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Maltodextrin Moderated Microwave Osmotic Dehydration of Mango Cubes with Finish Air-Drying: Optimum Considerations

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Abstract: The microwave osmotic dehydration of mango cubes under the continuous flow of maltodextrin moderated sucrose solution spray (MWODS) was evaluated based on the quality of the finish air-dried product. Experiments were designed according to a central composite rotatable design to evaluate the effect of maltodextrin moderated sucrose solution [sucrose + maltodextrin (10DE) at a proportion of 85:15] on the finish air-dried product. The process variables were temperature (30 to 70 °C), solute concentration (30 to 70%), contact time (10 to 50 min) and flow rate (0.8 to 3.8 L/min). The optimum processing conditions were determined based on several processes and product-related quality parameters such as moisture loss (ML), solids gain (SG), weight gain, ML/SG, color, texture, rehydration capacity (RHC), bulk density and drying time. The MWODS contact time was the largest significant contributor with respect to most of the parameters, followed by temperature. The optimum values found were an osmotic treatment temperature of 51.7 °C, a solute concentration of 58.5%, a contact time of 30.6 min and a solution flow rate of 1.8 L/min. Finally, these optimized processing conditions were used to compare three different solute mixtures [sucrose only, sucrose + dextrose and sucrose + maltodextrin (10DE) at a ratio of 85:15%] to understand the effect of various solutes on the quality of the finished dried product. Based on the color and textural parameters, along with the RHC, of the finished product, the sucrose + maltodextrin mixture was shown to result in the most desirable quality and the air-dried product without MWODS pretreatment (control) resulted in the least desirable. Overall, the results suggest that the sucrose + maltodextrin combination offered an advantage in terms of quality for the MWODS air-drying of mango cubes.

Keywords: microwave; maltodextrin; air drying; temperature and concentration

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1. Introduction

Drying is one of the oldest and most widespread processing methods in the food industry and accounts for a significant amount for energy usage in the industry [1]. Drying allows for the transformation of a fresh crop into a shelf-stable commodity, lowers storage and transportation costs by reducing weight and eliminating the need for refrigerated storage and offers the possibility of producing value added processed foods [2]. The air drying process is considered as the simplest process for the preservation of fruits and vegetables and is frequently used in tropical countries. However, particular concerns related to air drying are quality losses due to the degradation of color and flavor [3] and the loss of nutritional value, effects that are primarily attributed to the exposure of the product to high temperatures for long periods of time, resulting in a shrunken appearance with a tough texture, severe browning and low nutritive value [4]. Therefore, the key to improving the quality of dried products is to limit changes to the aforementioned quality characteristics during processing by employing pretreatments, such as osmotic dehydration.

Several studies have been carried out focusing on reducing the long operational time of conventional OD by providing pre-treatments such as skin removal or skin puncture, coating, the application of a pulsed electric field and high hydrostatic pressure treatment [5].

In addition, combining of a microwave environment and OD treatment has been shown to be successful without the need for any pre-treatments before OD [6]. This novel method was originally applied on apple cubes under an immersion mode, which was subsequently changed to a spray mode system [7]. The technique, known as Microwave-OD under continuous flow medium spray conditions, or MWODS, has been explored in several studies and has been combined finish drying [7–10].

In the above studies, only sucrose was used as the osmotic solute. The current series of studies are an extension of these studies with the aim of further improving the performance of MWODS using solute mixtures, rather than a single component solute, as osmotic agents. The types and mixtures of solute agents have also been considered important during OD, with these directly affecting the mass transfer as well as the finish drying quality characteristics. Therefore, the application of complex solutions made from sugar, water and salt, etc., has received considerable attention [11]. On a similar note, recent studies involving various solute mixtures such as sucrose, dextrose and maltodextrin have demonstrated that the application of maltodextrin moderated sucrose solution on the MWODS of mango cubes promotes moisture loss and limits the uptake of solids when compared with other solutes [12]. Further research compared different grades of maltodextrin, based on their dextrose equivalent values, and found that MD with 10DE had the highest mass transfer rates among the three grades studied [13], with these being optimized for MWODS applications [14]. Again, in all these MWODS studies, the quality parameters were assessed immediately after the MWODS treatment, which only produces an intermediate product with a relatively high residual moisture content and high water activity. These products can be refrigerated and used directly as ingredients in bakery products, or frozen or further dried to make them shelf stable.

The main focus of this current study was to evaluate the product quality of MWODS mango cubes following finish air-drying and to optimize the various parameters using a central composite rotatable design. Hence, during this study, a solute mixture of sucrose and maltodextrin was examined using four process variables, namely temperature, concentration, contact time and flow rate. The optimized conditions were then used to evaluate the effect of three different solute mixture combinations, such as sucrose + maltodextrin, sucrose + dextrose and sucrose only, on the quality of the product in terms of color, texture, bulk density and rehydration capacity.

2. Materials and Methods

2.1. Raw Material

Commercial grade sucrose (Lantic Sugar Ltd., Montreal, QC, Canada) and maltodextrin (10DE) (Univar Pvt. Ltd., Richmond, BC, Canada) were used, along with tap water, for preparing the osmotic solution, and the concentrations were maintained on the wet weight basis (wb). Maltodextrin 10DE was selected because of its superior performance compared to MD15DE and MD18DE [12,13].

Frozen mango pieces were obtained from a local food freezing company (Nature's Touch, Saint-Laurent, QC, Canada) and kept frozen (−21 °C) until use. Prior to use, the mango pieces were thawed overnight (8–10 h) in a refrigerator (4–7 °C). The mango pieces were generally cube shaped with side dimensions of approximately 15 ± 2 mm. The frozen mango cubes were of very high quality and much better than the fresh ones available in the market. The moisture content of the frozen-thawed (untreated) mango cubes was measured using the AOAC method with a small modification by drying the cubes in an oven at 105 °C for approximately 24 h (until a constant weight was achieved). While the dehydrated samples were ground, the fresh samples were chopped finely prior to drying. The moisture content of the mango cubes was determined to be 86.09% (wb) on average.

2.2. Microwave Setup

The MWODS assembly consisted of a domestic microwave oven (Danby DMW1153BL 0.031 m^3, Guelph, ON, Canada) with a nominal power output of 1100W at 2450MHz. This

was fitted with a custom built flow set up with a spray head (Waterpik, Model RPB-173C, 12.5 cm diameter, Waterpik Technology Inc., Markham, ON, Canada) attached to a custom-made glass chamber (12.5 cm diameter) (see schematics, Figure 1). Test samples were placed in a wide mesh Nylon packing bag which was positioned on the porous acrylic plate (stage) inside the glass sample chamber. The acrylic stage allowed for the draining of the sprayed osmotic solution while keeping the samples in direct contact with the microwave. The osmotic solution collected at the bottom of the glass chamber was recirculated through a long coil immersed inside a steam jacketed water bath (Model TDB/4 Groen Division, Dover Corp, Elk Grove Village, IL, USA) and then pumped through the spray head using a peristaltic pump (Model 75211-30 Digital gear pump, Barnant company, Barrington, IL, USA). The temperature of the water bath was adjusted accordingly to provide a set inlet temperature for the osmotic solution. The osmotic solution was continuously circulated through the assembly to equilibrate the set-up temperature before placing test samples into the system. The temperature of the osmotic solution was monitored using a pair of in-line Type-T thermocouples connected to a digital thermometer (Omega DP-462, Omega Technology, Laval, QC, Canada). The thermocouples were placed immediately at the exit ports of the microwave oven to continuously measure the temperature of the solution before it entered the microwave oven and immediately after it exited it (Figure 1). The increase in the temperature of the osmotic solution after circulating through the microwave cavity was only about 4–5 °C because of the rapid medium flow rate. This solution exiting the microwave oven was circulated and cooled by the heat exchanger coil in the water bath to obtain the required initial temperature before entering the microwave oven. The coil and the recirculation system were sufficiently long to allow for a solution sample ratio of 30:1. The large amount of osmotic solution in the closed system meant that a nearly constant solute concentration was maintained throughout the experiment.

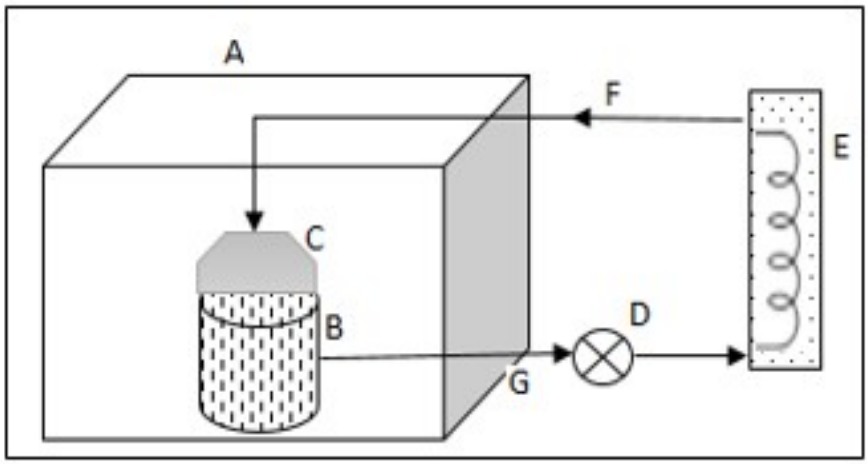

Figure 1. Schematic diagram of MWODS assembly. A: microwave oven cavity, B: microwave transparent sample chamber, C: spray head, D: digital gear pump, E: water bath (containing heat exchanging coils, not pictured), and F and G are thermocouple measuring points immediately before and after the solution enters and leaves the microwave cavity, respectively.

2.3. Osmotic Dehydration Procedure

The MWODS system was setup, and the solution was preheated according to the prescribed temperature of the test run. Mango cubes (~12–15 numbers), approximately 100 g, were accurately weighed and placed in the Nylon mesh bag used to hold the samples. The samples were then placed on the acrylic stage in the sample chamber and spread out in a single layer. The pump was turned on, and the solution allowed to flow, and then the microwave oven was turned on. The experiment was then terminated after each prescribed contact time (10 min, 20 min, 30 min, 40 min or 50 min) according to the experimental run type. The bag was taken out and excess osmotic solution removed from the surface of the

product was by rinsing the samples gently in water in a beaker 3–4 times. The mango cubes were then weighed again and were either examined for quality parameters or dried to a constant weight in an oven set at 105 °C for approximately 24 h [15].

Osmotic drying in a microwave environment provides additional opportunities for drying beyond the osmotic force that drives the OD. The microwaves have a strong affinity with dipole molecules and therefore selectively heat water moiety in the system. Hence, in the syrup fruit mixture, the water inside the fruit which is at a higher concentration tends to heat faster and creates on out flux driving force, thereby enhancing the mass transfer. In a spray-based system, this effect can be expected to be even better than in an immersion system because the spraying medium only covers the surface in a thin film profile providing for the easy penetration of MWs into the fruit tissue. This is demonstrated by the success of the several previous studies on MWOD [7–10].

2.4. Experimental Design

A CCRD experimental design was used for the MWODS treatment runs, with each one carried out under a given preset variable condition. The solute combination of sucrose + maltodextrin (10DE) was used in the proportion of 85 (sucrose) to 15 maltodextrin by weight. This proportion was adopted from the previous study which showed its better mass transfer properties along with high output quality attributes [14]. The CCRD design was used with four variables, namely solute concentration, temperature, contact time and flow rate, at five coded levels (−1.68, −1, 0, +1, +1.68) and each run with three replicates was demonstrated. The concentration (%) and temperature (°C) ranged from 33.7–66.7 (Table 1). A concentration range 40–60% and temperature range 40–60 °C have been commonly employed in most osmotic dehydration experiments. Lower limits of concentration are normally set based on limited mass transfer performance while higher ones are set due to high viscosity limiting the flow rates. With respect to temperature, the lower level was set for reasons of limited mass transfer and higher limits based on the browning effects on the osmotic solution and test sample. The CCRD design covered the 40–60 range in terms of both temperature and concentration for the orthogonal design, and the 33.7 and 66.7 levels were used as extreme cases for the statistically-based experimental design. In addition, the overall contact time and flow rate ranges were set between 10–50 min and 0.8L to 3.8 L/min, respectively. The contact time range was adopted from previous studies [16], whereas the flow rate range was chosen depending on the capacity that the digital peristaltic pump could achieve.

Similarly, the effect of different OD solute mixtures on finished air drying was finally studied using sucrose, sucrose + dextrose (85:15) and sucrose + maltodextrin (85:15) sample and only air drying without MWODS was treated as control and the results were compared.

2.5. Finished Air Drying

The post-MWODS treated mango cubes were subjected for finished air-drying process to obtain a final moisture content of 20% (db). Drying times were noted and the water activity of all samples was below 0.7. A domestic drying oven (Equi-Flow Food Dehydrator, Marysville, WA, USA) was used, with some modifications, with a digital thermostat to maintain the conditions of 60 ± 1 °C, 0.64 ± 0.02 m/s and an RH of approximately 15%. The post-MWODS mango cubes were arranged in a single layer on a metal mesh which was suspended from a balance inside the drying chamber. The mango cubes were subjected to a constant horizontal airflow inside the hot air-drying chamber. The door of the hot air chamber was quickly opened four–five times during the process for the purpose of rotating the samples by about 90° to alternate the side of each sample exposed to the hot incoming air. The mass of each sample was recorded every 10 min.

Table 1. CCRD experimental design for MWODS in real and coded values.

Std Order No.	Temp. (°C)	Conc. (%)	Contact Time (min)	Flow Rate (L/min)
1	40 (−1)	40 (−1)	20 (−1)	1.5 (−1)
2	60 (+1)	40 (−1)	20 (−1)	1.5 (−1)
3	40 (−1)	60 (+1)	20 (−1)	1.5 (−1)
4	60 (+1)	60 (+1)	20 (−1)	1.5 (−1)
5	40 (−1)	40 (−1)	40 (+1)	1.5 (−1)
6	60 (+1)	40 (−1)	40 (+1)	1.5 (−1)
7	40 (−1)	60 (+1)	40 (+1)	2.3 (0)
8	60 (+1)	60 (+1)	40 (+1)	1.5(−1)
9	40 (−1)	40 (−1)	20 (−1)	3.0 (+1)
10	60 (+1)	40 (−1)	20 (−1)	3.0 (+1)
11	40 (−1)	60 (+1)	20 (−1)	3.0 (+1)
12	60 (+1)	60 (+1)	20 (−1)	3.0 (+1)
13	40 (−1)	40 (−1)	40 (+1)	3.0 (+1)
14	60 (+1)	40 (−1)	40 (+1)	3.0 (+1)
15	40 (−1)	60 (+1)	40 (+1)	3.0 (+1)
16	60 (+1)	60 (+1)	40 (+1)	3.0 (+1)
17	30 (−1.68)	50 (0)	30 (0)	2.3 (0)
18	70 (+1.68)	50 (0)	30 (0)	2.3 (0)
19	50 (0)	30 (−1.68)	30 (0)	2.3 (0)
20	50 (0)	70 (+1.68)	30 (0)	2.3 (0)
21	50 (0)	50 (0)	10 (−1.68)	2.3 (0)
22	50 (0)	50 (0)	50 (+1.68)	2.3 (0)
23	50 (0)	50 (0)	30 (0)	0.8 (−1.68)
24	50 (0)	50 (0)	30 (0)	3.8 (+1.68)
25	50 (0)	50 (0)	30 (0)	2.3 (0)
26	50 (0)	50 (0)	30 (0)	2.3 (0)
27	50 (0)	50 (0)	30 (0)	2.3 (0)
28	50 (0)	50 (0)	30 (0)	2.3 (0)
29	50 (0)	50 (0)	30 (0)	2.3 (0)
30	50 (0)	50 (0)	30 (0)	2.3 (0)

2.6. Dehydration Responses and Data Analysis

Moisture loss (ML), solids gain (SG), the moisture loss to solids gain ratio (ML/SG) and weight reduction (WR) were obtained using the following equations:

$$\%\ \text{Moisture Loss (ML)} = 100\frac{M_0X_0 - M_tX_t}{M_0} \quad (1)$$

$$\%\ \text{Solids Gain (SG)} = 100\ \frac{M_tS_t - M_0S_0}{M_0} \quad (2)$$

$$\text{ML : SG ratio} = \frac{\%ML}{\%SG} \quad (3)$$

$$\% \text{ Weight Reduction (WR)} = 100 \frac{M_0 - M_t}{M_0} \quad (4)$$

where M_0 and M_t are the total mass of the fruit sample at time 0 and time t, respectively; X_0 and X_t are the moisture fractions (kg/kg, wet basis) at time 0 and time t, respectively; S_0 and S_t are the solid fractions (kg/kg, wet basis) at time 0 and time t, respectively.

2.7. Rehydration Capacity

The dried samples were accurately weighed and soaked in excess distilled water for 14 h at room temperature (23 °C). The ratio of sample to distilled water was maintained around 1:25. Then they were taken out and placed on wet filter paper further placed under a slight vacuum for 1 min to remove the surface moisture before the weighing of the samples. The rehydration capacity was determined in triplicate using the procedure described by Azarpazhooh and Ramaswamy (2011) [8]. The rehydration capacity was then determined according to Equation (5):

$$\text{Rehydration capacity} = \frac{W_r - W_d}{W_d} \quad (5)$$

where W_r and W_d are the masses of the rehydrated and dry material (g), respectively.

2.8. Bulk Density

Knowledge of the bulk density of food materials is an important consideration in storage, transport, mixing and packaging operations. The bulk density was determined in triplicate by weighing the dried mango cubes, and their approximate volume was determined via a volume displacement technique using rapeseed, as commonly used for irregular agricultural and dry food particles (Gupta et al., 2017) [17,18], and expressed in kg/m^3.

2.9. Quality Analysis

Separate test runs were carried out for each run type under the same conditions (Table 1) for quality analysis, and quality parameters were measured as detailed below. The quality of samples obtained after each experimental run was examined after completing the air-drying process.

2.10. Texture Evaluation

A TA.XT Plus Texture Analyzer (Stable Microsystems, Surrey, UK) was used for the texture profile analysis (TPA) of finished air dried samples after the MWODS treatments. A two-cycle compression test was carried out to obtain TPA, using a flat bottom probe 25 mm in diameter, with a pretest speed of 5 mm s^{-1}, a test speed of 5 mm s^{-1} and a post-test speed of 5 mm s^{-1}. The target compression was a distance of 3 mm into the sample during two consecutive cycles to target a 25% deformation from the average height of samples. These settings are typical of what is used in typical TPA analysis for physico-chemical and textural changes associated with the ripening of mangos [19]. The analysis was performed with six replicates, and the average values (with standard deviation) were used. A wide range of responses such as hardness, chewiness, adhesiveness, cohesiveness, factorability, gumminess and springiness can be obtained from TPA analysis [20]. Hardness and chewiness were selected in this study as the parameters used to determine the texture of osmotically processed mango cubes. The peak force during the first compression cycle was defined as the hardness, and the chewiness was obtained from the product of gumminess and springiness [20]. The chewiness was calculated using Equation (6).

$$\text{Chewiness} = \text{Gumminess} \times \text{Springiness} \quad (6)$$

2.11. Color

The color of MWODS-air dried samples was analyzed via the L*, a*, b* system using a tristimulus Minolta Chroma Meter (Minolta Corp., Ramsey, NJ, USA). The Chroma Meter

was warmed up 20 min prior to use, and the color was calibrated against a white standard. Six measurements were made for each sample, and the values were averaged to obtain the L* (lightness), a* (green (−) to red (+)) and b* (blue (−) to yellow (+)) values for all treated and control samples. The ΔE (total color change) was also computed as the total color change of processed samples, and the differences were obtained in comparison with the color of freeze-dried mango cubes (without MWODS pretreatment) which were expected to result in the least amount of change. Several studies have concluded that freeze-drying can produce dried products which are highly acceptable in terms of quality [21]. Hence, the freeze-dried mangoes were chosen as a control sample to measure the color difference in treated mango cubes. This can be measured using the following Equation (7) [22].

$$\Delta E = \sqrt{(L_0 - L)^2 (a_0 - a)^2 (b_0 - b)^2} \quad (7)$$

2.12. Effect of Solute Mixtures

Optimized conditions based on the desirability approach were employed for further study to compare different solute mixtures. In this approach, the mangoes pre-treated with MWODS using a solute mixture of sucrose + maltodextrin, sucrose + dextrose at a proportion of 85:15 or sucrose (100%) were subjected to the finish air-drying process and the results were compared in terms of quality characteristics along with rehydration capacity (RHC) and bulk density. All the MWODS-pretreated samples with different solute mixtures were compared with air-dried mangoes without pretreatment.

2.13. Statistical Analysis

Statistical analysis using JMP® v-13 (SAS Institute Inc., Cary, NC, USA) was carried out to understand the differences effects of the solute mixtures on the quality of dried mangoes. All the experiments were performed in three to six replicates and the mean values were compared to a 95% confidence interval using the analysis of variance function with Tukey groupings to understand if the compared values were significantly different.

3. Results and Discussions

3.1. Response Surface Methodology

The response surface methodology was applied using the composite rotatable design (CCRD, see Table 1). The responses gathered from the CCRD can be used for optimization using statistical models, and parametric performances can be compared using ANOVA. The results obtained from the design are presented in Table 2. Table 3 summarizes the selection of a model for each response and is based on their statistical significance as well as their lack of fit values. The quadratic model ($p < 0.05$) was selected for ML, SG, WR, ML/SG, hardness, L*, b*, ΔE, RHC and bulk density responses, whereas a*, chewiness and drying time were best represented by a linear model ($p < 0.05$). The lack of fit values for each selected model were not significant ($p > 0.05$), as shown in Table 3. An insignificant lack of fit suggests that the selected model can predict the responses using the predicted equations as a function of input variables. All the models had an insignificant lack of fit ($p > 0.05$). The main variables and all second order interactions (square terms, two parameter interactions) were generally significant and included in the models and response surface plots. In order reduce the number of figures, these were presented as 3-D plots of two variables, i.e., primarily temperature vs. each of the other three variables.

3.2. Moisture Loss

Contact time was found to be the most significant factor affecting moisture loss (ML), followed by temperature, as shown in Figure 2. An increase in contact time and temperature increased ML. The major cause of moisture reduction at a longer contact time is the rapid and accumulated heating of water molecules in the presence of microwaves, which increases the internal pressure and promotes the quick expulsion of water from the sample. The contribution of temperature has also been proven in earlier reports in that a

high temperature reduces the syrup viscosity, thus improving its mobility and allowing for more dynamic contact between the solution and mango cubes, which ultimately enhances the water extraction ability of the osmotic solution. The solute concentration was also positively correlated with ML because of increases in its osmotic potential [7,10,12,14,23,24]. Previous studies have demonstrated that a high molecular MD in the syrup makes solute impregnation into the samples more difficult by creating a barrier on the surface of the mango cubes, resulting in an overall increase in the osmotic potential for moisture removal from fruit samples [24].

In contrast, flow rate had a negative relationship with ML or WR, which meant that the ML would reduce at elevated flow rates. Hence, the overall performance and the trend of these variables agreed to the prior reports [10,23]. The trend also showed that even though contact time was the highest significant factor in terms of ML, temperature would also increase the ML to maximum values, as per the results shown in Table 3.

Table 2. CCRD run numbers with results for mass transfer, texture and color parameters, RHC and bulk density.

Std Order No.	ML (%)	SG (%)	ML/SG	WR (%)	Hardness (N)	Chewiness (N mm)	L*	a*	b*	ΔE	RHC (%)	BD (kg/m^3)	DT (min)
1	32.0 (±3.8)	4.65 (±1.1)	7.18 (±2.5)	27.4 (±4.9)	101 (±5.7)	44.0 (±2.4)	19.1 (±1.4)	10.7 (±1.3)	19.8 (±1.9)	24.6 (±1.4)	89.3 (±4.2)	387 (±21)	960 (±28)
2	39.3 (±1.4)	6.04 (±0.5)	6.54 (±0.7)	33.3 (±1.9)	108 (±5.2)	36.7 (±2.1)	18.3 (±1.5)	9.50 (±1.0)	21.6 (±1.6)	23.9 (±2.4)	72.2 (±2.9)	380 (±24)	870 (±21)
3	34.1 (±1.1)	5.70 (±0.3)	5.99 (±0.5)	28.4 (±1.3)	110 (±4.9)	52.8 (±2.2)	21.1 (±1.6)	11.6 (±1.0)	21.8 (±1.4)	21.8 (±1.5)	84.4 (±3.6)	385 (±26)	950 (±20)
4	41.0 (±1.6)	7.11 (±0.8)	5.78 (±0.4)	33.8 (±0.8)	130 (±7.1)	47.3 (±2.0)	20.1 (±1.5)	11.1 (±1.5)	29.1 (±2.1)	18.6 (±2.0)	88.2 (±3.9)	379 (±22)	720 (±17)
5	44.2 (±2.2)	6.33 (±0.4)	7.01 (±0.8)	37.9 (±2.6)	135 (±7.7)	47.3 (±3.4)	17.3 (±1.8)	10.7 (±1.2)	20.1 (±1.9)	26.1 (±2.6)	80.1 (±3.5)	365 (±18)	800 (±22)
6	56.5 (±2.2)	7.98 (±0.4)	7.10 (±0.7)	48.5 (±2.7)	138 (±7.9)	38.1 (±1.9)	16.1 (±1.9)	8.60 (±1.1)	15.4 (±1.8)	29.7 (±1.2)	75.4 (±3.2)	349 (±15)	650 (±10)
7	51.5 (±1.6)	7.42 (±1.5)	7.06 (±1.2)	44.1 (±0.1)	140 (±9.1)	55.2 (±3.5)	19.2 (±1.5)	10.9 (±1.3)	27.4 (±2.0)	20.2 (±1.7)	90.1 (±4.6)	357 (±17)	690 (±12)
8	58.8 (±0.9)	9.73 (±0.4)	6.04 (±0.2)	49.0 (±0.5)	147 (±10)	49.6 (±3.2)	18.1 (±1.9)	10.0 (±0.9)	24.4 (±1.8)	22.5 (±1.3)	81.5 (±3.3)	341 (±16)	438 (±8.0)
9	28.9 (±0.9)	6.12 (±0.4)	4.72 (±0.1)	22.7 (±0.7)	122 (±6.8)	49.9 (±2.2)	21.0 (±1.7)	9.40 (±1.4)	22.1 (±1.8)	21.5 (±2.5)	79.1 (±3.5)	385 (±24)	858 (±19)
10	32.8 (±0.8)	6.99 (±1.2)	4.77 (±0.9)	25.8 (±1.9)	129 (±7.4)	44.9 (±2.9)	20.3 (±1.8)	9.60 (±1.2)	23.3 (±2.2)	21.4 (±1.8)	91.3 (±4.5)	380 (±21)	720 (±16)
11	30.8 (±1.7)	6.47 (±1.2)	4.86 (±1.1)	24.3 (±2.8)	135 (±7.8)	58.9 (±3.1)	22.0 (±1.9)	9.80 (±1.3)	21.1 (±1.8)	21.6 (±0.8)	100 (±6.9)	381 (±19)	810 (±16)
12	40.7 (±1.7)	7.40 (±1.5)	5.64 (±1.4)	33.3 (±3.2)	143 (±8.9)	52.7 (±2.1)	20.5 (±1.6)	9.10 (±0.8)	22.4 (±1.8)	21.6 (±2.2)	105 (±6.6)	376 (±17)	710 (±13)
13	38.4 (±2.5)	6.98 (±1.1)	5.60 (±1.2)	31.5 (±3.6)	151 (±13)	52.4 (±2.5)	19.9 (±1.7)	8.50 (±1.7)	20.4 (±1.9)	23.5 (±2.8)	77.4 (±3.3)	379 (±19)	660 (±10)
14	41.8 (±1.9)	8.10 (±0.9)	5.18 (±0.3)	33.7 (±1.0)	154 (±11)	47.5 (±1.9)	18.1 (±1.9)	7.20 (±1.4)	18.2 (±1.9)	26.4 (±2.4)	86.1 (±3.5)	377 (±20)	528 (±10)
15	40.9 (±0.7)	7.89 (±0.8)	5.21 (±0.4)	33.0 (±0.1)	159 (±14)	61.2 (±3.2)	21.1 (±1.9)	9.90 (±1.7)	26.8 (±1.4)	18.7 (±1.7)	99.1 (±4.2)	376 (±18)	540 (±8.0)
16	50.0 (±1.9)	9.86 (±0.5)	5.08 (±0.5)	40.1 (±2.4)	161 (±16)	56.3 (±2.1)	19.4 (±1.8)	7.71 (±1.5)	21.6 (±1.7)	23.2 (±0.8)	106 (±6.1)	362 (±15)	432 (±7.0)
17	36.2 (±0.8)	6.95 (±0.3)	5.21 (±0.4)	29.2 (±1.1)	113 (±6.1)	51.8 (±2.5)	22.4 (±1.7)	10.2 (±1.4)	22.3 (±1.7)	20.5 (±1.5)	101 (±5.3)	373 (±12)	800 (±20)
18	58.8 (±2.5)	10.8 (±0.9)	5.46 (±0.7)	48.0 (±3.5)	143 (±8.9)	45.7 (±2.8)	18.0 (±1.8)	9.23 (±1.2)	19.3 (±1.9)	25.6 (±2.5)	101 (±5.5)	350 (±13)	490 (±10)
19	35.4 (±2.2)	5.36 (±0.7)	6.62 (±0.3)	30.0 (±2.0)	109 (±6.9)	41.7 (±2.1)	20.0 (±1.7)	10.1 (±1.8)	19.0 (±1.9)	24.4 (±2.5)	100 (±5.2)	380 (±24)	850 (±22)
20	52.1 (±2.1)	8.06 (±0.1)	6.47 (±0.3)	44.0 (±2.2)	145 (±9.6)	55.8 (±3.2)	24.4 (±1.7)	9.33 (±1.4)	23.5 (±1.9)	18.2 (±0.6)	110 (±6.5)	358 (±17)	622 (±11)
21	22.6 (±2.1)	4.51 (±0.5)	5.01 (±0.1)	18.1 (±1.6)	90.2 (±5.2)	43.9 (±1.9)	24.2 (±1.6)	11.4 (±1.7)	30.4 (±1.5)	14.5 (±1.9)	81.4 (±3.4)	380 (±24)	980 (±24)
22	48.3 (±0.7)	9.13 (±1.4)	5.35 (±0.8)	39.2 (±0.7)	127 (±8.0)	50.1 (±2.5)	18.4 (±1.7)	8.31 (±1.6)	22.9 (±1.9)	23.1 (±2.3)	71.2 (±3.2)	375 (±21)	360 (±9.0)
23	54.6 (±1.6)	6.77 (±0.8)	8.10 (±0.7)	47.9 (±0.9)	90.4 (±4.5)	40.8 (±1.7)	19.4 (±1.9)	10.4 (±1.3)	21.1 (±1.9)	23.5 (±1.8)	53.5 (±2.1)	352 (±14)	750 (±15)
24	39.7 (±1.0)	8.29 (±0.9)	4.81 (±0.4)	31.4 (±0.2)	128 (±5.4)	50.2 (±2.8)	20.0 (±1.7)	9.0 (3±1.3)	18.4 (±2.0)	24.8 (±2.0)	61.2 (±2.9)	377 (±19)	542 (±8.0)
25	38.8 (±2.1)	7.45 (±0.2)	5.21 (±0.4)	31.3 (±2.3)	71.1 (±3.9)	41.4 (±2.1)	17.5 (±1.9)	9.12 (±1.4)	19.3 (±2.0)	26.0 (±3.0)	91.4 (±4.0)	378 (±17)	674 (±12)
26	37.5 (±1.2)	7.91 (±0.2)	4.75 (±0.3)	29.6 (±1.5)	65.5 (±3.5)	43.8 (±1.9)	16.8 (±1.8)	9.94 (±1.2)	19.9 (±1.7)	26.1 (±2.4)	100 (±5.6)	383 (±20)	645 (±10)
27	36.7 (±1.8)	8.10 (±0.7)	4.55 (±0.6)	28.6 (±2.5)	75.2 (±3.7)	44.5 (±2.1)	17.9 (±1.8)	8.91 (±1.4)	20.2 (±1.6)	25.1 (±1.8)	97.3 (±4.7)	387 (±19)	690 (±14)
28	36.9 (±2.7)	7.11 (±0.3)	5.18 (±0.2)	29.8 (±2.4)	70.4 (±4.0)	48.9 (±2.0)	18.0 (±1.6)	10.1 (±1.7)	18.4 (±1.8)	26.3 (±1.4)	108 (±6.8)	382 (±19)	660 (±12)
29	39.5 (±1.8)	7.04 (±0.5)	5.59 (±0.7)	32.4 (±2.4)	61.4 (±3.4)	42.8 (±2.4)	16.5 (±1.9)	8.90 (±1.2)	18.6 (±1.9)	27.2 (±1.5)	105 (±5.8)	378 (±21)	690 (±15)
30	40.0 (±1.9)	6.92 (±0.3)	5.79 (±0.5)	33.1 (±2.2)	55.0 (±3.1)	44.4 (±1.9)	17.7 (±1.7)	9.50 (±1.5)	20.6 (±1.6)	25.0 (±1.3)	103 (±5.1)	375 (±16)	630 (±12)
Fresh dried							36.8 (±3.4)	9.91 (±2.0)	37.1 (±3.1)				

Table 3. Predicting equations and compiled ANOVA results for CCRD responses.

Responses	Model	Predicting Equations in Terms of Actual Variables	Lack of Fit	R^2
ML	Quadratic	ML = +38.2 + 4.39*T + 2.80*C + 6.41*t − 3.45*F + 1.97*T^2 + 1.03*C^2 − 1.05*t^2 + 1.88*F^2 + 0.39*T*C + 0.26*T*t − 0.47*T*F + 0.42*C*t + 0.44*C*F − 1.67*t*F	0.0506 (NS)	0.9568
SG	Quadratic	SG = +7.42 + 0.81*T + 0.57*C + 0.96*t + 0.33*F + 0.31*T^2 − 0.23*C^2 − 0.20*t^2 − 0.03*F^2 + 0.10*T*C + 0.15*T*t − 0.12*T*F + 0.16*C*t − 0.10*C*F − 0.13*t*F	0.7147 (NS)	0.9518
ML/SG	Quadratic	ML/SG = +6.68 + 0.02*T − 0.07*C + 0.36*t − 0.61*F − 0.27*T^2 − 0.03*C^2 − 0.22*t^2 − 0.21*F^2 + 0.03*T*C − 0.09*T*t + 0.14*T*F + 0.11*C*t + 0.36*C*F + 0.10*t*F	0.6945 (NS)	0.8717
WR	Quadratic	WR = +30.8 + 3.57*T + 2.21*C + 5.47*t − 3.79*F + 1.65*T^2 + 1.26*C^2 − 0.85*t^2 + 1.91*F^2 + 0.29*T*C + 0.09*T*t − 0.34*T*F + 0.25*C*t + 0.55*C*F − 1.52*t*F	0.1497 (NS)	0.9483
L*	Quadratic	L* = +17.4 − 0.78*T + 0.84*C − 1.03*t + 0.59*F + 0.47*T^2 + 0.97*C^2 + 0.75*t^2 + 0.35*F^2 − 0.05*T*C − 0.11*T*t − 0.10*T*F + 0.09*C*t − 0.25*C*F + 0.16*t*F	0.0559 (NS)	0.8496
a*	Linear	a* = +9.62 − 0.43*T + 0.18*C − 0.56*t − 0.60*F	0.3826 (NS)	0.7113
b*	Quadratic	b* = +19.5 − 0.39*T + 1.78*C − 0.90*t − 0.37*F + 0.33*T^2 + 0.47*C^2 + 1.80*t^2 + 0.09*F^2 + 0.28*T*C − 1.67*T*t − 0.41*T*F + 1.16*C*t − 1.12*C*F + 0.19*t*F	0.0643 (NS)	0.8856
ΔE	Quadratic	ΔE = +3.89 + 0.35*T + 0.93*C + 0.99*t − 3.79*F − 5.69x10^{-3}*T^2 − 0.01*C^2 − 0.01*t^2 − 0.55*F^2 − 8.12 x 10^{-4}*T*C + 8.69x10^{-3}*T*t + 0.04*T*F − 6.81x10^{-3}*C*t + 0.09*C*F − 0.03*t*F	0.0686 (NS)	0.9013
Hardness	Quadratic	Hardness = +66.1 + 4.88*T + 6.63*C + 11.7*t + 9.21*F + 18.3*T^2 + 18.1*C^2 + 13.4*t^2 + 13.6*F^2 + 1.06*T*C − 1.69*T*t − 1.06*T*F − 1.81*C*t − 0.19*C*F − 0.94*t*F	0.1007 (NS)	0.9300
Chewiness	Linear	Chewiness = +48.0 − 2.52*T + 4.24*C + 1.35*t + 3.00*F	0.3938 (NS)	0.8028
RHC	Quadratic	RHC = +100 + 0.25*T + 5.14*C − 1.38*t + 4.09*F + 0.51*T^2 + 1.55*C^2 − 5.73*t^2 − 10.4*F^2 + 0.56*T*C − 0.14*T*t + 3.71*T*F + 0.56*C*t + 3.14*C*F − 0.04*t*F	0.6120 (NS)	0.9127
Bulk density	Quadratic	BD = +380 − 4.88*T − 3.71*C − 6.54*t + 5.12*F − 4.03*T^2 − 2.16*C^2 − 0.03*t^2 − 3.28*F^2 − 0.69*T*C − 1.56*T*t + 1.19*T*F − 1.44*C*t − 0.44*C*F + 5.69*t*F	0.1275 (NS)	0.8608
Drying time	Linear	Drying time = +690 − 75.8*T − 50.5*C − 129*t − 51.5*F	0.0537 (NS)	0.9229

T is temperature (°C), C is concentration (%), t is contact time (min) and F is flow rate (L/min). Note that highly significant ($p < 0.0001$) models and variables are in bold, significant ($p < 0.05$) are normal type, while non-significant ($p > 0.05$) factors are italicized.

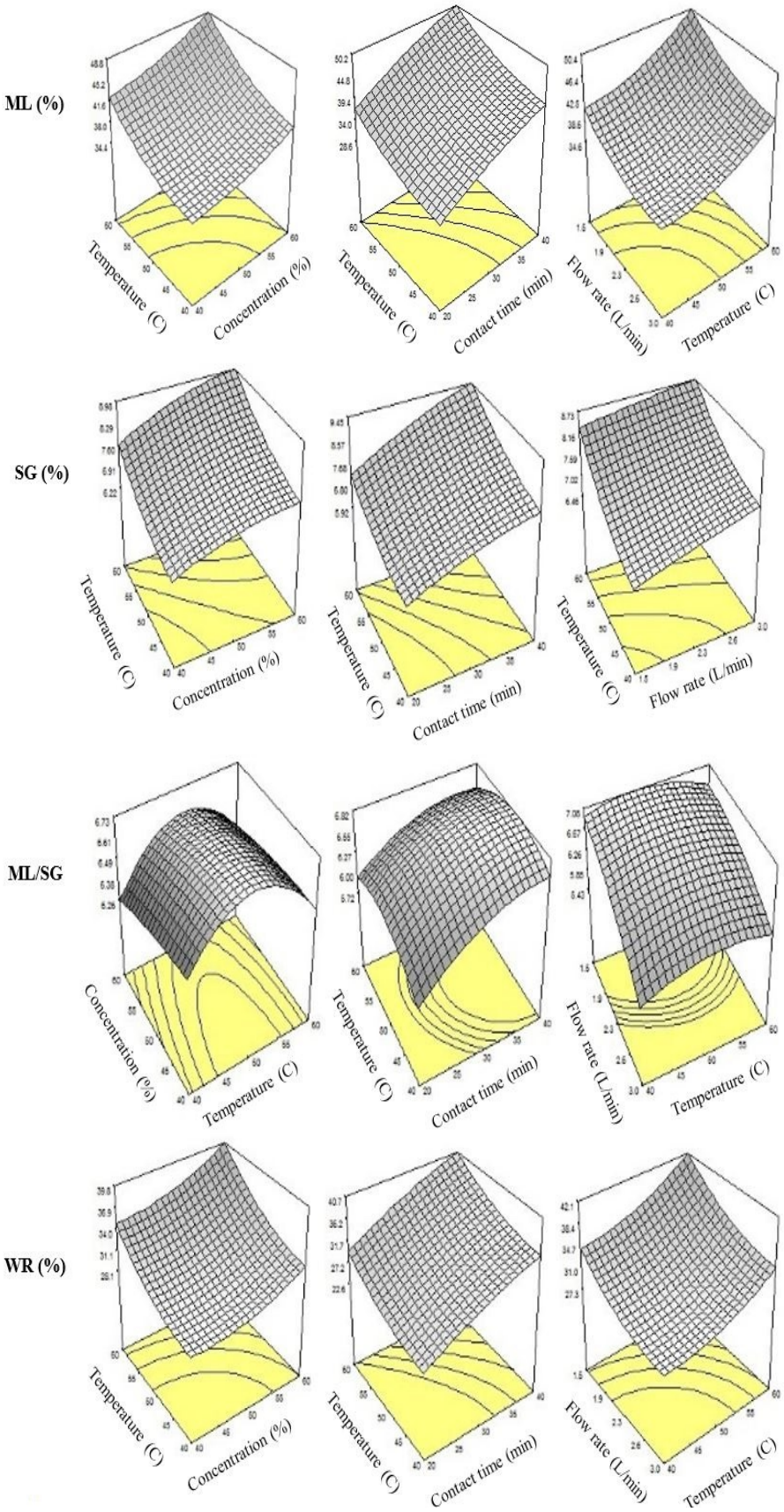

Figure 2. Response surface plots for mass transfer for ML, SG, ML/SG, WR. (When not a variable, inputs were fixed at their center point: Conc. 50%, contact time 30 min, flow rate 2.3 L/min).

3.3. Solids Gain

All factors were found to be significant ($p < 0.05$) for SG. From highest to lowest, temperature, concentration, contact time and flow rate were the contributors (Table 3). Similar observations were made in a previous report [10]. In addition, all coefficients were positive, thereby directly contributing to an increase in SG. Even so, the highest SG of 9.6% in this study, found at processing conditions of 60 °C-60%-40 min-3 L/min, was 35% lower than a prior work examining MWODS with cranberries using sucrose only solution at 60 °C-60%-45 min-3.7 L/min [10]. The major difference between these studies was the nature of the fruit and the inclusion of maltodextrin in the solute mixture. As stated in the prior work [12] and proven in previous research studies, the solute MD restricts the entry of solids into the fruit sample and results in lower solids gain value [25–27]. It was also reported by Hawkes and Flink (1978) that solids uptake is inversely correlated with the molecule size of the osmotic agent [28].

3.4. Weight Reduction

Contact time had a substantial influence on WR, followed by temperature (Table 3). Again, all variables had a positive influence on WR except for flow rate. An increase in flow rate dampened the WR effect. A possible explanation for this is that due to the rapid flow, the liquid absorbs a considerable part of the microwave radiation and moves out, thereby reducing the amount of MW absorbed by the sample and resulting in lower ML and ultimately affecting the WR. The overall weight reduction comes from moisture loss and is moderated by the solids gain. Hence, an increase in temperature, concentration and contact time would improve the weight loss of the samples, an effect which has also been demonstrated in prior studies [7,29–31]. Comparing these results with prior work, a WR of 26.1% was reported at 50 °C-50%-30 min-2.0 L/min with cranberries [17], whereas a WR of 33.8% was observed at 50 °C-50%-30 min-2.3 L/min in the current study. This effect was due to combining sucrose and maltodextrin (S: MD). As discussed earlier, high molecular maltodextrin is responsible for reducing SG and improving the ML, and hence it ultimately results in higher weight reduction [24,28].

3.5. ML/SG

ML/SG was considered as a dehydration efficiency index [32] of any osmotic dehydration processes. During the study, the flow rate was found to have the highest influence on the ML/SG ratio, followed by contact time. The negative coefficient of flow rate was explained earlier, and, as flow rate is elevated, the ML/SG ratio decreases, which is not desirable. In contrast, the positive coefficient of contact time indicated that there would be higher ML at longer contact times. However, temperature and concentration were found to be insignificant on ML/SG, which is different to what has been observed in prior work [24,28]. The reason behind the effects of concentration and temperature being non-significant is unclear. The higher number of experiments used in this study as compared earlier ones could be the reason for this, in that it might have introduced more experimental variability into the analysis, thus producing more noise and reducing the significance during model analysis.

3.6. Drying Time

For drying time, the linear model was found to be significant, and all variables were found to be significant as well. From ANOVA, it is clear that all factors had negative coefficients, indicating that an increase in any of the factors will reduce the finished drying time. This is because at higher levels of any of these variables, the residual moisture content will decrease and hence so will the time necessary to reduce it to the final desired level in the dried product. The highest coefficient was with contact time (Table 3), indicating that contact time was the largest contributor to drying time. As demonstrated in other published reports [9], higher temperatures, concentrations and contact times contribute to higher moisture loss during OD treatment and hence shorter air-drying time during the second stage air-drying process.

3.7. Product Properties

3.7.1. Rehydration Capacity

The effect of process variables on RHC is shown in Figure 3. Solute concentration and flow rate have been found to be significant individual terms affecting the rehydration capacity of finish-dried products. The non-significant terms of temperature and contact time resulted in minor changes being produced in RHC associated with the finished product. The interaction of temperature and flow rate along with the higher order polynomial for contact time were found to be the significant as well. Although temperature and contact time were not significant at individual levels, the higher degree polynomials and interaction terms associated these variables still necessitates that they are included. Again with respect to MWODS factors, the concentration had a negative coefficient whereas the flow rate had a positive coefficient in the ANOVA model for RHC (Table 3), indicating the opposing influences of these variables. The negative concentration effect of MWODS can be attributed to a higher ML potential and cell structural damage to mango cells. A higher concentration also tends to increase the SG of the product, restricting the moisture mobility and limiting the ability of moisture to diffuse back into the sample during rehydration process [10]. On the other hand, an increased flow rate might enhance the heat dissipation cooling effect, thus reducing the influence of temperature and ultimately producing a better product in terms of RHC. The flow rate was found to be a significant factor in this study unlike previous studies [10,33]. However, RHC can also by the type and efficiency of finished drying step as they can have an important influence on the structural properties of the product.

3.7.2. Bulk Density

Bulk density (BD) is an important parameter in terms of sensory perception, easy transportation and space-saving. BD is represents the ability of the dried product to store in minimal space with a maximum mass balance. From sensory and quality perspective, however, the bulk density should be at a maximum, representing the least damage to or shrinkage of the finished dried products. This is generally at the maximum for vacuum or freeze-dried products (no shrinkage) and for conventional air-dried (maximum shrinkage) products. From ANOVA, shown in Table 3, it was observed that all the factors were negatively correlated with bulk density except for flow rate. The response surface plots representing the effect of process factors on BD is presented in Figure 3. Temperature, concentration and contact time directly attributed to higher moisture reduction, higher shrinkage potential and therefore a negative correlation [10]. On the other hand, the flow rate had a positive coefficient with the selected model of bulk density, contributing to an increased bulk density at higher flow rates. This follows the fact that the flow rate had a negative effect on moisture loss [10]. Nevertheless, the BD values under MWODS finish-drying are still superior to conventional air-drying because microwave drying often contributes to texture retention due to the infusion of solutes into the structure.

3.7.3. Texture

Hardness: The temperature, concentration, contact time and flow rate were positively correlated with hardness, indicating that an increase in any of these parameters will increase the hardness of the product. The response surface plots indicating the effect of process variables on hardness are presented in Figure 3. Based on the results of ANOVA (Table 3), it was found that contact time was the most significant factor and the largest contributor to hardness. A similar outcome was also recorded in prior studies [10,34]. During this study, the higher degree polynomial (t^2) was also found to have a significant effect on hardness. Since all of the variables were positively correlated with hardness, an increase in process intensity tended to increase the hardness (desirable in this study). Compared to conventional air-dried products, MWODS-finish air-dried samples were generally softer and more desirable than the simple air-dried finished products without MWODS, as these were found to be hard in texture, as reported in prior studies [10,14].

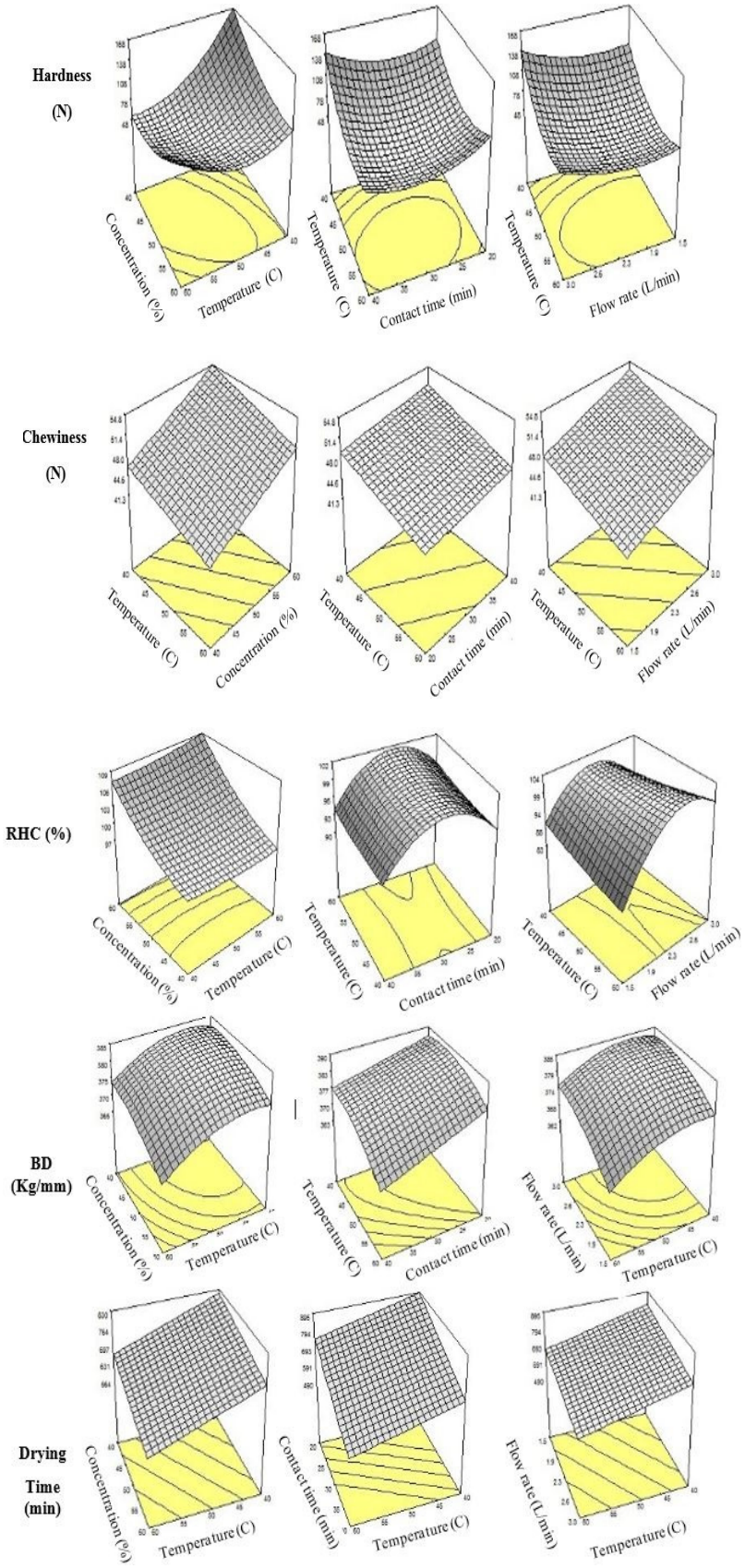

Figure 3. Response surface plots for texture analysis for hardness, chewiness, rehydration capacity (RHC), bulk density (BD) and air-drying time to reach 20% moisture (db) (when not a variable, inputs were fixed at their center point: Conc. 50%, contact time 30 min, flow rate 2.3 L/min).

Chewiness: The solute concentration was found to be the largest contributor to chewiness (Table 3). Apart from temperature, all the other factors were shown to have positive coefficients with chewiness. It has been shown in previous studies that an elevated concentration and contact time tend to increase the solids uptake, which ultimately results in softer and chewier products [6,35]. On the other hand, the temperature had a negative coefficient, indicating that higher temperatures reduce the product's chewiness. A possible explanation for this phenomenon could be that higher temperatures are responsible for the destruction of cell bonds and ultimately their mechanical behavior. Water reduction at a high temperature during OD can result in the detachment of the middle lamella of plant cells and the loss of cell turgor, which in turn affects the cell wall and puncture strength [36] and reduces the chewiness of the product.

3.8. Color

The fresh freeze-dried mangoes were chosen as a control sample to measure the color differences (ΔE) between air-dried samples. Freeze drying was employed as a "best case" scenario in terms of maintaining quality attributes during dehydration [8]. The freeze-dried mangoes were considered as a control sample to measure the color difference (ΔE).

The response surface plots for L*, a*, b* and ΔE are shown in Figure 4. Looking at an individual color parameter, factors such as temperature and contact time had a negative effect on the L* value, which can be observed from the coefficients of each term presented in Table 3. This is largely attributed to the increase in the darkness (low L* value) of the samples with increased temperature and contact time. Moreover, this substantial darkening is likely due to both the browning phenomenon and charring during the finish drying process. A similar effect was confirmed by Wray and Ramaswamy (2015) [10], where they determined that temperature, contact time and flow rate had negative effects on the lightness (L*) of the samples.

On the other hand, the flow rate was found to have a non-significant factor with most color parameters, which is also in agreement with prior work [10]. However, the flow rate was found to have significant effect on the a* value, which is unusual compared to previous results. This might be that due to the maltodextrin coating, which acts as a protective layer and influences the migration of color pigments [37]. Hence, upon increasing flow rates and an increase in the contact time, the solute migration between the fruit and the solute mixture increases and the a* value reduces. This implies that the MD content in the solute allowed for the leaching out of low molecular monomers, which are the reactive components for non-enzymatic browning in plant tissues, and therefore a reduction in the effect of browning [38]. Chun et al. (2012) [39], however, found a reduced discoloration upon the incorporation of maltodextrin in osmotic drying without the use of MWs. Similarly, based on ANOVA analysis, significant factors such as temperature and contact time had a negative effect on b* values (Table 3). The b$*$ values are likely related to the loss of the brighter yellow color (positive b$*$ value) to a darker blue (negative b$*$ value), which indicates that the temperature and contact time have negative effects when it comes to promoting the loss of carotenoid pigments.

A similar trend could be seen with ΔE (the total color change), which represents the total deviation of the product from the freeze-dried samples. From the ANOVA analysis (Table 3), it was observed that solute concentration was the largest contributor to the ΔE value, followed by contact time. Similar findings were observed in earlier studies with respect to total color change while studying the MWODS of cranberries and apple cylinders [10,34]. The total color change was mostly due to color degradation during the finished air-drying process and color changes due to the browning effect in the MWODS process.

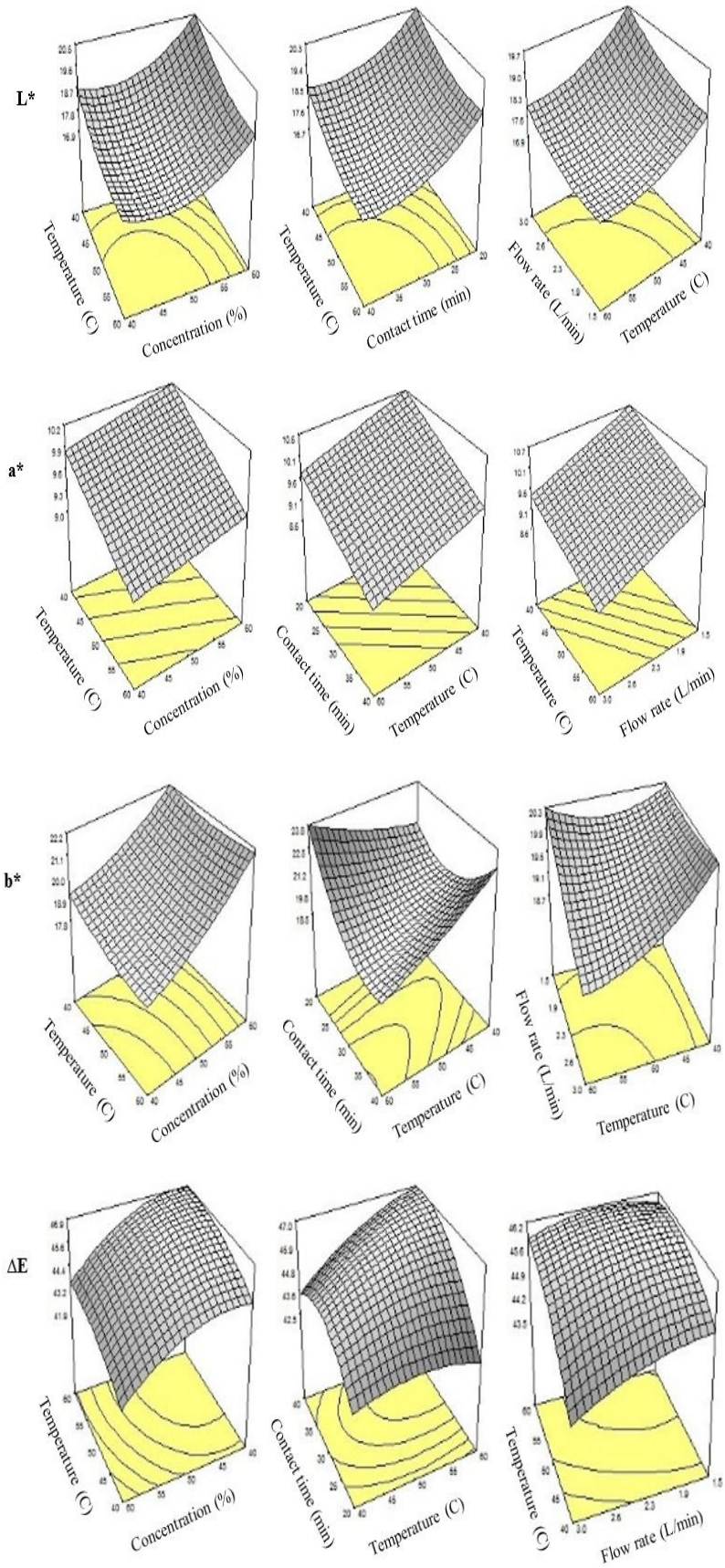

Figure 4. Response surface plots for texture analysis for color measurements such as L*, a*, b* and ΔE (when not a variable, inputs were fixed at their center point: Conc. 50%, contact time 30 min, flow rate 2.3 L/min).

3.9. Optimization and Process Validation

The optimization function of expert design software was used to obtain the optimized condition for MWODS-air-dried samples. The optimum conditions were determined to maximize ML, WR, ML/SG, rehydration capacity and bulk density while favoring SG, ΔE and hardness and minimizing chewiness while keeping the process variables, such as temperature (40–60 °C), concentration (40–60%), contact time (10–30 min) and flow rate (1.5–3.0 L/min), within the experimental range. Amongst various optimization conditions, the solution which obtained the highest desirability (0.591) value within all the imposed constraints was chosen to validate the process. The optimized conditions were: a temperature of 51.7 °C, a concentration of 58.5%, a contact time of 30.6 min and a flow rate of 1.8 L/min. The validation experiments were carried out under these optimized conditions, and the outcomes for the various parameters are tabulated in Table 4 alongside the predicted values and the predicted confidence intervals. From the Table 4, it can be observed that most of the experimental values were close to the predicted values and were within the given CI interval, which indicated that validation of the process using the optimized values can be achieved.

Table 4. Predictive model validation.

Responses	Predicted Value	CI Low	CI High	Verified Value
ML	45.6	43.3	48.0	46.1 (±1.78)
SG	7.83	7.43	8.22	7.57 (±1.00)
ML/SG	6.63	6.25	7.02	6.17 (±0.85) *
WR	37.8	35.5	40.1	38.6 (±2.12)
L*	19.0	18.0	20.0	18.1 (±1.48)
a*	10.1	9.70	10.4	9.99 (±1.19)
b*	22.7	21.3	24.1	21.2 (±1.59) *
ΔE	43.1	41.9	44.2	44.5 (±1.02) *
Hardness	92.4	81.0	102	92.8 (±1.91)
Chewiness	49.9	48.2	51.7	49.3 (±1.62)
RHC	98.9	93.6	104	98.2 (±6.45)
Bulk density	369	363	375	369.3 (±11.4)
Drying time	656	626	685	674 (±40 min)

Mean values (with standard deviation shown). CI: Confidence interval (95%), '*' denotes observed value falls outside of the predicted value confidence interval.

Since the given variable constraints and required goal of each response, only one run was returned as the best/optimization function in CCRD (with a best desirability 0.591). Obviously, this condition does not give the best outcome for any of the parameters, and from Table 2 it is evident that much higher values than those shown in Table 4 for different parameters is clearly possible. For example, the best ML value was 58.8%, the minimum SG was 4.5%, the highest ML/SG was 8.1, WR 49%, hardness value 161 N, chewiness value 61 N, RHC 110%, BD 387 kg/m^3 and L value 24.4, whereas the lowest a was 7.7, b 15.4, DE 18.6 and drying time 360 min. If the number of constraints are limited to just one variable, then the optimized conditions with highest desirability value can be achieved for any given parameter and the best possible outcome for that parameter can be realized; however, the downside of this is that the other parameters would be further away from their optimum values. Again, as an example, if only two constraints (maximizing ML and ML/SG) were chosen from mass transfer parameters and hardness, ΔE, RHC and drying time were chosen at required goal levels, then the optimized condition of 50.8 °C, 59.9%, 38.3 min and 2.1 L/min flow rate would yield a desirability value of 0.663 compared to 0.591. Furthermore, others scenarios involving the single parameter optimization is included in Table 5, in which

a desirability index as high as 1.000 are shown which means that the parameter in question has its maximum value; other options with slightly lower desirability values are shown if it is desirable to look at additional parameters simultaneously. For example, for ML maximization (55–59%), the achieved SG were as high as 9–10%, and with SG minimization (4.7–4.8%), the achieved ML were significantly low (31–32%). This necessitates the use of specific constraints with an intended optimization, as demonstrated earlier.

Table 5. Optimization results with single parameter constraints and the resulting desirability values.

Set	Constraint	Temp. (°C)	Conc. (%)	Cont. Time (min)	Flow Rate (L/min)	ML (%)	SG (%)	ML/SG	WR (%)	RHC (%)	BD (Kg/m^3)	Air-Drying Time (min)	ΔE	Hardness (g)	Chewiness (g mm)	Desirability
1	Maximize ML	60	57	40	1.6	58.9	10.0	6.44	48.9	89.0	347	477	22.9	128	48.9	1.000
		60	59	40	1.6	58.8	9.74	6.47	49.0	85.0	347	505	23.1	123	48.2	1.000
		58	59	40	1.6	54.5	8.83	6.79	46.0	80.0	347	555	23.8	105	48.2	0.891
2	Minimize SG	42	40	20	1.5	31.4	4.74	6.96	26.7	85.0	385	980	23.5	76.0	41.6	0.963
		42	40	20	1.6	30.4	4.82	6.83	25.6	88.0	385	974	23.4	76.0	42.0	0.950
		40	40	21	1.5	32.5	4.83	6.99	27.7	87.0	383	979	24.0	80.0	42.1	0.949
3	Maximize ML/SG	46	44	36	1.5	45.0	6.74	7.39	38.3	84.0	369	729	27.3	83.0	44.2	1.000
		44	45	36	1.5	44.6	6.78	7.32	37.9	85.0	369	732	26.7	83.0	45.3	1.000
		49	43	36	1.6	44.7	7.01	7.32	37.7	87.0	370	697	27.7	81.0	43.8	1.000
4	Maximize WR	60	55	39	1.5	58.8	9.69	6.50	49.0	80.0	346	519	25.0	117	46.0	1.000
		59	57	39	1.5	58.8	9.62	6.51	49.1	80.0	346	518	24.0	118	47.1	1.000
		59	58	40	1.6	58.8	9.80	6.48	48.9	84.0	346	494	23.4	123	48.1	0.998
5	Minimize ΔE	60	60	20	1.7	43.2	7.27	5.80	35.9	88.0	372	736	19.1	111	46.0	0.699
		40	60	40	2.9	42.6	8.11	6.21	34.5	96.0	375	543	19.6	137	58.6	0.664
		40	60	40	2.9	42.5	8.13	6.17	34.4	95.0	375	538	19.6	139	58.8	0.663
6	Maximize Hardness	40	60	40	3.0	42.3	8.14	6.11	34.2	93.0	376	534	19.7	140	58.9	0.882
		57	60	40	3.0	49.5	9.64	6.40	39.9	111	367	403	23.4	140	54.7	0.881
		41	60	40	3.0	42.5	8.16	6.16	34.4	94.0	376	529	19.8	139	58.9	0.873
7	Maximize Chewiness	40	60	40	3.0	42.3	8.11	6.09	34.2	94.0	376	543	19.7	140	59.0	0.911
		40	60	40	3.0	42.5	8.15	6.14	34.3	94.0	376	531	19.7	140	59.0	0.910
		42	60	40	3.0	42.7	8.23	6.25	34.5	95.0	376	517	20.3	136	58.5	0.889
8	Maximize RHC	56	60	28	2.5	43.5	8.27	6.30	35.2	110	372	600	23.4	103	51.4	1.000
		59	60	31	2.7	46.7	8.97	6.25	37.7	111	369	531	24.0	117	52.0	1.000
		60	59	26	2.6	44.1	8.41	6.06	35.6	110	371	605	23.0	110	50.1	1.000
9	Maximize Bulk D.	47	43	21	2.5	28.9	6.03	5.84	22.9	94.0	387	845	23.3	72.0	45.6	1.000
		47	46	21	2.3	29.7	6.04	6.15	23.6	96.0	388	849	23.6	64.0	45.9	1.000
		49	48	20	2.0	31.3	5.98	6.42	25.3	93.0	387	850	23.4	61.0	45.0	1.000
10	Minimize Drying T.	60	59	40	3.0	51.0	9.97	6.28	41.0	101	365	389	24.0	144	53.8	0.954
		60	59	40	3.0	50.7	9.97	6.25	40.7	101	365	389	24.2	143	53.5	0.949
		60	60	40	2.9	51.8	10.0	6.36	41.8	104	363	391	23.7	144	53.6	0.949

3.10. Comparison of MWODS Sucrose, Sucrose-Dextrose, Sucrose + Maltodextrin Plus Finish Air-Drying vs. Air-Drying Alone

MWODS with three different solute mixtures followed by finish air-drying and direct air-drying without MWODS were compared. The optimal MWODS process established in the previous section was used for quality comparison. The outcome relating to L*, a*, b*, ΔE, hardness, chewiness, RHC and bulk density were included for the comparison (Table 6). As shown in Table 6, most parameters were significantly different ($p < 0.05$), some for better and some for worse, and were improved compared to other samples. L*, b* and RHC values were significantly higher, and a*, ΔE, hardness and chewiness values were lower compared to the other treatments. Bulk density showed a difference only when compared to the air-dried sample without MWODS. The hardness and chewiness values were slightly lower than for the other samples, indicating that the samples were slightly softer (not necessarily a defect). In general, the S:MD treatment with just simple air-drying for the finished product appeared to give an excellent quality product with maximized ML and WR, minimal SG, and more importantly a higher ML/SG ratio, which is indicative of a better-quality product. The direct air-dried product (the conventional method) was the least desirable among the different treatments tested. The sucrose only and S:D combinations provided good ML and WR, but also had higher SG, which was not desirable.

Table 6. Comparison of dried mangoes using different osmotic solutes.

	Sucrose	S:D	S:MD	Fresh-AD
L*	15.3 (1.18) ^{ab}	14.0 (1.86) ^{bc}	16.8 (1.80) ^{a}	12.2 (1.55) ^{c}
a*	15.0 (1.25) ^{a}	13.0 (1.86) ^{a}	9.94 (1.17) ^{b}	14.1(1.76) ^{a}
b*	14.8 (1.29) ^{b}	15.7 (1.94) ^{b}	19.8 (1.60) ^{a}	11.0 (2.08) ^{c}
ΔE	31.3 (1.39) ^{b}	31.3 (2.50) ^{b}	26.2 (1.97) ^{c}	36.0 (2.07) ^{a}
Hardness	68.1 (1.81) ^{ab}	67.7 (1.89) ^{ab}	65.6 (1.35) ^{b}	69.2 (2.32) ^{a}
Chewiness	52.6 (1.90) ^{ab}	52.1(1.85) ^{bc}	49.3 (1.62) ^{c}	55.2 (1.82) ^{a}
Bulk density	397.5 (8.52) ^{ab}	389.5 (8.71) ^{b}	379.3 (9.70) ^{b}	411 (9.22) ^{a}
RHC	79.5 (7.48) ^{ab}	89.0 (4.09) ^{ab}	98.2 (6.45) ^{a}	78.8 (7.84) ^{b}

Mean values with standard deviation shown—values that do not share a letter (a,b,c) are significantly different (determined by Tukey method on 95% confidence interval).

The beneficial effect was clearly due to the maltodextrin content in the solute mixture, which acted as a protective layer and reduced the darkness caused due to browning at elevated processing conditions, namely high concentrations, temperatures and contact times [10]. The lowest L* value (darker samples) recorded for air-dried samples resulted in excessive browning, which implies the importance of MWOD pretreatment during the dehydration process. In addition, the minimum a* and maximum b* values were observed when samples were treated with MD. As explained earlier, the MD content restricts the leakage of color pigments and creates a barrier layer on the fruit samples, thus reducing the destruction of color pigments [37]. As shown in Table 6, the overall color change (ΔE) was found to be the lowest for MD and reached its maximum for air-dried samples without MWODS. This proves the commonly accepted notion that pretreatments, such as, for example, osmotic dehydration, reduce losses in quality with respect to the processed product [21].

Secondly, textural changes were evaluated to understand the behavior of each solute mixture on the finished dried mango fruit. A lower hardness and chewiness was observed when samples were treated with MD solute mixture, and this trend, similar to other studies using MD to treat mango chips, was found to be desirable [40]. Similarly, the highest RHC was found for the samples pretreated with MD solute mixture. The only deviation was the slightly lower bulk density compared with others, and this may have a small role in the finished dried weight of mangoes, as observed in some studies [24,26,27]. Overall, it was found that the solute mixture S:MD produced better a quality product when compared with S:D or sucrose alone, even when accompanied with the MWODS process.

4. Conclusions

Overall, it has been found that the input variables of temperature, concentration and contact time can normally be expected to increase ML, SG and WR during osmotic dehydration. High intensity processing conditions (a high temperature and concentration and a long contact time) will also compromise the quality of dried mangoes. On the other hand, optimized processing conditions under set constraints and the inclusion of maltodextrins in the sugar solution can result in better quality products under the different MWODS treatment conditions and to a greater degree than is possible using direct air-drying without MWODS. Predictive models were obtained using ANOVA for different outcomes as a function of process variables, and optimized parameters were achieved and verified. As is common with a majority of dehydrated products, the quality of a dried product even under the best conditions deviates from that of a fresh sample; however, the MWODS minimizes quality losses by employing more quality-friendly operating conditions and shorter dehydration times. Furthermore, the use of a maltodextrin supplement to sucrose (S:MD) helps to further increase ML and reduce SG, providing even better quality advantages. In conclusion, the dehydrated product with a minimal change in color and a

comparatively firm texture along with a high rehydration capacity and reduced dehydration time was obtained by using a MWODS-finish air-drying concept by incorporating S:MD at a ratio of 85:15 under the following conditions: a temperature of 51.7 °C, a concentration of 58.5%, a contact time of 30.6 min and a flow rate of 1.8 L/min.

It is suggested that this process be further explored with other fruits and that such explorations are likely to succeed. Scale up considerations are important when exploring these concepts for pilot and industrial scale applications. These techniques involve the combination of multiple operations, such as osmotic drying, MW heating and finish drying by hot air or the evaluation of alternatives such as fluidized bed air, MW, refraction window and other novel techniques.

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