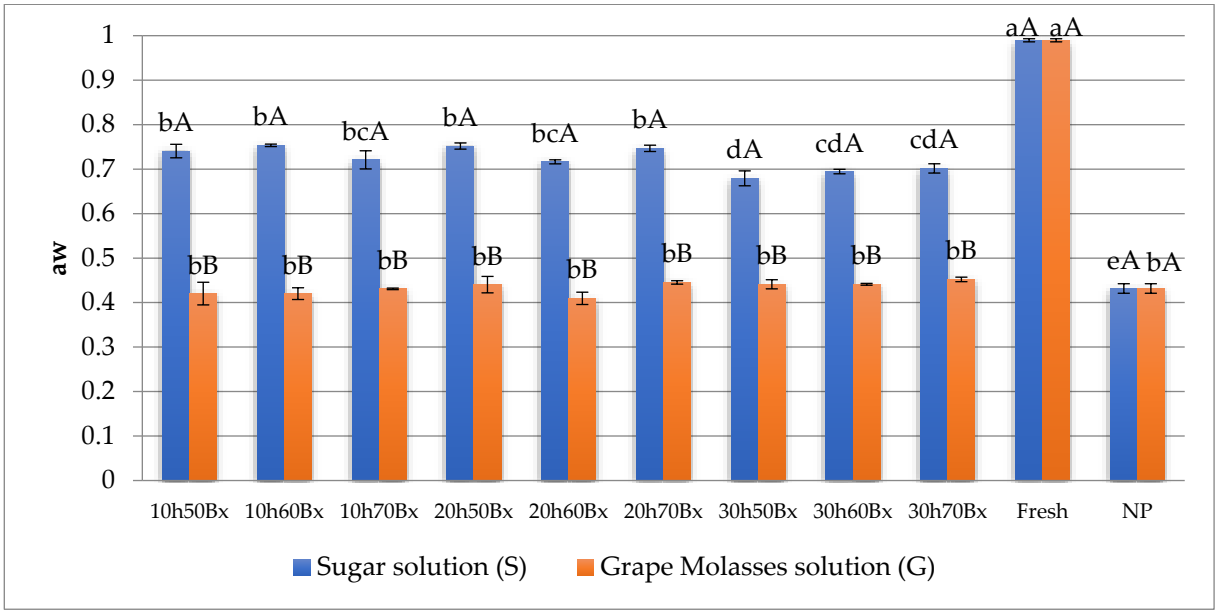

Figure 6. a_w values of bitter gourd samples dipped at different dipping times (10, 20 and 30 h) and °Brix values (50, 60 and 70) of sugar (S) and grape molasses (G) solutions*. Results are means ± standard error. Values with different superscript lowercase letters are significantly ($p < 0.05$) different between the treatments for each solution. Values with different superscript capital letters are significantly ($p < 0.05$) different between the solutions with the same treatments.

3.2. Mathematical Modeling of Drying Processes

Thirteen different types of mathematical models for bitter gourd were made. The gourd was sliced into 8-mm-thick slices at 70 °C drying air temperature and dipped in different °Brix values for different times and then dried. The most suitable models were examined. These analyses were evaluated separately for sugar (S) (Table 4) and grape molasses (G) (Table 5).

As a result of all "S" pre-treatments, the "Diffusion Approach", "Logarithmic", and "Midilli et al." models gave the highest R^2 and lowest X^2—RMSE values, respectively. In the "NP" pre-treatment, the highest R^2 (0.999) was seen in the "Midilli et al." model, followed by the "Two-term", "Modified Henderson and Pabis" and "Verma et al." models with a value of 0.9976. The samples with "S" pre-treatment are the same as the model with the lowest X^2 value of "NP". The lowest RMSE values of "NP" was seen in the "Midilli et al.", "Verma et al.", and "Two-term" models, respectively. Among the samples with "S" pre-treatment, the highest R^2 was seen with a value of 0.9999 in the 10h60Bx, 20h60Bx, and 30h70Bx samples in the "Diffusion approach" model. The smallest X^2 is again in the same model and was calculated as 1.35×10^{-6} in the 30h70Bx trial. The minimum RMSE was calculated as 0.0012 in the same model, in the 30760Bx trial (Table 4).

Following all preprocessing treatments of "G", the "Diffusion Approach", "Logarithmic", and "Midilli et al." models yielded the highest R^2 values while demonstrating the lowest X^2—RMSE values, respectively. The same results were seen in the "NP" process. The samples with "G" pre-treatment and the model with the lowest X^2 value of "NP" are the same. Among the "G" pre-treated samples, the highest R^2 "Diffusion approach" model was observed with a value of 0.9999 in the 10h50Bx, 10h60Bx, and 30h70Bx samples. In addition, all R^2 values in the same model are between 0.9985 and 0.9999 in other trials. While the smallest X^2 was seen in the same model in all pre-treatments, the same value was seen in the "Logarithmic" model, with the value of 4.60×10^{-5} in the 10h60Bx trial. The smallest RMSE was calculated as 0.0012 in the "Diffusion approach" model, in the 30h70Bx trial (Table 5).

Table 4. Parameters of the kinetic models used to fit data for samples dried after pre-treatments with sugar solution various concentrations and time.

		Lewis	Henderson and Pabis	Page	Two-Term	Two-term Exponential	Logarithmic	Wang and Singh	Modified Henderson and Pabis	Midilli et al.	Verma et al.	Diffusion Approach	Root of B-B0	Modified Page
10h50Bx	R^2	0.6454	0.7973	0.963	0.9115	0.6454	0.9997	0.9272	0.9115	0.9977	0.9115	0.9998	0.7465	0.963
	χ^2	0.0107	0.0067	0.0012	0.0036	0.0117	9.15×10^{-6}	2.40×10^{-3}	0.0046	9.37×10^{-5}	0.0032	5.64×10^{-6}	8.30×10^{-3}	0.0012
	RMSE	0.1034	0.0817	0.0349	0.0597	0.108	0.003	0.049	0.0677	0.0097	0.0566	0.0024	0.0914	0.0349
20h50Bx	R^2	0.4997	0.7392	0.9596	0.9039	0.6971	0.9998	0.8877	0.9039	0.9959	0.9039	0.9998	0.6953	0.9596
	χ^2	0.0123	0.007	1.10×10^{-3}	0.0032	0.0082	5.94×10^{-6}	0.003	0.0041	0.0001	0.0028	6.31×10^{-6}	0.0082	1.10×10^{-3}
	RMSE	0.1111	0.0838	0.033	0.0562	0.0903	0.0024	0.055	0.0638	0.0115	0.0533	0.0025	0.0906	0.033
30h50Bx	R^2	0.7136	0.8243	0.9616	0.912	0.8424	0.999	0.9437	0.912	0.9971	0.912	0.9992	0.7702	0.9616
	χ^2	0.0097	0.0065	0.0014	0.004	0.0058	4.21×10^{-5}	0.0021	0.0051	0.0001	0.0036	3.24×10^{-5}	0.0085	0.0014
	RMSE	0.0983	0.0804	0.0376	0.0629	0.0762	0.0065	0.0455	0.0714	0.0114	0.0597	0.0057	0.092	0.0376
10h60Bx	R^2	0.552	0.7729	0.9703	0.9202	0.7377	0.9997	0.9047	0.9202	0.9982	0.9202	0.9999	0.732	0.9703
	χ^2	0.0105	0.0058	0.0008	0.0025	0.0067	7.65×10^{-6}	0.0024	0.0032	5.52×10^{-5}	0.0023	1.77×10^{-6}	0.0069	0.0008
	RMSE	0.1027	0.0764	0.0276	0.0501	0.0821	0.0028	0.0495	0.0568	0.0074	0.0475	0.0013	0.083	0.0276
20h60Bx	R^2	0.4921	0.7425	0.968	0.9171	0.6925	0.9997	0.8755	0.9171	0.9977	0.9171	0.9999	0.698	0.968
	χ^2	0.0127	0.007	9.00×10^{-4}	0.0028	0.0084	9.25×10^{-6}	0.0034	0.0036	7.69×10^{-5}	0.0025	1.66×10^{-6}	0.0082	9.00×10^{-4}
	RMSE	0.1127	0.0839	0.0295	0.0526	0.0916	0.003	0.0583	0.0597	0.0088	0.0499	0.0013	0.0908	0.0295
30h60Bx	R^2	0.6051	0.7886	0.9652	0.9129	0.7736	0.9999	0.9238	0.9129	0.9972	0.9129	0.9998	0.7463	0.9652
	χ^2	0.0099	0.0058	0.0009	0.0029	0.0062	4.22×10^{-6}	0.0021	0.0037	9.16×10^{-5}	0.0026	4.54×10^{-6}	0.0069	0.0009
	RMSE	0.0992	0.0758	0.0308	0.0538	0.0785	0.0021	0.0455	0.061	0.0096	0.051	0.0021	0.0831	0.0308
10h70Bx	R^2	0.4848	0.7568	0.9756	0.9281	0.6922	0.9984	0.8861	0.9281	0.999	0.9281	0.9993	0.7207	0.9756
	χ^2	0.0104	0.0054	5.00×10^{-4}	0.0019	0.0068	3.90×10^{-5}	0.0025	0.0025	2.64×10^{-5}	0.0017	1.77×10^{-5}	0.0062	5.00×10^{-4}
	RMSE	0.1022	0.0733	0.0232	0.0441	0.0825	0.0062	0.0502	0.05	0.0051	0.0418	0.0042	0.0786	0.0232
20h70Bx	R^2	0.3369	0.7176	0.9763	0.928	0.5889	0.9973	0.8582	0.928	0.9986	0.928	0.9992	0.6918	0.9763
	χ^2	0.0089	0.0041	0.0003	0.0013	0.006	4.35×10^{-5}	0.0021	0.0017	2.48×10^{-5}	0.0012	1.21×10^{-5}	0.0045	0.0003
	RMSE	0.0942	0.0642	0.0186	0.0359	0.0775	0.0066	0.0455	0.0407	0.005	0.034	0.0035	0.0671	0.0186
30h70Bx	R^2	0.5482	0.7765	0.9665	0.9129	0.7379	0.9999	0.9229	0.9129	0.9972	0.9129	0.9999	0.7441	0.9665
	χ^2	0.0082	0.0044	0.0007	0.0021	0.0052	2.67×10^{-6}	0.0015	0.0027	6.71×10^{-5}	0.0019	1.35×10^{-6}	0.0051	0.0007
	RMSE	0.0908	0.0667	0.0258	0.046	0.0722	0.0016	0.0392	0.0522	0.0082	0.0437	0.0012	0.0714	0.0258
NP	R^2	0.9943	0.9952	0.9964	0.9976	0.9962	0.9953	0.9805	0.9976	0.9999	0.9976	0.9959	0.9828	0.9964
	χ^2	0.0006	0.0005	0.0004	0.0003	0.0004	5.00×10^{-4}	0.0021	0.0004	9.02×10^{-6}	0.0003	5.00×10^{-4}	0.0018	0.0004
	RMSE	0.0237	0.0227	0.0197	0.0176	0.0201	0.0234	0.0457	0.02	0.003	0.0167	0.022	0.0429	0.0197

Table 5. Parameters of the kinetic models used to fit data for samples dried after pre-treatments with grape molasses solution various concentrations and time.

		Lewis	Henderson and Pabis	Page	Two-Term	Two-Term Exponential	Logarithmic	Wang and Singh	Modified Henderson and Pabis	Midilli et al.	Verma et al.	Diffusion Approach	Root of B-B0	Modified Page
10h50Bx	R^2	0.54	0.7452	0.9682	0.9199	0.7199	0.9997	0.8531	0.9199	0.9976	0.9199	0.9999	0.6847	0.9682
	χ^2	0.0153	0.0092	0.0012	0.0035	0.0101	1.06×10^{-5}	5.30×10^{-3}	0.0046	1.00×10^{-4}	0.0032	3.03×10^{-6}	1.14×10^{-2}	0.0012
	RMSE	0.1235	0.096	0.0339	0.0595	0.1007	0.0033	0.0729	0.0675	0.0103	0.0565	0.0017	0.1068	0.0339
20h50Bx	R^2	0.5409	0.7604	0.9717	0.9236	0.7262	0.9994	0.8755	0.9236	0.9978	0.9236	0.9999	0.7112	0.9717
	χ^2	0.0129	0.0074	9.00×10^{-4}	0.0029	0.0084	$2.14 \times 10-5$	0.0038	0.0037	8.32×10^{-5}	0.0026	1.70×10^{-6}	0.0089	9.00×10^{-4}
	RMSE	0.1137	0.0857	0.0295	0.0535	0.0917	0.0046	0.0618	0.0607	0.0091	0.0508	0.0013	0.0941	0.0295
30h50Bx	R^2	0.6435	0.7952	0.9635	0.9123	0.796	0.9997	0.9188	0.9123	0.9969	0.9123	0.9997	0.7425	0.9635
	χ^2	0.0112	0.007	0.0012	0.0037	0.007	1.24×10^{-5}	0.0028	0.0047	0.0001	0.0033	1.31×10^{-5}	0.0088	0.0012
	RMSE	0.1056	0.0836	0.0353	0.0605	0.0834	0.0035	0.0526	0.0686	0.0114	0.0574	0.0036	0.0937	0.0353
10h60Bx	R^2	0.4291	0.7078	0.9613	0.9078	0.6432	0.9985	0.8658	0.9078	0.9987	0.9078	0.9985	0.6602	0.9613
	χ^2	0.0147	0.0082	0.0011	0.0032	0.01	4.60×10^{-5}	0.0038	0.0041	4.62×10^{-5}	0.0028	4.60×10^{-5}	0.0095	0.0011
	RMSE	0.1212	0.0906	0.033	0.0562	0.1001	0.0068	0.0614	0.0637	0.0068	0.0533	0.0068	0.0976	0.033
20h60Bx	R^2	0.4709	0.7199	0.962	0.9095	0.6726	0.9995	0.8463	0.9095	0.9948	0.9095	0.9997	0.6685	0.962
	χ^2	0.0151	0.0087	1.20×10^{-3}	0.0035	0.0102	1.74×10^{-5}	0.0048	0.0044	2.00×10^{-4}	0.0031	1.10×10^{-5}	0.0103	1.20×10^{-3}
	RMSE	0.123	0.0935	0.0344	0.0588	0.101	0.0042	0.0692	0.0666	0.0141	0.0557	0.0033	0.1017	0.0344
30h60Bx	R^2	0.5229	0.7547	0.9629	0.9085	0.7157	0.9998	0.8987	0.9085	0.9963	0.9085	0.9998	0.7139	0.9629
	χ^2	0.0111	0.0062	0.0009	0.0028	0.0072	5.43×10^{-6}	0.0026	0.0036	0.0001	0.0025	4.55×10^{-6}	0.0072	0.0009
	RMSE	0.1052	0.0788	0.0306	0.0532	0.0848	0.0023	0.0506	0.0603	0.0107	0.0505	0.0021	0.0851	0.0306
10h70Bx	R^2	0.4877	0.7531	0.9744	0.9264	0.693	0.9987	0.8764	0.9264	0.998	0.9264	0.9998	0.7144	0.9744
	χ^2	0.0113	0.0059	6.00×10^{-4}	0.0022	0.0074	3.54×10^{-5}	0.003	0.0028	5.86×10^{-5}	0.0019	4.20×10^{-6}	0.0069	6.00×10^{-4}
	RMSE	0.1062	0.077	0.0248	0.0465	0.0859	0.0059	0.0545	0.0527	0.0077	0.0441	0.002	0.0828	0.0248
20h70Bx	R^2	0.4605	0.742	0.9686	0.9168	0.6741	0.9989	0.8775	0.9168	0.9958	0.9168	0.9998	0.7069	0.9686
	χ^2	0.0106	0.0055	0.0007	0.0022	0.007	2.64×10^{-5}	0.0026	0.0028	1.00×10^{-4}	0.002	4.54×10^{-6}	0.0063	0.0007
	RMSE	0.103	0.0744	0.0259	0.0467	0.0836	0.0051	0.0513	0.0529	0.0106	0.0443	0.0021	0.0793	0.0259
30h70Bx	R^2	0.4878	0.7552	0.9677	0.9145	0.6953	0.9995	0.9001	0.9145	0.9966	0.9145	0.9999	0.7232	0.9677
	χ^2	0.0091	0.0047	0.0006	0.002	0.0059	1.00×10^{-5}	0.0019	0.0026	7.92×10^{-5}	0.0018	1.46×10^{-6}	0.0054	0.0006
	RMSE	0.0953	0.0688	0.025	0.045	0.0768	0.0032	0.044	0.051	0.0089	0.0427	0.0012	0.0732	0.025
NP	R^2	0.9943	0.9952	0.9964	0.9976	0.9962	0.9953	0.9805	0.9976	0.9999	0.9976	0.9959	0.9828	0.9964
	χ^2	0.0006	0.0005	0.0004	0.0003	0.0004	5.00×10^{-4}	0.0021	0.0004	9.02×10^{-6}	0.0003	5.00×10^{-4}	0.0018	0.0004
	RMSE	0.0237	0.0227	0.0197	0.0176	0.0201	0.0234	0.0457	0.02	0.003	0.0167	0.022	0.0429	0.0197

Shahari et al. [38] carried out a study on the mathematical modeling of cucumber drying, which is also from the same family as bitter gourd, at a drying air temperature of 50 °C. In the study, the "Newton", "Page", "Modified Page", "Henderson and Pabis", "Logarithmic", "Wang and Singh", and "Midilli et al." models were tested, and the most suitable model was chosen, since the "Logarithmic" model gave the highest R^2, lowest RMSE, and SSE (sum of square error) values. da Cunha et al. [39] dried the melon at 60 °C drying air temperature by applying four different pre-treatments as dipping, dipping with ultrasound, with vacuum and with ultrasound and vacuum. As a result of drying, the "Single exponential", "Henderson and Pabis", "Logarithmic", "Two-term", and "Wang and Singh" models were tried, and "Two-term exponential" gave the best model result.

During drying the immature bitter gourd with a slice thickness of 5–7 mm with a solar dryer, 10 different models, "Lewis", "Page", "Henderson and Pabis", "Two-term", "Logarithmic", "Wang and Singh", "Two-term exponential", "Verma et al.", "Approximation of diffusion", and "Midilli–Kucuk" were tried to make the mathematical modeling. As a result of the study, the "Two-term" and "Midilli–Kucuk" models gave the highest correlation coefficient R^2 and the lowest RMSE values [40].

After the 13 models were tested, the model constants of the three models that gave the best results for the "S" pre-treated samples were examined. In all three models, the highest "a" value was observed in the 30h50Bx trial, while the "k" value remained at the lowest level in the same trial. In a similar contrast, in the 20h70Bx trial where the "a" value was the minimum, it was observed that the "k" value was the maximum. Among these three models, the maximum "a" value was 0.6430 in 30h50Bx; the minimum "a" value was 0.3480 in 20h70Bx in trials in the "Diffusion approach" model. The maximum "k" value was 0.0268 in the 20h70Bx trial, in the "Midilli et al." model, and the minimum "k" value was 0.0121 in the 30h50Bx trial in the "Diffusion approach" model (Table 6).

Table 6. Kinetic parameters of selected models for samples dried after pre-treatments with sugar (S) solution various concentrations and time.

Mathematical Model	Concentration Method	Model Constants			
		a	k	b	n
Diffusion approach	10h50Bx	0.5911	0.0137	−0.0121	
	20h50Bx	0.5204	0.0165	-6.8425×10^{-5}	
	30h50Bx	0.6430	0.0121	−0.0309	
	10h60Bx	0.4855	0.0163	0.0093	
	20h60Bx	0.5066	0.0180	0.0085	
	30h60Bx	0.5180	0.0143	9.2387×10^{-5}	
	10h70Bx	0.4345	0.0183	0.0141	
	20h70Bx	0.3480	0.0207	0.0112	
	30h70Bx	0.4326	0.0147	0.0044	
Logarithmic	10h50Bx	0.5719	0.0145	0.4316	
	20h50Bx	0.5219	0.0166	0.4799	
	30h50Bx	0.6025	0.0136	0.4054	
	10h60Bx	0.5064	0.0151	0.4908	
	20h60Bx	0.5261	0.0168	0.4711	
	30h60Bx	0.5196	0.0144	0.4820	
	10h70Bx	0.4707	0.0157	0.5225	
	20h70Bx	0.3845	0.0169	0.6090	
	30h70Bx	0.4442	0.0142	0.5559	
Midilli et al.	10h50Bx	1.0036	0.0164	0.0009	0.8244
	20h50Bx	1.0037	0.0221	0.0009	0.7508
	30h50Bx	1.0049	0.0132	0.0009	0.8756
	10h60Bx	1.0023	0.0212	0.0009	0.7415
	20h60Bx	1.0024	0.0263	0.0008	0.7134
	30h60Bx	1.0035	0.0169	0.0009	0.7926
	10h70Bx	1.0013	0.0252	0.0008	0.6878
	20h70Bx	1.0012	0.0268	0.0008	0.6296
	30h70Bx	1.0030	0.0162	0.0009	0.7653

Among the samples dried by dipping "G", the best models were found to be "Diffusion approach", "Logarithmic", and "Midilli et al.", as was the case with "S" immersed samples. In the "Diffusion approach"/"Logarithmic" models, the maximum/minimum "a" values were found to be 0.5919/0.4154 and 0.6092/0.4398 in the 10h50Bx/30h70Bx trials, respectively. In the same models, the maximum/minimum "k" values were found to be 0.0194/0.0185 and 0.0145/0.0148, respectively, in the 20h60Bx/30h50Bx trials. While the maximum and minimum values were seen in similar trials in all three models in the samples with "S" pre-treatment, it was observed that the "Midilli et al." model did not give similar results compared to the other two models in the samples immersed with "G". In the "Midilli et al." model, the minimum "a" and "k" values were found in the trials of 10h60Bx (1.0015) and 30h50Bx (0.0179), respectively. The maximum "a" and "k" values were found in the 30h50Bx (1.0042) and 10h50Bx (0.0316) trials, respectively (Table 7).

Table 7. Kinetic parameters of selected models for samples dried after pre-treatments with grape molasses (G) solution various concentrations and time.

Mathematical Model	Concentration Method	Model Constants			
		a	k	b	n
Diffusion approach	10h50Bx	0.5919	0.0192	0.0090	
	20h50Bx	0.5251	0.0184	0.0142	
	30h50Bx	0.5884	0.0145	−0.0045	
	10h60Bx	0.5451	0.0180	−0.0025	
	20h60Bx	0.5494	0.0194	0.0068	
	30h60Bx	0.4949	0.0161	0.0034	
	10h70Bx	0.4513	0.0189	0.0154	
	20h70Bx	0.4307	0.0185	0.0119	
	30h70Bx	0.4154	0.0167	0.0088	
Logarithmic	10h50Bx	0.6092	0.0181	0.3880	
	20h50Bx	0.5570	0.0166	0.4390	
	30h50Bx	0.5830	0.0148	0.4206	
	10h60Bx	0.5365	0.0182	0.4608	
	20h60Bx	0.5667	0.0185	0.4340	
	30h60Bx	0.5042	0.0158	0.4968	
	10h70Bx	0.4918	0.0162	0.5027	
	20h70Bx	0.4649	0.0163	0.5332	
	30h70Bx	0.4398	0.0153	0.5589	
Midilli et al.	10h50Bx	1.0025	0.0316	0.0008	0.7184
	20h50Bx	1.0025	0.0278	0.0008	0.7123
	30h50Bx	1.0042	0.0179	0.0009	0.8116
	10h60Bx	1.0015	0.0276	0.0009	0.7204
	20h60Bx	1.0037	0.0306	0.0008	0.7079
	30h60Bx	1.0035	0.0206	0.0009	0.7520
	10h70Bx	1.0020	0.0271	0.0008	0.6837
	20h70Bx	1.0030	0.0246	0.0008	0.6929
	30h70Bx	1.0029	0.0199	0.0009	0.7226

3.3. Color Measurement

Color is a crucial aspect of fruits and vegetables since people choose which ones to eat and buy based on their color. Color alterations can occur as a result of chemical reactions such as enzymatic browning and non-enzymatic browning, which result in the production of brown pigmentation and are facilitated by enzymes like polyphenol oxidase or peroxidase [35]. Among the "S" trials, it was observed that the highest ΔE value was in the 30h60Bx, followed by the 20h50Bx trial. All "S" trials ΔE value are higher than "NP". ΔE value is higher in all "G" trials than "S" trials. In the "G" trials, a significant decrease was observed in the ΔE value due to the increase in the Brix value in the samples dried in 10 h of dipping time. No such difference was observed in the 20 h application. In the 30 h dipping process, it was the opposite compared to the 10 h dipping process, and the

increase in the Brix value increased the ΔE value. The highest ΔE value was seen in the 30h70Bx trial, while the lowest was in the 20h60Bx trial (Figure 7). Because of the increase in pigment density throughout osmotic pre-treatment and the drying process, Falade et al. [41] noticed that watermelon that had been osmotically dried had a deeper hue. The variation of concentration of osmotic pre-treatment solution may cause differences in the appearance of vegetables and fruits. In a previous study, Kowalski and Mierzwa [42] demonstrated that the color change took place between 20% and 60% sucrose solutions of osmotically pre-treated carrot samples. Similarly, the results of the present study revealed that alterations in the osmotic pre-treatment solution concentration make differences in the total color changes. Because grape syrup solutions are rich in monosaccharides (glucose and fructose), they have a greater impact on color indices when used as osmotic solutions. Changes in the color index during the process are probably influenced by the colored pigments of osmotic solutions (grape and mulberry syrups), pigmented chemical interactions such as Milliard's reaction between sugar and protein, and production of Melanoidin [43]. The ΔE value represents how much the dried product's color changed overall. The finest samples in terms of visual appeal are those with low color change values (ΔE). The untreated samples showed minimum color change. In comparison to grape molasses pre-treated samples, those that had been pre-treated with sucrose exhibited the fewest color alterations, after the untreated samples. The interactions and synthesis of color pigments are actively influenced by the chemical composition of glucose and fructose. Due to the high amount of monosaccharides including glucose and fructose that they contain, osmotic solutions like grape and mulberry syrups have an impact on color changes. Therefore, it is thought that it may be the reason why the color change in the "G" trials is greater than in the "S" trials [43].

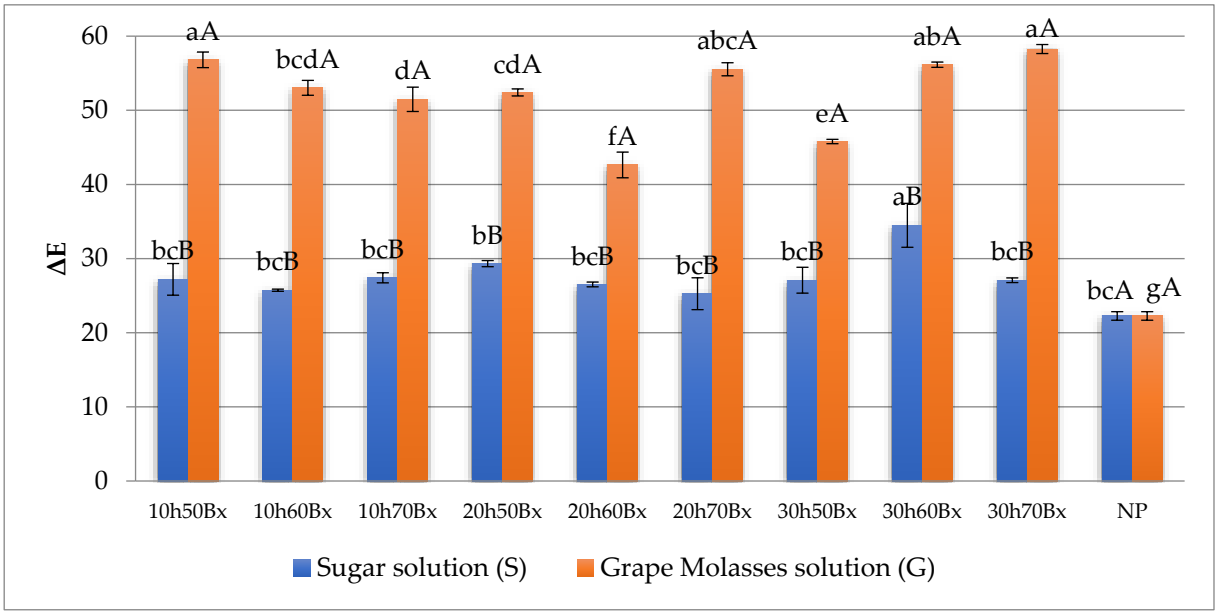

Figure 7. ΔE values of bitter gourd samples dipped at different dipping times (10, 20 and 30 h) and °Brix values (50, 60 and 70) of sugar (S) and grape molasses (G) solutions*. Results are means ± standard error. Values with different superscript lowercase letters are significantly ($p < 0.05$) different between the treatments for each solution. Values with different superscript capital letters are significantly ($p < 0.05$) different between the solutions with the same treatments.

3.4. Total Phenolic Content and Antioxidant Activity

One of the most significant classes of compounds in plants is the phenolic compounds [44]. Regarding total phenolic contents, differences were examined by applying statistical analyses after bitter gourd drying, in which different applications were conducted. Differences were examined by applying statistical analyses after bitter gourd drying, in

which different applications were made. From the phenolic content of view, all samples treated with "S" showed a decrease, while all samples treated with "G" were higher than those with "S", and this difference is statistically significant. One of the fruits with the highest concentrations of phenolic compounds is grapes; as a result of their high phenolic content, these fruits have high antioxidant activity [45]. Therefore, grape molasses is rich in phenolics and antioxidants, and it is assumed that grape molasses dipping samples demonstrated higher total phenolics and antioxidants than sugar dipping samples. Despite the different Brix and dipping times, there was no statistically significant difference between all "S" treated samples. While the highest phenolic content 50 °Brix value was observed in the samples that were immersed for 10 h, the "G" mixture and the 60 and 70 °Brix mixtures decreased gradually; this decrease is statistically significant. It was observed that dipping pre-treatment at different Brix values in the 20 h treatment, the "G" mixture did not cause any change in the samples in terms of phenolic content. In the 30 h and "G" mixture, 60 °Brix shows the highest phenolic content value, while there is no difference between the other Brix values. In addition, bitter gourd dried by dipping in a mixture of "G" for 30 h and 60 °Brix, although not statistically significant, showed the highest phenolic content value, outstripping the "Fresh" and "NP" samples. While "NP" and 10h50Bx samples followed the 30h60Bx, there was no statistical difference between these three highest samples (Figure 8). The greater antioxidant activities were determined at non-pre-treated bitter gourd samples. The differences in antioxidant activity of bitter gourd slices at different dipping solutions showed different responses to dipping time treatment. Increased antioxidant activity was determined in high-Brix-treated grape molasses treatment samples and in the 20 h dipping time, which means that increasing dipping time ends with an increase in phenolic content. In a similar trend to the present study, Dermesonlouoglou et al. [46] demonstrated the highest total phenolic content with increased osmotic pre-treatment time in the goji berry. The increase in antioxidant activities of bitter gourd samples might be due to the increase in phenolic content and variation of polyphenols in the matrix after dipping time and thermal processing as reported by Kim et al. [47]. It is assumed that polyphenols and antioxidant activity are highly linked to each other. Therefore, it is possible to say that the increasing total phenolic content of bitter gourd slices is a consequence of thermally treated sugar and grape molasses dipping procedures.

The antioxidant activity values of all samples subjected to both "S" and "G" pre-treatment at different dipping times were lower than the "NP" group. A decrease in the antioxidant activity level was observed due to the increase in the Brix value in the "G" pre-treatment at 10 h dipping time. Although an increase was observed due to the increase in the Brix value in the 20 h dipping time in the "G" pre-treatment, there was no statistical difference between the 60 and 70 °Brix values. The increase in antioxidant activity was probably caused by the increased Brix of grape molasses solution when the dipping time was increased from 10 to 20 h. The lowest antioxidant activity in the "S" trial was seen in the 20h50Bx trial followed by the 10h60Bx trial. In the "G" pre-treatment trial, the lowest antioxidant activity was observed at 10h70Bx, and this trial was in the lowest group statistically. No statistical difference was observed in different Brix values in both "S" and "G" trials in the 30 h dipping pre-treatment. Only in the 10h60Bx and 20h50Bx trials was there a statistical difference in terms of antioxidant activity between the "S" and "G" pre-treatments (Figure 9). The significant release of soluble antioxidant substances through the osmotic pre-treatment process is assumed to be the cause of the reduced antioxidant value in osmotic pre-treatment bitter gourd slices compared to non-pre-treated bitter gourd slices. It is believed that grape molasses can boost antioxidant activity while preventing the degradation of phytochemicals [45].

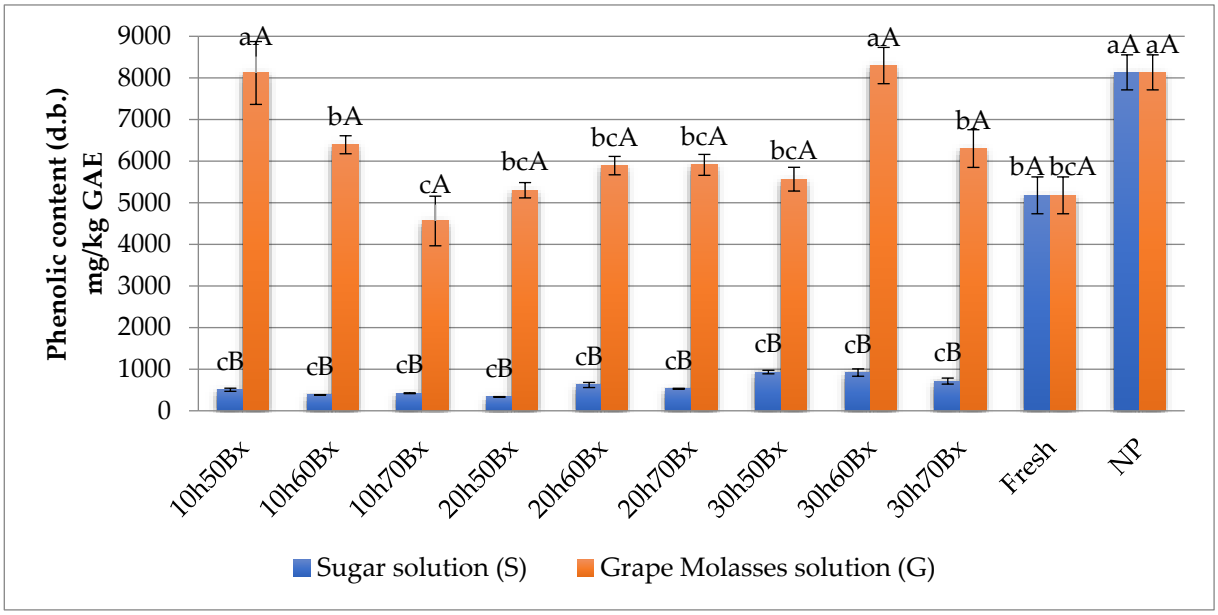

Figure 8. Phenolic content values of bitter gourd samples dipped at different dipping times (10, 20 and 30 h) and °Brix values (50, 60 and 70) of sugar (S) and grape molasses (G) solutions*. Results are means ± standard error. Values with different superscript lowercase letters are significantly ($p < 0.05$) different between the treatments for each solution. Values with different superscript capital letters are significantly ($p < 0.05$) different between the solutions with the same treatments.

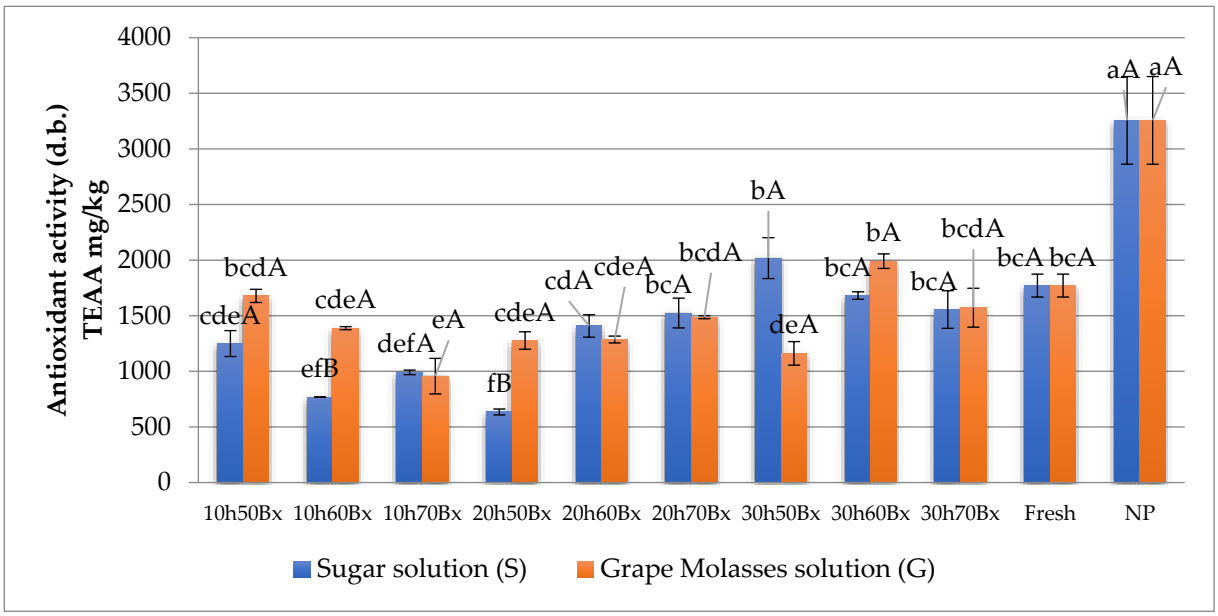

Figure 9. Antioxidant activity values of bitter gourd samples dipped at different dipping times (10, 20 and 30 h) and °Brix values (50, 60 and 70) of sugar (S) and grape molasses (G) solutions*. Results are means ± standard error. Values with different superscript lowercase letters are significantly ($p < 0.05$) different between the treatments for each solution. Values with different superscript capital letters are significantly ($p < 0.05$) different between the solutions with the same treatments.

3.5. Total Carotenoid Content

Carotenoids are delicate substances which are easily degraded by acid, light, and high temperatures [48]. When the dried samples were examined in terms of carotenoid content, it was determined that the "S" treated samples showed higher results than the "G" treated samples in all trial repetitions, apart from 10 h 60 °Brix and 30 h 50 °Brix, and it was

statistically significant. However, the carotenoid content value is higher in "Fresh" and "NP" samples than in pre-treated samples. It is thought that the cell structure is affected by the process and carotenoids are leached during the osmotic pre-treatment. Since carotenoids are rich in conjugated double-bond structures, they are easily degraded or isomerized during heated air drying [49]. The dipping time and different Brix values between the "S" treated samples did not cause any difference. On the other hand, 10 h 60 °Brix and 30 h 50 °Brix trials were statistically higher in "G" samples than all other "G" samples. Although there is no statistically significant difference, the highest carotenoid content values in dried bitter gourd samples applied "S" and "G" were observed in 10 h 50 °Brix and 10 h 60 °Brix trials, respectively (Figure 10). Luchese et al. [50] reported that osmotic solution concentration did not significantly affect the carotenoid content of osmotic pre-treatment of physalis fruits. The same researchers indicated that the higher the temperature during the osmotic pre-treatment process caused the higher loss of carotenoids from products. It was also reported that regardless of the osmotic solution concentration, physalis fruits which was subjected to a 10 h osmotic pre-treatment process had no carotenoid loss. In the current study, non-pre-treated and fresh samples of bitter gourd slices showed higher values of the carotenoid content than the bitter gourd slices pre-treated with various concentrations of sugar and grape molasses osmotic solutions. Sanjinez-Argandona et al. [51] found a reduction on the total carotenoid content of guava which was subjected to air drying after osmotic pre-treatment. It was also reported that the loss of carotenoid was much greater when the guava samples were subjected to a hot-air drying process without osmotic pre-treatment. It is hypothesized that the loss of carotenoids is triggered by high drying temperatures, increased exposure to oxygen, and the low relative humidity of the drying air as they all accelerate the decomposition rate [50].

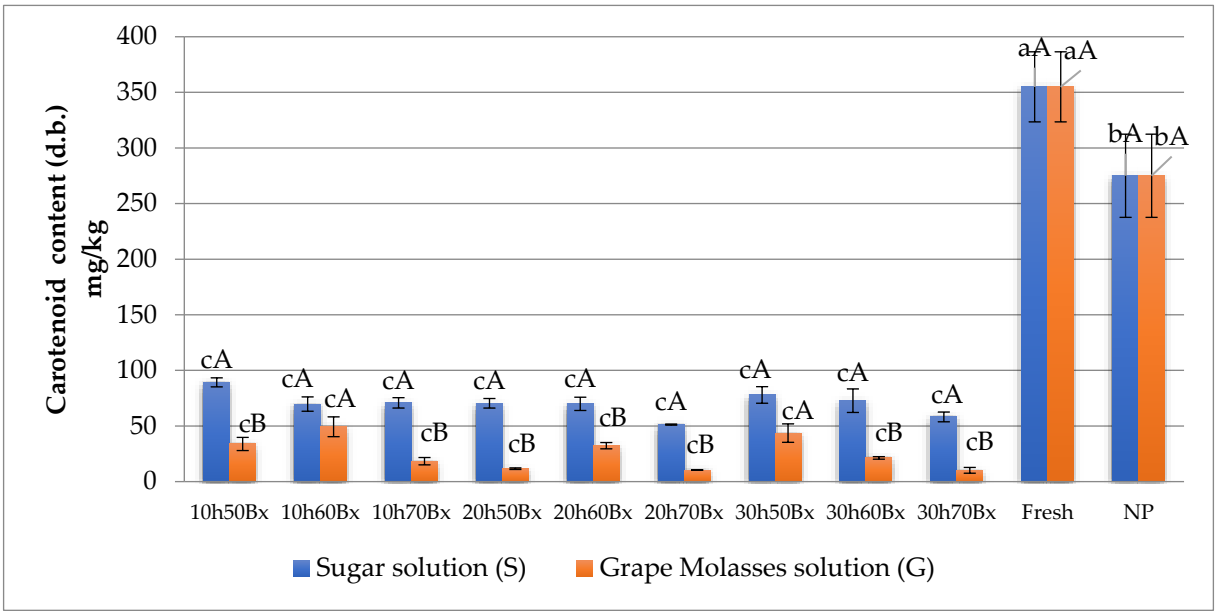

Figure 10. Carotenoid content values of bitter gourd samples dipped at different dipping times (10, 20 and 30h) and °Brix values (50, 60 and 70) of sugar (S) and grape molasses (G) solutions*. Results are means ± standard error. Values with different superscript lowercase letters are significantly ($p < 0.05$) different between the treatments for each solution. Values with different superscript capital letters are significantly ($p < 0.05$) different between the solutions with the same treatments.

4. Conclusions

Regarding the mathematical modeling, "Diffusion approach", "Logarithmic", and "Midilli et al." were the most suitable ones among the 13 mathematical models tried, respectively. The sugar 70 °Brix pre-treatment trial started the drying process at the lowest

moisture content % (w.b.) level in all dipping times, while grape molasses 70 °Brix remained at the highest level at the end of drying in all trials. It has been observed that the shortest drying time (130 min) is achieved in the sugar 50 °Brix trial with 20 h of dipping time. All of the pre-treatments increased the total color change. Sucrose pre-treated samples, which were compared to grape molasses pre-treated samples, showed the fewest color changes following the untreated samples. The highest carotenoid content was found in 10 h dipping time in 50 °Brix sugar solution with 89.228 mg/kg. The highest total phenolic content was found in 30 h dipping time in 60 °Brix grape molasses solution with 8296.873 mg/kg GAE. All of the pre-treatments increased the total color change. Pre-treatment trials caused a decrease in the antioxidant activity level. In addition, the highest antioxidant activity was found in 30h50Bx in sugar pre-treatment and 30h60Bx in grape molasses pre-treatment. While the antioxidant activity of the grape molasses trial was high at short dipping times, this difference became less as the holding time increased. The highest carotenoid content was found in 10 h dipping time in 50 °Brix sugar solution with 89.228 mg/kg. Regarding the mathematical modeling, "Diffusion approach", "Logarithmic", and "Midilli et al." were the most suitable ones among the 13 mathematical models tried, respectively. Bitter gourd slices pre-treated with grape molasses were enriched with antioxidants. Similarly, in samples pre-treated with sugar, the carotenoid content also increased accordingly by increasing drying time. In other words, depending on demand, grape molasses for high antioxidants or sugar osmotic pre-treatments for high carotenoids may be preferred.

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References

1. Porat, R.; Lichter, A.; Terry, L.A.; Harker, R.; Buzby, J. Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. *Postharvest Biol. Technol.* **2018**, *139*, 135–149. [CrossRef]
2. Huang, L.L.; Zhang, M. Trends in development of dried vegetable products as snacks. *Dry. Technol.* **2012**, *30*, 448–461. [CrossRef]
3. Palacios Romero, I.; Gómez, M.J.R.; Iñiguez, F.M.S.; Magro, P.C. Optimization of the osmotic dehydration process of plums (*Prunus salicina* Lindl.) in solutions enriched with inulin, using response surface methodology. *LWT* **2022**, *157*, 113092. [CrossRef]
4. Wojdyło, A.; Figiel, A.; Lech, K.; Nowicka, P.; Oszmiański, J. Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. *Food Bioprocess Technol.* **2014**, *7*, 829–841. [CrossRef]
5. Lech, K.; Michalska, A.; Wojdyło, A.; Nowicka, P.; Figiel, A. The influence of physical properties of selected plant materials on the process of osmotic dehydration. *LWT* **2018**, *91*, 588–594. [CrossRef]
6. Lemus-Mondaca, R.; Noma, S.; Igura, N.; Shimoda, M.; Pérez-Won, M. Kinetic modeling and mass diffusivities during osmotic treatment of red abalone (*Haliotis rufescens*) slices. *J. Food Process Preserv.* **2015**, *39*, 1889–1897. [CrossRef]
7. Uddin, M.B.; Ainsworth, P.; İbanoğlu, Ş. Evaluation of mass exchange during osmotic dehydration of carrots using response surface methodology. *J. Food Eng.* **2004**, *65*, 473–477. [CrossRef]
8. Ispir, A.; Toğrul, İ.T. Osmotic dehydration of apricot: Kinetics and the effect of process parameters. *Chem. Eng. Res. Des.* **2009**, *87*, 166–180. [CrossRef]
9. Ruiz-López, I.I.; Castillo-Zamudio, R.I.; Salgado-Cervantes, M.A.; Rodríguez-Jimenes, G.C.; García-Alvarado, M.A. Mass transfer modeling during osmotic dehydration of hexahedral pineapple slices in limited volume solutions. *Food Bioprocess Technol.* **2010**, *3*, 427–433. [CrossRef]
10. Yadav, B.S.; Yadav, R.B.; Jatain, M. Optimization of osmotic dehydration conditions of peach slices in sucrose solution using response surface methodology. *J. Food Sci. Technol.* **2012**, *49*, 547–555. [CrossRef]
11. Sulistyawati, I.; Verkerk, R.; Fogliano, V.; Dekker, M. Modelling the kinetics of osmotic dehydration of mango: Optimizing process conditions and pre-treatment for health aspects. *J. Food Eng.* **2020**, *280*, 109985. [CrossRef]

12. Bchir, B.; Besbes, S.; Karoui, R.; Paquot, M.; Attia, H.; Blecker, C. Osmotic dehydration kinetics of pomegranate seeds using date juice as an immersion solution base. *Food Bioprocess Technol.* **2012**, *5*, 999–1009. [CrossRef]
13. Jin, W.; Zhang, M.; Shi, W. Evaluation of ultrasound pretreatment and drying methods on selected quality attributes of bitter melon (*Momordica charantia* L.). *Dry. Technol.* **2019**, *37*, 387–396. [CrossRef]
14. Yan, J.K.; Wu, L.X.; Qiao, Z.R.; Cai, W.D.; Ma, H. Effect of different drying methods on the product quality and bioactive polysaccharides of bitter gourd (*Momordica charantia* L.) slices. *Food Chem.* **2019**, *271*, 588–596. [CrossRef] [PubMed]
15. Mehta, D.; Prasad, P.; Bansal, V.; Siddiqui, M.W.; Sharma, A. Effect of drying techniques and treatment with blanching on the physicochemical analysis of bitter-gourd and capsicum. *LWT* **2017**, *84*, 479–488. [CrossRef]
16. Yadav, A.K.; Singh, S.V. Osmotic dehydration of fruits and vegetables: A review. *J. Food Sci. Technol.* **2014**, *51*, 1654–1673. [CrossRef]
17. Kudri, S.; Harshitha, T.; Hegde, P.; Tadkod, M.; Deasei, S.; Hemalatha, S. Effect of molasses, honey, and sugar on osmoticdehydration of muskmelon (*Cucumis melo* L.). *Pharm. Innov.* **2022**, *11*, 162–166.
18. Ozsan Kilic, T.; Boyar, I.; Gungor, K.K.; Torun, M.; Perendeci, N.A.; Ertekin, C.; Onus, A.N. Improvement of hot air dried bitter gourd (*Momordica charantia* L.) product quality: Optimization of drying and blanching process by experimental design. *Agriculture* **2023**, *13*, 1894. [CrossRef]
19. Ertekin, C.; Heybeli, N. Thin-layer infrared drying of mint leaves. *J. Food Process Preserv.* **2014**, *38*, 1480–1490. [CrossRef]
20. Hazar, D.; Boyar, I.; Dincer, C.; Ertekin, C. Investigation of Color and Bioactive Compounds of Different Colors from Pansy (*Viola* × *wittrockiana* Gams.) Dried in Hot Air Dryer. *Horticulturae* **2023**, *9*, 186. [CrossRef]
21. Sahin-Nadeem, H.; Dinçer, C.; Torun, M.; Topuz, A.; Özdemir, F. Influence of inlet air temperature and carrier material on the production of instant soluble sage (*Salvia fruticosa* Miller) by spray drying. *LWT Food Sci. Technol.* **2013**, *52*, 31–38. [CrossRef]
22. Ozdemir, M.; Devres, Y.O. The thin layer drying characteristics of hazelnuts during roasting. *J. Food Eng.* **1999**, *42*, 225–233. [CrossRef]
23. Delgado, T.; Pereira, J.A.; Baptista, P.; Casal, S.; Ramalhosa, E. Shell's influence on drying kinetics, color and volumetric shrinkage of *Castanea sativa* Mill. fruits. *Food Res. Int.* **2014**, *55*, 426–435. [CrossRef]
24. Yaldiz, O.; Ertekin, C. Thin layer solar drying of some vegetables. *Dry. Technol.* **2001**, *19*, 583–597. [CrossRef]
25. Ertekin, C.; Firat, M.Z. A comprehensive review of thin-layer drying models used in agricultural products. *Crit. Rev. Food Sci. Nutr.* **2017**, *57*, 701–717. [CrossRef]
26. Kayisoglu, S.; Ertekin, C. Vacuum drying kinetics of barbunya bean (*Phaseolus vulgaris* L. *elipticus* Mart.). *Philip. Agric. Sci.* **2011**, *94*, 285–291.
27. Midilli, A.; Kucuk, H.; Yapar, Z. A new model for single-layer drying. *Dry. Technol.* **2002**, *20*, 1503–1513. [CrossRef]
28. Swain, S.; Samuel, D.V.K.; Bal, L.M.; Kar, A.; Sahoo, G.P. Modeling of microwave assisted drying of osmotically pretreated red sweet pepper (*Capsicum annum* L.). *Food Sci. Biotech.* **2012**, *21*, 969–978. [CrossRef]
29. Vega-Gálvez, A.; Puente-Díaz, L.; Lemus-Mondaca, R.; Miranda, M.; Torres, M.J. Mathematical modeling of thin-layer drying kinetics of C ape gooseberry (*Physalis peruviana* L.). *J. Food Process Preserv.* **2014**, *38*, 728–736. [CrossRef]
30. Dincer, C.; Dogan, A.; Erkan, M. Effect of various drying methods on drying characteristics of black and white myrtle fruits (*Myrtus communis* L.). *Erwerbs-Obstbau* **2022**, *64*, 433–443. [CrossRef]
31. Akman, H.E.; Boyar, I.; Gozlekci, S.; Saracoglu, O.; Ertekin, C. Effects of convective drying of Quince fruit (*Cydonia oblonga*) on color, antioxidant activity and phenolic compounds under various fruit juice dipping pre-treatments. *Agriculture* **2022**, *12*, 1224. [CrossRef]
32. Dincer, C.; Tontul, I.; Çam, I.B.; Özdemir, K.S.; Topuz, A.; Nadeem, H.Ş.; Tuğrul, A.S.; Göktürk, R.S. Phenolic composition and antioxidant activity of Salvia tomentosa Miller: Effects of cultivation, harvesting year, and storage. *Turk. J. Agric. For.* **2013**, *37*, 561–567. [CrossRef]
33. Fernández-León, M.F.; Fernández-León, A.M.; Lozano, M.; Ayuso, M.C.; Amodio, M.L.; Colelli, G.; González-Gómez, D. Retention of quality and functional values of broccoli 'Parthenon' stored in modified atmosphere packaging. *Food Control* **2013**, *31*, 302–313. [CrossRef]
34. Chan, P.T.; Matanjun, P. Chemical composition and physicochemical properties of tropical red seaweed, *Gracilaria changii*. *Food Chem.* **2017**, *221*, 302–310. [CrossRef] [PubMed]
35. Raja, S.; Asman, S. Effect of pre-treatment on the impregnation of osmotically dehydrated fruits: A review. *Borneo J. Resour. Sci. Technol.* **2023**, *13*, 1–21. [CrossRef]
36. Nyangena, I.; Owino, W.; Ambuko, J.; Imathiu, S. Effect of selected pretreatments prior to drying on physical quality attributes of dried mango chips. *J. Food Sci. Technol.* **2019**, *56*, 3854–3863. [CrossRef] [PubMed]
37. Belessiotis, V.; Delyannis, E. Solar drying. *Sol. Energy* **2011**, *85*, 1665–1691. [CrossRef]
38. Shahari, N.; Hussein, S.M.; Nursabrina, M.; Hibberd, S. Mathematical modelling of cucumber (*Cucumis sativus*) drying. *AIP Conf. Proc.* **2014**, *1605*, 307–312.
39. da Cunha, R.M.C.; Brandão, S.C.R.; de Medeiros, R.A.B.; da Silva Júnior, E.V.; da Silva, J.H.F.; Azoubel, P.M. Effect of ethanol pretreatment on melon convective drying. *Food Chem.* **2020**, *333*, 127502. [CrossRef] [PubMed]
40. Vijayan, S.; Arjunan, T.V.; Kumar, A. Mathematical modeling and performance analysis of thin layer drying of bitter gourd in sensible storage based indirect solar dryer. *Innov. Food Sci. Emerg. Technol.* **2016**, *36*, 59–67. [CrossRef]

41. Falade, K.O.; Igbeka, J.C.; Ayanwuyi, F.A. Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon. *J. Food Eng.* **2007**, *80*, 979–985. [CrossRef]
42. Kowalski, S.; Mierzwa, D. Influence of preliminary osmotic dehydration on drying kinetics and final quality of carrot (*Daucus carota* L.). *Chem. Process Eng.* **2011**, *32*, 185–194. [CrossRef]
43. Roueita, G.; Hojjati, M.; Noshad, M. Study of physicochemical properties of dried kiwifruits using the natural hypertonic solution in ultrasound-assisted osmotic dehydration as pretreatment. *Int. J. Fruit Sci.* **2020**, *20*, 491–507. [CrossRef]
44. Phisut, N.; Rattanawedee, M.; Aekkasak, K. Effect of osmotic dehydration process on the physical, chemical and sensory properties of osmo-dried cantaloupe. *Int. Food Res. J.* **2013**, *20*, 189–196.
45. Türkben, C.; Suna, S.; İzli, G.; Uylaşer, V.; Demir, C. Physical and chemical properties of pekmez (molasses) produced with different grape cultivars. *J. Agri. Sci.* **2016**, *22*, 339–348. [CrossRef]
46. Dermesonlouoglou, E.; Chalkia, A.; Taoukis, P. Application of osmotic dehydration to improve the quality of dried goji berry. *J. Food Eng.* **2018**, *232*, 36–43. [CrossRef]
47. Kim, J.H.; Lim, Y.J.; Duan, S.; Park, T.J.; Eom, S.H. Accumulation of antioxidative phenolics and carotenoids using thermal processing in different stages of *Momordica charantia* fruit. *Molecules* **2023**, *28*, 1500. [CrossRef]
48. Boon, C.S.; McClements, D.J.; Weiss, J.; Decker, E.A. Factors Influencing the chemical stability of carotenoids in foods. *Crit. Rev. Food Sci. Nutr.* **2010**, *50*, 515–532. [CrossRef]
49. Wang, F.; Bi, J.; Lyu, J.; Wu, X.; Xie, J. Effect of osmotic dehydration with different osmosis agents on water status, texture properties, sugars, and total carotenoid of dehydrated yellow peach slices. *J. Food Sci.* **2023**, *88*, 109–118. [CrossRef]
50. Luchese, C.L.; Gurak, P.D.; Marczak, L.D.F. Osmotic dehydration of physalis (*Physalis peruviana* L.): Evaluation of water loss and sucrose incorporation and the quantification of carotenoids. *LWT Food Sci. Technol.* **2015**, *63*, 1128–1136. [CrossRef]
51. Sanjinez-Argandona, E.J.; Cunha, R.L.; Menegalli, F.C.; Hubinger, M.D. Evaluation of total carotenoids and ascorbic acid in osmotic pretreated guavas during convective drying. *Ital. J. Food Sci.* **2005**, *17*, 305–315.