EFFECTS OF ULTRASOUND PRE-TREATMENT ON THE COLOUR CHANGES KINETICS OF KIWIFRUIT SLICES DURING OSMOTIC DEHYDRATION AND HOT-AIR DRYING

F. SALEHI† and R. CHERAGHI‡

† *Associate Professor, Department of Food Science and Technology, Bu-Ali Sina University, Hamedan, Iran.*
F.Salehi@Basu.ac.ir

‡ *MSc Student, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Iran.*
Ranaaacheraghi18@gmail.com

Abstract - The purpose of this study was to examine the influence of ultrasound-assisted osmotic dehydration (OD) on the appearance characteristics (colour indexes) of kiwifruit slices. As the sonication power (40 kHz) increased from 0W to 150W, the lightness (*L) index values of kiwifruit slices reduced from 64.8 to 60.6 (30°Brix). Also, with increasing sucrose solution concentration from 20°Brix to 40°Brix the lightness index values of kiwifruit slices decreased from 61.8 to 59.3 (power=150W). The results showed that the mean of ΔE (total colour difference) index values of dehydrated kiwifruit slices increased during OD period. The highest ΔE index (8.03) and lowest surface area (8.64 cm^2) values were for the kiwifruit slices treated by the lowest ultrasound power (0W) and the highest sucrose solution (40°Brix). The average surface area of fresh kiwifruit slices, dehydrated samples, hot-air drying samples, and rehydrated samples were 9.50 cm^2, 9.05 cm^2, 6.44 cm^2, and 7.82 cm^2, respectively.**

Keywords **- Colour index, Kiwifruit slices, Sonication power, Surface area.**

I. INTRODUCTION

Ultrasound treatments (sonication) in combination with OD process accelerate the rate of moisture removal from the fruits or vegetables pieces and decreases the dehydration duration (Fijalkowska *et al.*, 2016; Salehi, 2020). The use of continuous high-frequency sonication improves the water transport rate during osmo-concentration (Nowacka *et al.*, 2012; Salehi, 2023). Akhoundzadeh Yamchi *et al.* (2022) investigated on the impacts of ultrasonic pre-treatment on mass transfer rate and characteristics of peach slices. The authors reported that the use of ultrasound before drying decreases the drying duration by up to 40%. Also, the sonication duration and its influences on the colour changes of the peach slices were not significant. In another study, the impact of ultrasound-assisted OD pretreatments on dehydration of pulsed fluidized-bed microwave freeze-dried strawberries was studied by Jiang *et al.* (2021). Their results showed that ultrasound-assisted OD treatments helps to additionally enhance the dehydration rate and decrease drying time by 10% since it increases moisture loss. The results of Azarpazhooh *et al.* (2019) showed that sonication treatment (20 kHz, 50°C, and 60 min) had a significant impact on the physicochemical characteristics of *Aloe vera* gel. The objective of Sakooei-Vayghan *et al.* (2020) study was to examine the effect of OD (with and without ultrasound) and the use of various types of edible coating on functional and colour parameters of dried apricot cubes. Their results confirmed that ultrasound-assisted OD led to the loss of total phenolic compounds and vitamin C compared to OD. Also, total phenolic compounds and β-carotene contents reduced with the increase in ultrasound frequency from 25 kHz to 35 kHz. The authors reported that the compared to OD treated cubes, ultrasound-assisted OD treatment resulted in decreasing L* and b* indexes values and increasing a* index value. Prithani and Dash (2020) used kinetics models to predict the water distributions within the kiwi slices at any moment during OD. The effective moisture diffusivity (D_{eff}) during this process of ultrasonically treated kiwi slices was ranged between 5.46×10^{-10} m^2s^{-1} to 7.30×10^{-10} m^2s^{-1} within the temperature range between 25°C and 60°C.

We found no report on the effects of ultrasound pretreatment on the colour changes kinetics of kiwifruit slices during OD and hot-air drying in the literature. Hence, the purpose of this study was to estimate the impacts of ultrasound-assisted OD treatment on the colour parameters (L^*, a^*, b^*, and ΔE) and surface area changes of kiwifruit slices. In addition, the ΔE index changes of kiwifruit slices during OD were modeled.

II. MATERIALS AND METHODS

A. Samples preparation

Fresh kiwifruits (*Actinidia deliciosa*) were obtained from a garden located in Sari, Mazandaran, Iran. The fresh and uniform-size kiwifruits with no external damage were selected, and with the aid of an industrial slicer (food slicer, model AF-23, Girmi, Italy) cut into 5 mm-thick samples. The initial kiwifruit slices moisture content (MC) was 84% w.b. (moisture determination was performed in a Shimaz oven, Iran, at 105°C for 4 h).

B. Ultrasound-assisted OD procedure

To apply the sonication treatments on the kiwifruit slices, a Backer vCLEAN1-L6 ultrasonic bath (Iran) was employed with a frequency of 40 kHz and a power of 75 and 150 watts. The device tank was filled with 4L of 20, 30, and 40% (w/w) sucrose solutions and, then, after the temperature of the solutions reached to 50°C, the kiwifruit slices were placed directly in the bath. Sonication treatments were applied to the kiwifruit slices in three replicates and 8 time intervals (10, 20, 30, 40, 50, 60, 70, and 80 min), using a kiwifruit: solution mass ratio of 1:180. Following this, to determine the mass of the slices a digital scale model SL1000 (with an accuracy of ±0.01g, Iran) was used. Subsequently, after the termination of

each experiment, kiwifruit slices were removed from the bath with forceps and wrapped them immediately with clean tissue paper to remove excess osmotic solution.

C. Drying by hot-air and rehydration

After each treatment, the dehydrated kiwifruit slices were dried in an oven (70°C, Shimaz, Iran), until reaching a constant weight. Rehydration tests were conducted at 50°C for 20 min. The tests were conducted with a water bath. 0.2 L of water was added to a 0.25 L glass container (Tepe and Tepe, 2020).

D. Surface colour and area

A computer vision technique was utilized to examine the impact of ultrasound-assisted OD therapy on the colour indexes and surface area of untreated and treated kiwifruit slices during OD. A scanner was used to photograph the kiwifruit slices (HP Scanjet-300). The photos were converted from RGB to CIE L*a*b* colour space with the colour space converter plugin in the image analysis software (Image J, V.1.42e, USA) and then separated into respective channels of L*(lightness), a*(greenness/redness), and b*(blueness/yellowness). This software was used to choose a rectangular section within each photo of a kiwifruit slice and analyze it. The fresh kiwifruit slices exhibited a green colour, with L*, a* and b* equal to 59.43, -7.61 and 28.35, respectively. The colour variation was with respect to the fresh sample. Equation 1 was used to compute the total colour difference (ΔE) (Salehi, 2019):

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

In addition, the surface area of the kiwifruit slice during OD was calculated using the threshold colour plugin in the image analysis software (Image J, V.1.42e, USA). The average surface area of fresh kiwifruit slice was 9.50 cm^2.

E. Kinetic modelling

The total colour difference index changes during the OD process of the un-treated and treated kiwifruit samples with ultrasound were modeled using the power equation, quadratic equation, and sigmoidal equations (Gompertz, Logistic, Richards, Morgan-Mercer-Flodin (MMF) and Weibull) (Salehi *et al.*, 2021; Salehi and Satorabi, 2021). The coefficients of these equations were estimated using Matlab software (version R2012a). The square of the correlation between the response values and the expected response values (R-square or R^2), the sum of squares due to error (SSE), and the root mean squared error (RMSE) were the three criteria used to estimate the experimental data adjustment. When the highest R^2 value is combined with the lowest SSE and RMSE values, a satisfactory fit between the actual data and the correlations is established.

F. Statistical analysis

The dehydration tests were conducted in a 3×3×3 (ultrasound intensity, sucrose solution Brix, and three replicates) factorial design in a completely randomized design. Also, the means were compared using Duncan's multiple range test at p-value<0.05 (using the SAS 9.1, USA).

III. RESULTS AND DISCUSSION

A. Colour indexes of kiwifruit slices

Figure 1 shows the impacts of ultrasound treatment on the colour and surface area of kiwifruit slices after OD, hot-air drying, and rehydration process. In table 1 the mean of colour indexes and surface area of untreated and treated kiwifruit slices by ultrasound after OD were reported. After dehydration process of kiwifruit slices, we measured the flesh colour of samples and the average of L^*, a^*, and b^* indexes values for dehydrated kiwifruit slices were 60.74, -5.05, and 30.73, respectively. These data indicated that the average lightness and yellowness indexes of dehydrated kiwifruit slices were increased after OD process. Also, the redness index of samples was increased (decrease the greenness of the samples). Similar findings were reported by Rahaman *et al.* (2019), where the authors reported that colour of ultrasound-assisted osmotic dehydrated plum was influenced by sonication time (30 and 60 minutes) and the type of osmotic solution (50% glucose and sucrose). Fijalkowska *et al.* (2016) reported that the sonication treatment changed the colour of apples slices by reducing the values of redness index and rising the dried particles L^* and the value of yellowness index. Also, the authors reported that lower frequency of sonication treatment caused higher alterations of samples colour. In addition, Çağlayan and Barutçu Mazı (2018) results indicated the pumpkin slices dried after being subjected to ultrasound-assisted OD pre-treatment had higher redness index and lower lightness index values compared to non-pretreated samples.

Fresh kiwifruit slice | After osmotic dehydration | After drying | After rehydration

Figure 1. Effect of ultrasound treatment on the colour and surface area (shrinkage) of kiwifruit slices during osmotic dehydration process (150W and 30°Brix).

Table 1. Mean of colour indexes and surface area of untreated and treated kiwifruit slices by ultrasound after osmotic dehydration.

Sucrose solution concentration	Ultrasound treatment	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Surface area (cm^2)
20°Brix	Untreated (0W)	60.92±2.61 ^{bcd}	-4.30±1.25 ^{b}	27.95±3.68 ^{d}	9.05±0.10 ^{bc}
	Treated (75W)	59.13±1.04 ^{d}	-4.30±0.83 ^{b}	31.40±2.49 ^{ab}	9.15±0.11 ^{ab}
	Treated (150W)	61.77±1.63 ^{bcd}	-5.17±1.53 ^{bc}	30.04±1.28 ^{abcd}	9.25±0.10 ^{a}
30°Brix	Untreated (0W)	64.83±0.55 ^{a}	-2.96±0.43 ^{a}	29.21±2.33 ^{cd}	8.95±0.11 ^{c}
	Treated (75W)	62.13±3.90 ^{abc}	-8.02±0.45 ^{e}	32.27±1.19 ^{ab}	9.10±0.14 ^{ab}
	Treated (150W)	60.58±2.28 ^{bcd}	-4.97±1.55 ^{b}	31.42±1.61 ^{abc}	9.22±0.13 ^{a}
40°Brix	Untreated (0W)	63.05±1.73 ^{ab}	-2.35±0.87 ^{a}	31.79±2.89 ^{abc}	8.64±0.19 ^{d}
	Treated (75W)	54.99±2.03 ^{e}	-7.02±1.47 ^{de}	32.70±1.53 ^{a}	8.92±0.12 ^{c}
	Treated (150W)	59.27±4.07 ^{cd}	-6.35±0.88 ^{cd}	29.80±1.95 ^{bcd}	9.13±0.13 ^{ab}

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

Table 2- Mean of colour indexes and surface area of dehydrated kiwifruit slices after drying process by hot-air.

Sucrose solution concentration	Ultrasound treatment	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Surface area (cm^2)
20°Brix	Untreated (0W)	48.68±4.75 ^{bcd}	9.11±5.26 ^{bc}	32.04±5.25 ^{ab}	6.31±0.76 ^{c}
	Treated (75W)	49.23±3.13 ^{bcd}	9.01±3.57 ^{bc}	35.96±4.58 ^{a}	6.51±0.46 ^{bc}
	Treated (150W)	44.29±4.85 ^{d}	13.61±1.08 ^{a}	25.18±6.71 ^{c}	6.91±0.57 ^{b}
30°Brix	Untreated (0W)	50.36±3.78 ^{abc}	10.51±2.40 ^{abc}	27.16±6.14 ^{bc}	6.73±0.62 ^{bc}
	Treated (75W)	50.18±5.13 ^{abc}	9.94±3.07 ^{bc}	26.51±4.73 ^{bc}	6.18±0.79 ^{cde}
	Treated (150W)	53.61±4.51 ^{ab}	8.38±2.44 ^{c}	35.32±5.88 ^{a}	7.72±0.27 ^{a}
40°Brix	Untreated (0W)	45.62±6.60 ^{cd}	12.45±2.38 ^{ab}	22.25±6.18 ^{c}	5.64±0.37 ^{e}
	Treated (75W)	54.88±2.15 ^{a}	7.26±2.48 ^{c}	27.87±6.17 ^{bc}	5.69±0.20 ^{de}
	Treated (150W)	47.90±2.78 ^{cd}	7.97±2.23 ^{c}	36.14±4.12 ^{a}	6.25±0.18 ^{cd}

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

In table 2 the mean of colour parameters and surface area of dehydrated kiwifruit slices after drying by hot-air were reported. Our results showed that the average of L^*, a^*, and b^* indexes values for dried kiwifruit slices were 49.42, 9.81, and 29.83, respectively. These data indicated that the lightness of dried kiwifruit slices were decreased after drying process, but, the redness and yellowness indexes of dried samples were increased. Also, in this table, the average surface area of dried kiwifruit slices after different pretreatment were reported. In summary, during hot-air drying process, the surface area of dried kiwifruit slices decreased from 9.05 cm^2 to 6.44 cm^2.

After rehydration process of dried kiwifruit slices, we measured the flesh colour of samples and the average of L*, a*, and b* indexes values for rehydrated kiwifruit slices were 54.95, 5.31, and 33.78, respectively (Table 3). These data indicated that the lightness and yellowness indexes of rehydrated kiwifruit slices were increased after rehydration process, but, the redness index values decreased (increase the greenness of the samples). Based on moisture absorption during the rehydration process, the mass, volume, and surface area of the rehydrated pieces increases. In this study, the surface area of rehydrated kiwifruit slices increased from 6.44 cm^2 to 7.82 cm^2.

Mierzwa and Kowalski (2016) reported that high colour change was obtained for ultrasound-assisted OD treated and dehydrated apple pieces compared to OD pretreated dehydrated ones. The use of sonication treatment during the OD causes the changes in colour indexes. Figure 2 demonstrate the influence of ultrasound intensity, sucrose solution Brix values and sonication time on the ΔE index of kiwifruit slices during OD. It was observed that the ΔE index decreased from 7.13 to 4.86 with the increasing in ultrasound intensity from 0 to 150 W, and increased from 5.11 to 6.61 with the increasing in sucrose solution Brix values from 20°Brix to 40°Brix. As well, with increasing treatments time, the total colour difference index of dehydrated kiwifruit slices increased. Alizehi *et al.* (2020) examined the influence of using different vacuum pre-treatments and different ultrasound intensity levels (0 and 130 W) on OD, diverse air drying temperatures (55-75°C), infrared power (0 and 250 W), and the presence of teflon beads as inert particles of carrot cubes were examined. Their results explicitly confirmed that the application of OD in combination with sonication and vacuum has lower drying duration compared to those just treatment with OD. Also, the highest total carotenoid content and the lowest total colour difference values belonged to the carrot cubes exposed to ultrasonically vacuum-assisted OD.

B. Surface area of kiwifruit slices

Fruit and vegetable particles with high levels of moisture content can be successfully dehydrated using ultrasound-assisted OD pre-treatment which reduces the dehydration time and improves final products quality. The impacts of ultrasound intensity, sucrose solution concentration and sonication time on the surface area of ultrasound-assisted osmotically dehydrated kiwifruit slices are shown in Fig. 3. As is seen from this figure, an incremental increase in the ultrasound intensity, from 0 to 150 W, raised the average surface area values. Also, the average surface area values were decreased with increasing osmotic solution concentrations from 20 to 40 °Brix. The average surface area of fresh kiwifruit slices, dehydrated samples, hot-air dried samples, and rehydrated samples were 9.50 cm^2, 9.05 cm^2, 6.44 cm^2, and 7.82 cm^2, respectively. The average surface area of

Table 3- Mean of colour indexes and surface area of rehydrated kiwifruit slices.

Sucrose solution concentration	Ultrasound treatment	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Surface area (cm^2)
20°Brix	Untreated (0W)	56.06±5.07 ^{a}	3.06±3.72 ^{c}	32.89±2.87 ^{b}	7.86±0.53 ^{b}
	Treated (75W)	56.13±3.38 ^{a}	4.55±3.27 ^{c}	35.29±2.51 ^{ab}	8.17±0.22 ^{ab}
	Treated (150W)	49.54±4.37 ^{b}	9.99±1.27 ^{a}	32.85±2.04 ^{b}	7.94±0.51 ^{b}
30°Brix	Untreated (0W)	54.87±4.83 ^{a}	7.77±3.36 ^{ab}	35.04±1.72 ^{ab}	8.14±0.23 ^{ab}
	Treated (75W)	55.34±4.15 ^{a}	5.01±2.94 ^{bc}	34.41±2.38 ^{ab}	7.71±0.50 ^{b}
	Treated (150W)	58.58±2.55 ^{a}	3.86±2.31 ^{c}	37.16±2.71 ^{a}	8.44±0.20 ^{a}
40°Brix	Untreated (0W)	50.59±5.56 ^{b}	8.57±2.95 ^{a}	28.99±3.32 ^{c}	6.75±0.64 ^{d}
	Treated (75W)	56.54±1.82 ^{a}	3.13±1.25 ^{c}	34.67±1.98 ^{ab}	7.21±0.36 ^{c}
	Treated (150W)	56.92±2.11 ^{a}	1.83±1.79 ^{c}	32.75±2.15 ^{b}	8.14±0.22 ^{ab}

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

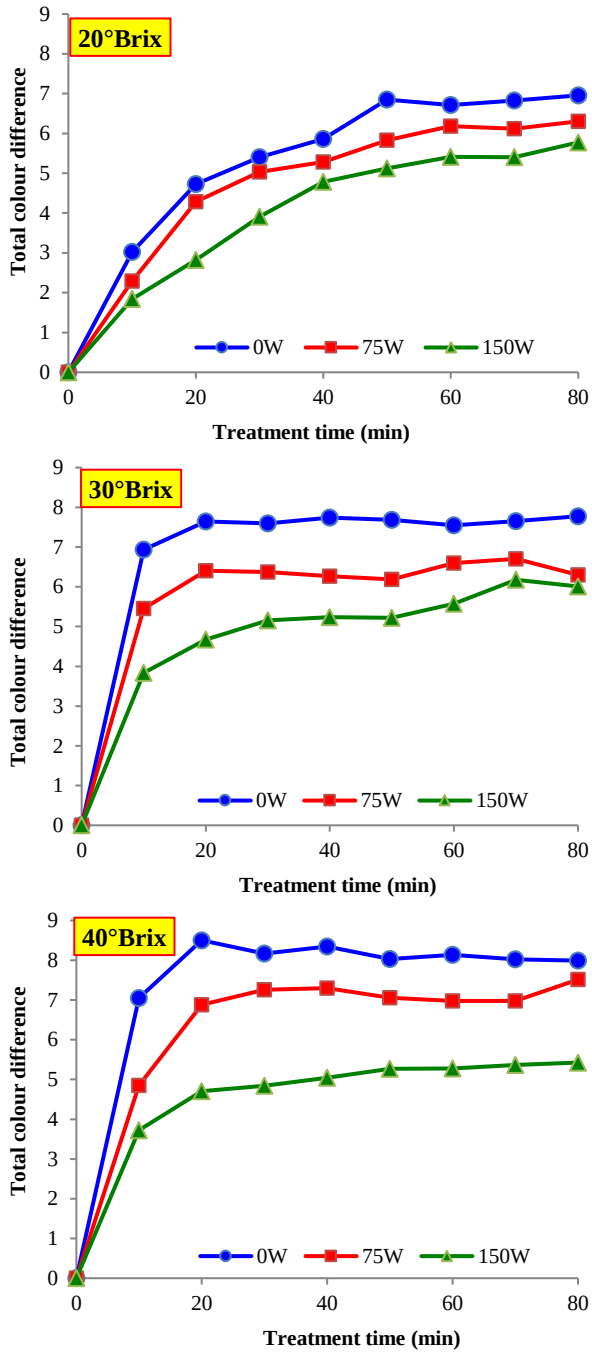

Figure 2. Effects of ultrasound intensity, sucrose solution concentration and treatment duration on the total colour difference (ΔE) of kiwifruit slices during osmotic dehydration.

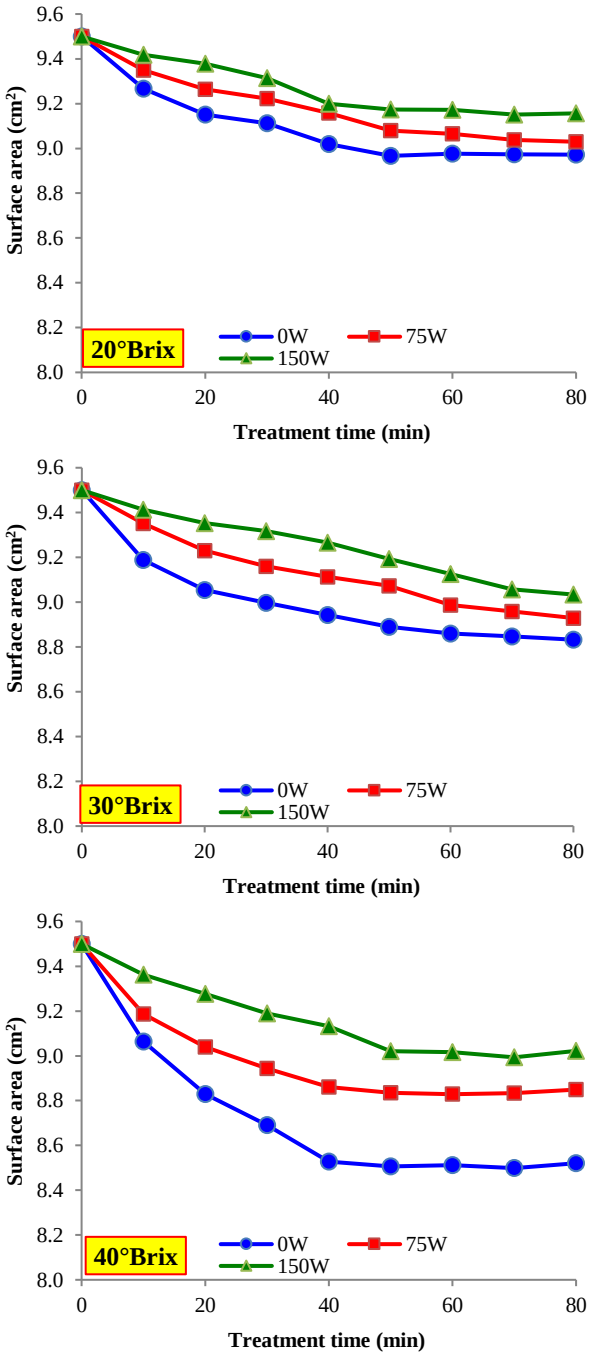

Figure 3. Effects of ultrasound intensity, sucrose solution Brix and sonication duration on the surface area (cm^2) of kiwifruit slices during osmotic dehydration.

Table 4- The MMF model constants for total colour difference index of kiwifruit slices during osmotic dehydration.

Solution concentration	Ultrasound treatment	a*	b	c	d	R^2	SSE**	RMSE***
20°Brix	Untreated (0W)	0.0013	25.36	8.209	1.185	0.994	0.248	0.223
	Treated (75W)	-0.011	64.91	6.724	1.547	0.996	0.122	0.156
	Treated (150W)	0.0264	63.21	7.011	1.296	0.994	0.172	0.185
30°Brix	Untreated (0W)	-1.6e-6	5259	7.668	4.7	0.999	0.041	0.090
	Treated (75W)	-4.0e-5	1.2e4	6.411	4.832	0.994	0.202	0.201
	Treated (150W)	-6.9e-4	5.847	15.17	0.308	0.991	0.244	0.221
40°Brix	Untreated (0W)	-9.1e-4	1.6e4	8.172	5.016	0.996	0.242	0.219
	Treated (75W)	2.3e-4	2423	7.188	3.7	0.995	0.244	0.221
	Treated (150W)	-5.9e-4	7.029	5.652	1.14	0.999	0.027	0.074

* The *a*, *b*, c and *d* are the MMF model constants; ****** The sum of squares due to error (SSE); ******* Root mean squared error (RMSE)

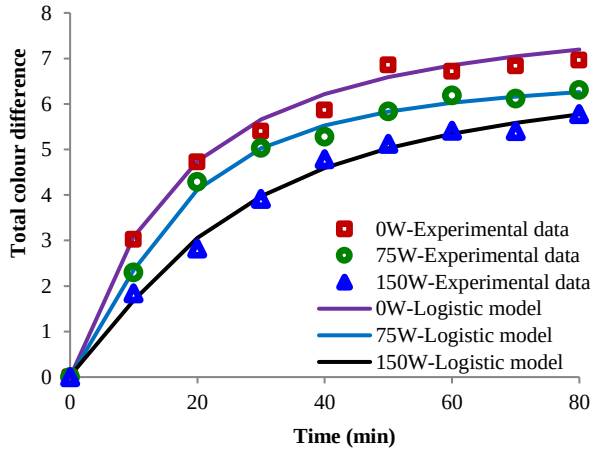

Figure 4. Fitting ability of MMF equation to empirical data of total colour difference parameter of kiwifruit slices during osmotic dehydration (20°Brix).

kiwifruit slices increased from 8.88 cm^2 to 9.20 cm^2 with increasing ultrasound intensity levels from 0 to 150 W. In addition, with increasing sonication duration, the surface area of dehydrated kiwifruit slices decreased. The results confirmed that the kiwifruit slices submitted to OD treatment for 10 minutes and for 80 minutes have maximum and minimum surface area, respectively. The average surface area of kiwifruit slices reduced from 9.15 cm^2 to 8.90 cm^2 with increasing sucrose solution Brix values from 20% to 40%.

C. Kinetic modelling

Among examined equations, the MMF model (Eq. 2) is given better prediction than the other models and satisfactorily described total colour difference index. This model considers the effects of dehydration conditions provided good fitting of the predicted total colour difference with the highest R^2, and the lowest SSE and RMSE values (the average R^2=0.995, the average SSE=0.171, and the average RMSE=0.177).

$$\Delta E = \frac{a\,b+c\,x^d}{b+x^d} \quad (2)$$

where the ΔE is total colour difference index. The constants (a,b,c, and d) of the kiwifruit slices dehydration kinetics model (MMF model) at various dehydration conditions are presented in Table 4. The statistical parameters used for selecting the samples drying kinetics model (R^2, SSE and RMSE) are also presented in the table. The R^2 values for all dehydration conditions were between 0.991 and 0.999. In addition, the SSE and RMSE values for all dehydration conditions were between 0.027 and 0.248, and 0.074 and 0.223, respectively. Figure 4 show the estimation of fitted ΔE index data by MMF equation with experimental values (osmotic solution concentration=20°Brix). Figure 4 corresponds to the osmotic treatment in 20°Brix sucrose solution as an example, because similar results were observed in the other conditions.

IV. CONCLUSION

In this manuscript, we evaluated the influence of the ultrasound-assisted OD procedure on the colour parameters (L^*, a^*, b^*, and ΔE) and surface area changes of kiwifruit slices. Our results showed that the ultrasound intensity levels and sucrose solution Brix values influenced on the appearance characteristics of kiwifruit slices. The lightness and yellowness of dehydrated kiwifruit slices were increased after OD process. The average surface area values was increased with rising ultrasound intensity from 0 to 150 W and it was decreased with increasing sucrose solution Brix values from 20 to 40 °Brix. It was observed that the ΔE index decreased from 7.13 to 4.86 with the increasing in ultrasound intensity from 0 to 150 W, and increased from 5.11 to 6.61 with the increasing in sucrose solution Brix values from 20°Brix to 30°Brix. In summary, the optimum conditions for osmotic dehydration of kiwifruit slices were found to be ultrasound intensity = 150W, and sucrose solution concentration = 20°Brix. In addition, the Δ*E* index changes of kiwifruit slices during OD were modeled according to mathematical equations. The MMF model was found to match the experimental data (Δ*E* index) very closely with the maximum SSE and RMSE less than 0.248 and 0.223, respectively.

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