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OPTIMIZING MICROWAVE DRYING OF BLACK CARROT PRETREATED WITH OSMOTIC DEHYDRATION: TAGUCHI-BASED DESIRABILITY FUNCTION APPROACH

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Abstract: This study aimed to optimize the microwave drying process of black carrot pretreated with ultrasound-assisted osmotic dehydration (UAOD). The effect of salt concentration (2-10%), sonication time (5-15 min), and microwave power (300-600 W) on total phenolic matter (TFM) and drying time was monitored. Single response optimization was performed using the Taguchi method (TM), while the desirability function approach (DFA) was used to optimize multiple responses. The analyses were conducted using Taguchi L_9 orthogonal design. Single response optimization results showed that TFM content was changed between 11.59 and 18.57 mg GAE/g sample dry matter, while the drying time ranged from 8 to 20 min. In multiple response optimization, the DFA with a composite desirability (CD) value of 0.973 demonstrated that the optimal conditions for both maximizing TPC and minimizing drying time were obtained with 10% salt concentration, 15 min sonication, and 600 W microwave power. ANOVA results revealed that microwave power contributed the highest to both responses, followed by salt concentration and sonication time, respectively. However, microwave power and salt concentration had a substantial impact on the CD. Overall results showed that the Taguchi-based DFA was successfully applied to optimize the microwave drying process of black carrots pretreated with UAOD, maximizing the phenolic compound content and minimizing the drying time.

Keywords: Microwave drying, Osmotic dehydration, Sonication, Black carrot, Optimization

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1. Introduction

The black carrot (*Daucus carota subsp. sativus var.*) is characterized by its dark purple color, attributable to anthocyanins—water-soluble plant pigments with antioxidant and anti-inflammatory properties. In addition to anthocyanins, black carrots contain a variety of phytonutrients, including carotenoids, flavonoids, and phenolic acids, which have been associated with a range of health benefits (Ayar-Sumer et al., 2024). All these compounds contribute to reducing the risk factors associated with chronic diseases. While carrots are primarily consumed in their fresh form, their extracts are extensively utilized in various food products such as juices, soft drinks, baked goods, confectionery, ice cream, and as natural colorants. In Türkiye, the black carrot has a cultural significance, particularly in producing "shalgam," a traditional fermented beverage (Keskin et al., 2021).

Drying, one of the oldest and most significant preservation methods, plays a crucial role in enhancing storage capacity while preserving the physical and nutritional quality of agricultural products (Kaveh et al., 2021). Hot air drying, a widely employed technique, relies on the concurrent application of heat and mass transfer to facilitate the removal of moisture from fruits and vegetables. However, this conventional technique has several disadvantages, including alterations to physical properties such as texture, color, nutritional value, and shape. Furthermore, it is a time-consuming and energy-intensive process. Consequently, there is an increasing demand for developing novel drying methods that can address these limitations, while offering the advantages of reduced energy consumption and accelerate drying times. Microwave drying has emerged as a promising alternative, offering several advantages over traditional methods. These include enhanced drying efficiency, reduced energy consumption, and decreased drying time. However, it is important to note that microwave drying can result in non-uniform drying, leading to uneven heat distribution within the product. This, in turn, can compromise the quality of the final product. To address these concerns, the employment of non-conventional techniques, including pretreatment methods prior to drying, emerges as a pivotal strategy to enhance the quality of the final product. Pretreatment application can enhance material porosity, thereby facilitating mass transfer, reducing drying time, and minimizing undesired alterations during the drying process. Ultrasound-assisted osmotic dehydration

(UAOD) is one such pretreatment technique that can further improve the drying process (Mohammadi et al., 2023).

Osmotic dehydration is a non-thermal, partial drying process that removes water from food by immersing it in a hypertonic solution, thereby creating a concentration gradient that drives water loss and cellular shrinkage. The UAOD enhances this process through acoustic cavitation, where rapid compression and relaxation cycles induce bubble formation and collapse, significantly increasing mass transfer rates. Recent studies have emphasized that ultrasound pretreatment both increases the drying rate and reduces the loss of bioactive components compared to conventional methods. These improvements highlight the potential of UAOD as a technique to improve both process efficiency and product quality (Memis et al., 2024).

The Taguchi method (TM) has been widely utilized in numerous studies to investigate the effects of control parameters on an output response. It provides a structured and systematic approach to optimizing manufacturing processes, ensuring efficient and effective control over process variables to enhance product quality and performance (Dang et al., 2024). The TM employs orthogonal arrays to minimize the experimental trials and reduce the costs. The data obtained from the analysis transform the signal-to-noise ratio (SNR) to optimize response variables. The TM is employed to optimize the process in studies on drying in food processing. In a recent study, Chen et al. (2023) investigated the impact of drying factors on the quality of the final product and energy consumption using the TM. The results revealed that the transition moisture content was the most influential characteristic affecting the MAFD in pineapple drying. Türkan and Etemoğlu (2020) adopted the Taguchi approach to minimize the drying time of cucumber in a convective drier. The optimal levels for air velocity, drying temperature, and sample thickness were determined as 1 m/s, 60 °C, and 5 mm, respectively. A study conducted by Mecha et al. (2024) utilized Taguchi design to optimize the responses such as drying rate, specific moisture extraction rate, color change, and rehydration ratio in the chanterelle mushroom drying process. The drying process was conducted in a heat pump drier, and the experiments were run according to the Taguchi L_9 design to optimize the mushroom shape and the drying air temperature parameters. The results indicated that the mushrooms with cubic shapes dried at 56 °C exhibited optimum characteristics. The aforementioned studies demonstrate the application of the TM in the optimization of single-response problems. On the other hand, hybrid optimization techniques are required for the optimization of multi-response problems. The desirability function approach (DFA) is an optimization method that provides optimal solutions for multi-response problems. The DFA is often integrated into response surface methodology designs to optimize multiple responses in microwave drying studies of pretreated apple slices (Taghinezhad et al., 2023), mango cubes (Shinde and Ramaswamy, 2021), and tomato slices (de Souza et al., 2023).

To the best of our knowledge, no DFA integrated with TM for the optimization of drying processes in food drying. Therefore, the objective of this study was to optimize the drying conditions for UAOD followed by microwave drying of black carrots. The Taguchi L9 experimental design was employed, and the optimization process was conducted using the Taguchi-based DFA method. The process factors were selected as salt concentration, sonication time, and microwave power, while the response variables were identified as total phenolic matter (TFM) content and drying time.

2. Materials and Methods

2.1. Material

Fresh black carrots were procured from a local supplier in Sakarya, Türkiye. After peeling, the samples were cleaned and sliced into spherical by a mechanical slicing machine. The salt and chemicals utilized in the study were of analytical purity.

2.2. Ultrasound-Assisted Osmotic Dehydration (UAOD)

Osmotic dehydration was conducted using aqueous NaCI solutions containing 20, 60, and 100 g of soluble solids per kg of solution. The solutions were prepared at room temperature by dissolving the osmotic agent in distilled water. The sample weight was 35 ± 0.2 g and kept constant throughout the process. Osmotic dehydration experiments were conducted in an ultrasonic water bath (Creworks, PS-30A, China) at a constant temperature (30±2 °C). The ultrasonic bath operated at a fixed power of 150 kW and a frequency of 40 kHz. Samples were exposed to osmotic solutions for various durations (5-15 min) under acoustic treatment.

2.3. Microwave Drying

Osmotic dehydrated samples were gently placed between filter paper for 1 min to remove surface water. Subsequently, the black carrots were placed on the tray of a domestic microwave (Samsung, Model MS23F300EES, Malaysia) and dried at power levels of 300, 450, or 600 W. The weight of the tray was noted at 30 s intervals during the drying process, which continued until the sample achieved a constant moisture content of 10%.

2.4. Analysis

2.4.1. Total phenolic matter (TFM) content

Total phenolic content in black carrot powders was analyzed by a modified assay reported by Sonmez and Sahin (2023). Briefly, 1 g of powder was mixed with 25 mL of 80% (v/v) methanol, agitated at 400 rpm for 15 min. The mixture was then centrifuged (K242R, Centurion Scientific, England) for 15 min at 5000 rpm, and the resulting supernatant was used to determine the TFM. In this method, 0.1 mL of the resulting extract was mixed with 2 mL of distilled water and 0.2 mL of Folin-Ciocalteu reagent. After 5 min, 1 mL of Na_2CO_3 solution

(20% (w/v)) was added into the test tube. The reaction was allowed to proceed for 60 min in the dark and the absorbance was read in a UV-VIS spectrophotometer (Shimadzu, UVmini-1240, Japan) at 765 nm. Various concentration of gallic acid solutions (25-100 mg/L) was used to obtain a calibration curve. The results were calculated as mg gallic acid equivalent (mg GAE) in g sample dry matter (dm).

2.4.2. Drying time

The drying time for each pretreated black carrot was defined as the duration required for the moisture content of the final product to fall below 10%. The moisture content of the samples was measured by drying them in a laboratory oven at 105 °C until a constant weight was achieved.

2.5. Experimental Design

2.5.1. Taguchi optimization technique

The TM was developed to optimize total quality control processes by systematically analyzing the effects of various factors on response characteristics and determining their optimal levels. This method enables the identification of experimental conditions with minimal variability, offering a significant advantage over conventional statistical design approaches (Zolgharnein et al., 2013). Traditional experimental design methods are often complex, with the number of required experiments increasing proportionally to the number of experimental factors, making them less practical for food applications (Li et al., 2024). The TM basically uses orthogonal arrays to quantify the effect of process factors on response variables and then evaluates experimental test results using SNR values. In the present study, the Taguchi L_9 orthogonal array, which was composed of three factors and three levels, was selected (Table 2). The process factors including salt concentration, sonication time and microwave power and their corresponding levels were given in Table 1.

Table 1. Process parameters and levels

Process parameters	Symbol	Unit	-1	0	+1
Salt concentration	A	%	2	6	10
Sonication time	B	min	5	10	15
Microwave power	C	W	300	450	600

Table 2. Taguchi L_9 orthogonal array

Run	Experimental design			Mean values		SNR (dB)	
	A	B	C	TFM	Drying time	TFM	Drying time
1	-1	-1	-1	11.59	20.00	21.28	-26.02
2	-1	0	0	16.27	15.00	24.23	-23.52
3	-1	+1	+1	14.14	11.50	23.01	-21.21
4	0	-1	0	18.57	14.50	25.37	-23.23
5	0	0	1	17.28	9.50	24.75	-19.55
6	0	+1	-1	13.35	17.00	22.51	-24.61
7	+1	-1	1	14.09	8.00	22.98	-18.06
8	+1	0	-1	13.02	16.00	22.29	-24.08
9	+1	+1	0	18.10	9.00	25.15	-19.08

For responses, the “larger is better” function (equation 1) was selected to maximize TFM. However, the “smaller is better” (equation 2) was chosen because drying time was targeted to minimize in this research.

$$S/_N = -10log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right] \tag{1}$$

$$S/_N = -10log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \tag{2}$$

where i indicates the experimental order, y_i is the result and n is the design parameter.

2.5.2. Desirability function approach (DFA)

The DFA is an effective tool for optimizing multiple responses. The primary advantage of desirability function analysis lies in its ability to address multi-response optimization problems by transforming multiple responses into a normalized scale within the range [0, 1]. A desirability value of “1” represents the most favorable outcome, while “0” indicates the least favorable. Depending on the specific response characteristics, desirability functions are classified into three forms: the nominal-the-best, larger-the-best, and smaller-the-best. In this study, the “larger-the-best” was used for TFM (equation 3). On the other hand, the “smaller-the-best” form given in equation 4 was utilized for drying time.

$$= \begin{cases} 0 \\ \left(\frac{y_i - y_{min}}{y_{max} - y_{min}}\right)^s, \\ 1 \end{cases} \quad \begin{matrix} y_i < y_{min} \\ y_{min} \le y_i \le y_{max}, \ s \ge 0 \\ y_i > y_{max} \end{matrix} \tag{3}$$

$$= \begin{cases} 0 \\ \left(\frac{y_i - y_{max}}{y_{min} - y_{max}}\right)^s, \\ 1 \end{cases} \quad \begin{matrix} y_i < y_{min} \\ y_{min} \le y_i \le y_{max}, \ s \ge 0 \\ y_i > y_{max} \end{matrix} \tag{4}$$

where y_{min} and y_{max} denote the lower and upper limits of the response variables. The parameter “s” in equations 1-2 represents the weight value, which is determined using either subjective or objective weighting methods.

Finally, these individual desirability values are then combined using equation 5 to determine the overall desirability (OD), enabling the simultaneous optimization of multiple responses in a straightforward and effective manner (Dang et al., 2024).

$$OD = \sqrt[w]{d_1^{w_1} \times d_2^{w_2} \times \ldots\ldots\ldots\ldots.. d_i^{w_3}} \tag{5}$$

where d_i indicates the desirability value of response “i”, while w represents the number of responses.

2.6. Statistical Analysis

Minitab (version 19.0, USA) was used to develop an L_9 orthogonal array based on the Taguchi optimization method for microwave drying black carrot samples pre-treated with UAOD. Additionally, the software was used to conduct ANOVA analysis to evaluate the contribution ratio of independent variables such as salt concentration, sonication time, and microwave power on TFM and drying time, within the context of the Taguchi-based DFA optimization.

3. Results and Discussion

3.1. Taguchi Optimization

The TM was used to obtain optimal process levels for each response variable. Table 2 shows the mean and the corresponding SNR values for the TFM and drying time responses. The TFM content of the nine samples ranged from 11.59 to 18.57 mg GAE/ g sample dm. However, the drying time of the samples exposed to sonication for different durations (5-15 min) in the medium with different salt content (2-10%) varied between 8 and 20 min in the microwave with various powers (300-600 W). One of the most critical stages in the TM is that the results of the responses are transformed into the SNR values (Zhang et al., 2024). In this project, the “larger the better” and “smaller the better” functions were used to convert the response values of TFM and drying time into the SNR values, respectively. To obtain the SNR table, these SNR values were further analyzed through Minitab software. In Table 3, the level with the highest SNR value among each process factor level for a response indicates its optimum setting. Therefore, it can be concluded that the maximum TFM content was determined using %6 salt, 10 min sonication, and 450W microwave power ($A_2B_2C_2$). On the other hand, the optimal drying time could be obtained under experimental conditions using %10 salt, 15 min sonication, and 600W microwave power ($A_3B_3C_3$).

Table 3. The SNR table for the responses

	TFM			Drying time		
Level	A	B	C	A	B	C
1	22.84	23.21	22.03	-23.59	-22.44	-24.90
2	*24.21*	*23.76*	*24.92*	-22.46	-22.39	-21.94
3	23.47	23.56	23.58	*-20.41*	*-21.64*	*-19.61*
Delta	1.37	0.54	2.89	3.18	0.80	5.29
Rank	2	3	1	2	3	1

*Italic values indicate optimal levels.

Analysis of variance (ANOVA) can be used to observe the impact of each control factor (salt, sonication time, microwave power) on the response variable (TFM and drying time). In this study, ANOVA analyses were carried out using Minitab software. Statistical analysis of the results was carried out with a 95% confidence level. The ANOVA results for TFM and drying time are shown in Table 4. It can be deduced from Table 4 that the percent contribution of salt, sonication time, and microwave power on TFM response is 17.75, 1.85, and 76.72, respectively. Similarly, the variation in microwave power is identified as a dominant factor, attributing contribution rates of 72.47% for drying time, followed by 22.86% for salt concentration and 3.14% for sonication time. These findings indicated that microwave power is a critical determinant in optimizing the response variables. Furthermore, salt concentration was observed to have a moderate effect. Sonication time, on the other hand, has a limited effect on the optimization process.

Table 4. ANOVA results for the responses

Factors		df	SS	MS	F-value	Contribution (%)
T*	A	2	8.653	4.326	4.81	17.75
	B	2	0.901	0.451	0.50	1.85
	C	2	37.41	18.703	20.79	76.72
	Error	2	1.799	0.899		
	Total	8	48.76			
D*	A	2	30.722	15.361	14.95	22.86
	B	2	4.222	2.111	2.05	3.14
	C	2	97.389	48.694	47.38	72.47
	Error	2	2.056	1.028		
	Total	8	134.389			

T*= TFM, D*= Drying time.

3.2. Desirability Function Approach (DFA) Optimization

The DFA was applied for multiple response optimization of TFM and drying time responses in the microwave drying process of black carrot slices subjected to UAOD. In this method, firstly, the experimental results obtained using Taguchi L_9 orthogonal design were normalized. In this process, since the TFM response has a maximization objective, the “larger-the-best” (equation 3) was selected. On the other hand, the “smaller-the-best” (equation 4) was used because the aim of the study was to reduce the drying time. Then, the desirability values (d_i) were calculated by considering the weighting factor values of the normalized results obtained for the responses. For a subjective approach, principal component analysis (PCA) was used to calculate the weighting factors for the responses (Güldane, 2023). As a result, these values for TFM and drying time were determined as 0.15 and 0.85, respectively. Composite desirability (CD) values were obtained by using the weighted desirability values in equation 5. Table 5 shows the normalization, d_i and CD values calculated for all experiments. Among the nine runs, Run 9 achieved the highest CD value (CD=0.959), indicating the optimal conditions for both responses, which is referred to as the initial process parameter. This was followed closely by Run 5 (CD=0.930) and Run 7 (CD=0.926). In contrast, Run 1 exhibited the lowest desirability index (CD=0.000), suggesting non-optimal conditions for both TFM and drying time.

Table 6 presents the average impact of each parameter level on CD. In this table, the Max-Min value corresponds to the difference between the highest and lowest level data of each process parameter. This indicates the degree of importance of the respective parameter on CD. Also, in this table, the highest value of the process parameter levels indicates the optimal value for relevant process factor. When the Max-Min results were analyzed, it was determined that the effect of the microwave power parameter was the most significant on CD, followed by salt concentration and sonication time, respectively. In addition, the optimum parameter combination for maximization of TFM and minimization of drying time was obtained as 10% salt, 15 min sonication, and 600W microwave power ($A_3B_3C_3$).

Table 5. Multi-response optimization with DFA

Run	Normalization		Desirability index (di)		CD	Range
	TFM	Drying time	TFM	Drying time		
1	0.000	0.000	0.000	0.000	0.000	9
2	0.671	0.417	0.942	0.475	0.669	6
3	0.365	0.708	0.860	0.746	0.801	4
4	0.999	0.458	1.000	0.515	0.718	5
5	0.815	0.875	0.970	0.893	0.930	2
6	0.252	0.250	0.813	0.308	0.500	8
7	0.358	1.000	0.857	1.000	0.926	3
8	0.204	0.333	0.788	0.393	0.557	7
9	0.933	0.917	0.990	0.929	0.959	1*

*Initial process parameters, CD= composite desirability.

Table 6. Response table for the mean values of the CD

Factors	Level 1	Level 2	Level 3	Max-Min	Rank
A	0.4899	0.7162	0.8137	0.3238	2
B	0.5479	0.7186	0.7533	0.2054	3
C	0.3523	0.7818	0.8857	0.5334	1

The bold values show the optimal process levels.

Figure 1 plots the effect of control factors on the CD. As shown in the graph, an increase in salt concentration leads to a significant increase in CD. This means that osmotic dehydration at an increasing level from 2% to 10% in osmotic solution had a positive influence on maximizing the TFM and especially minimizing the drying time. The formation of chemical bonds between salt and the plant tissue matrix causes a decrease in the resistance of the cell wall and membrane and an improvement in the diffusion process (Asghari et al., 2024). An increase in water loss and a decrease in solute gain was observed in the osmotic dehydration process of lemon (Deepika and Sutar, 2017), aonla (Alam and Singh, 2010), and cauliflower (Vijayanand et al., 1995) samples in an increasing salt concentration. Figure 1 also revealed that the mean CD value increased with increasing sonication treatment during the osmotic dehydration process. The application of sonication during the osmotic dehydration process leads to the disruption of cell walls due to the cavitation effect and thus accelerates the drying process. Furthermore, this process prevents the degradation of phenolic compounds (Cichowska-Bogusz et al., 2020). Similarly, Guo et al. (2023) studied the effect of ultrasound treatment on hot air drying characteristics of garlic slices. They reported a significant improvement in the drying process in sonicated samples, which had a more porous structure compared to untreated garlic slices. This reduction in drying time was also observed in freeze drying of goji (Wang et al., 2024), air drying of apple cubes (Magalhães et al., 2017), and microwave freeze drying of sea cucumber (Duan et al., 2008). The plot drawn in Figure 1 also indicated that an increase in the level of microwave power leads to an increment in CD value, as expected. Saha et al. (2019) investigated the effect of the microwave drying process at different power levels (300W, 600W, 900W) on antioxidant compounds and the drying time of corncob slices. As a result, microwave power levels higher than 300W had a negative effect on the antioxidant capacity of the dried samples. On the other hand, the drying rate of the samples increased as increasing microwave power levels. Similarly, we observed the SNR values of the black carrot samples dried at higher microwave power levels than 450W (Table 3).

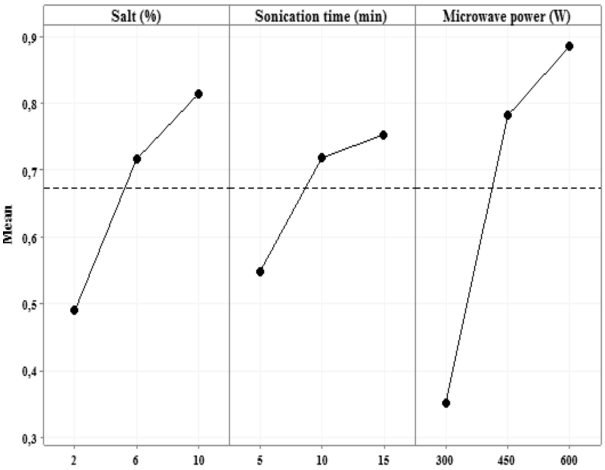

Figure 1. Effect of process variables on CD.

ANOVA results in Table 7 show the effect of process variables on CD. F- and *p*- values were used to evaluate this effect in the black carrot drying process where UAOD pretreatment was applied. Higher F- and lower *p*- values increase effective drying factors' contribution to the process. The results showed that microwave power was the most important parameter affecting CD, followed by salt concentration and sonication time. Microwave power contributed 66.05% on CD, followed by salt concentration and sonication time with 22.78% and 9.98%, respectively.

Table 7. ANOVA table for composite desirability (CD)

Factors	df	SS	MS	F-value	P-value	Contribution (%)
A	2	0.166	0.083	19.23	0.049	22.78
B	2	0.073	0.036	8.43	0.106	9.98
C	2	0.480	0.240	55.74	0.019	66.05
Error	2	0.009	0.004			
Total	8	0.726				

*Significant at $p<0.05$; S=0.0656. R^2=98.82%. R^2(adj)=95.26. R^2(pred)=76.01.

3.3. Validation Experiments

Confirmation experiments were carried out to determine the enhancement in CD value obtained statistically by the DFA. The hybrid improvement in TFM and drying time responses was evaluated by comparing the values obtained at the initial parameter settings (salt concentration 6%, sonication time 15 min, microwave power 450W) with those obtained at the optimum parameter levels (salt concentration 10%, sonication time 15 min, microwave power 600W). The results were also predicted using Minitab software. To obtain observational data, 3 replicate experiments were performed with the optimum combination of CD values. Table 8 illustrates the average results of the validation studies. As can be seen, the CD for the initial drying parameter setting of black carrot samples pretreated with UAOD was 0.959. While this value increased to 0.973 after the optimization process, an improvement of 1.46%. Consequently, the overall results of this study revealed that the optimal drying conditions, which were determined using a Taguchi-based desirability function approach to reduce drying time and produce a product with a high concentration of phenolic compounds for black carrots subjected to osmotic dehydration via microwave drying, were as follows: a salt concentration of 10%, sonication for 15 minutes, and 600 W microwave power.

Table 8. Results of validation tests

Responses	Initial settings	Optimal process parameters	
		Predicted	Test
	$A_2B_3C_2$	$A_3B_3C_3$	$A_3B_3C_3$
TFM	18.10	15.13	16.42
Drying time	9.00	6.39	7.50
CD	0.959	1.000	0.973

4. Conclusion

This study was carried out to optimize the microwave drying process of black carrot slices with ultrasound-assisted osmotic dehydration pretreatment. Salt concentration, sonication time, and microwave power variables were selected as control factors. The total phenolic matter content and drying time variables of the dried samples were optimized using a hybrid method, Taguchi-based desirability function approach. The study revealed that an increase in the control parameter levels led to an increase in the composite desirability value. Furthermore, the contributions of these parameters to the drying process were determined to be in the following order of importance: microwave power > salt concentration > sonication time. This study demonstrated that the Taguchi-based desirability function approach is effective for optimizing multiple response optimization in similar drying operations.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	M.G.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Alam MS, Singh A. 2010. Optimization of osmotic dehydration process of aonla fruit in salt solution. Int J Food Eng, 6. https://doi.org/10.2202/1556-3758.1476

Asghari A, Zongo PA, Osse EF, Aghajanzadeh S, Raghavan V, Khalloufi S. 2024. Review of osmotic dehydration: Promising technologies for enhancing products' attributes, opportunities, and challenges for the food industries. Compr Rev Food Sci Food Saf, 23: 1-28. https://doi.org/10.1111/1541-4337.13346

Ayar-Sumer EN, Nyambe C, Hashim MA. Altin-Yavuzarslan G, El-Messery TM, Ozçelik B. 2024. Optimizing encapsulation of black carrot extract using complex coacervation technique: Maximizing the bioaccessibility and release kinetics in different food matrixes. Lwt, 198: 115995. https://doi.org/10.1016/j.lwt.2024.115995

Chen BL, Lin GS, Amani M, Yan WM. 2023. Microwave-assisted freeze drying of pineapple: Kinetic, product quality, and energy consumption. Case Stud Therm Eng, 41: 102682. https://doi.org/10.1016/j.csite.2022.102682

Cichowska-Bogusz J, Figiel A, Carbonell-Barrachina AA, Pasławska M, Witrowa-Rajchert D. 2020. Physicochemical properties of dried apple slices: Impact of osmo-dehydration, sonication, and drying methods. Molecules, 25: 1078. https://doi.org/10.3390/molecules25051078

Dang X, Al-Rahawi M, Liu T, Mohammed STA. 2024. Single and Multi-response Optimization of Scroll Machining Parameters by the Taguchi Method. Int J Precis Eng Manuf, 25: 1601-1614. https://doi.org/10.1007/s12541-024-01026-3

de Souza AU, Corrêa JLG. Junior RE, Silveira PG, de Mendonça KS, Junqueira JR de J. 2023. Optimization of osmotic pretreatment of tomato slices using response surface methodology and further hot-air drying. Acta Sci Technol, 45: 1-12. https://doi.org/10.4025/actascitechnol.v45i1.62457

Deepika S, Sutar PP. 2017. Osmotic dehydration of lemon (Citrus limon L.) slices: Modeling mass transfer kinetics correlated with dry matter holding capacity and juice sac losses. Dry Technol, 35: 877-892. https://doi.org/10.1080/07373937.2016.1229675

Duan X, Zhang M, Li X, Mujumdar A. 2008. Ultrasonically enhanced osmotic pretreatment of sea cucumber prior to microwave freeze drying. Dry Technol, 26: 420-426. https://doi.org/10.1080/07373930801929201

Güldane M. 2023. Optimizing foam quality characteristics of model food using Taguchi-based fuzzy logic method. J Food Process Eng, 46(8): e14384.

Guo X, Hao, Q, Qiao X, Li M, Qiu Z, Zheng Z, Zhang B, 2023. An evaluation of different pretreatment methods of hot-air drying of garlic: Drying characteristics, energy consumption and quality properties. Lwt, 180: 114685. https://doi.org/10.1016/j.lwt.2023.114685

Kaveh M, Abbaspour-Gilandeh Y, Nowacka M. 2021. Optimisation of microwave-rotary drying process and quality parameters of terebinth. Biosyst Eng, 208: 113-130. https://doi.org/10.1016/j.biosystemseng.2021.05.013

Keskin M, Guclu G, Sekerli Y.E, Soysal Y, Selli S, Kelebek H. 2021. Comparative assessment of volatile and phenolic profiles of fresh black carrot (Daucus carota L.) and powders prepared by three drying methods. Sci Horticult, 287: 110256. https://doi.org/10.1016/j.scienta.2021.110256

Li J, Huang W, Xie Y, Yang J, Zhao M. 2024. The parameters optimization of robotic polishing with force controlled for mold steel based on Taguchi method. J Brazilian Soc Mech Sci Eng, 46: 1-11. https://doi.org/10.1007/s40430-024-04889-9

Magalhães ML, Cartaxo SJM, Gallão MI, García-Pérez JV, Cárcel JA, Rodrigues S, Fernandes FAN. 2017. Drying intensification combining ultrasound pre-treatment and ultrasound-assisted air drying. J Food Eng, 215: 72-77. https://doi.org/10.1016/j.jfoodeng.2017.07.027

Mecha P, Zhu R, Zhang J, Awuah E, Soomro SA, Chen K. 2024. Optimization of chanterelle mushroom drying kinetics under heat pump dryer using taguchi design method. Int J Agric Biol Eng, 16: 273-279. https://doi.org/10.25165/j.ijabe.20231606.6408

Memis H, Bekar F, Guler C, Kamiloğlu A, Kutlu N. 2024. Optimization of ultrasonic-assisted osmotic dehydration as a pretreatment for microwave drying of beetroot (Beta vulgaris). Food Sci Technol Int, 30: 439-449. https://doi.org/10.1177/10820132231153501

Mohammadi S, Karimi S, Layeghinia N, Abbasi H. 2023. Microwave drying kinetics and quality of Allium hirtifolium Boiss: effect of ultrasound-assisted osmotic pretreatment. J Food Meas Charact, 17: 4747-4759. https://doi.org/10.1007/s11694-023-01957-x

Saha SK, Dey S, Chakraborty R. 2019. Effect of microwave power on drying kinetics, structure, color, and antioxidant activities of corncob. J Food Process Eng, 42: 1-13. https://doi.org/10.1111/jfpe.13021

Shinde B, Ramaswamy HS. 2021. Optimization of maltodextrin (10DE)—Sucrose moderated microwave osmotic dehydration of mango cubes under continuous flow spray mode (MWODS) conditions. J Food Process Eng, 44: 1-13. https://doi.org/10.1111/jfpe.13835

Sonmez F, Sahin Z. 2023. Comparative study of total phenolic content, antioxidant activities, and polyphenol oxidase enzyme inhibition of quince leaf, peel, and seed extracts. Erwerbs-Obstbau, 65: 745-750.

Taghinezhad E, Kaveh M, Szumny A, Figiel A, Blasco J. 2023. Qualitative, energy and environmental aspects of microwave drying of pre-treated apple slices. Sci Rep, 13: 1-19. https://doi.org/10.1038/s41598-023-43358-6

Türkan B, Etemoğlu AB. 2020. Optimization of parameters effecting food drying using Taguchi method. Pamukkale Univ. J Eng Sci, 26: 654-665. https://doi.org/10.5505/pajes.2019.93695

Vijayanand P, Chand N, Eipeson WE. 1995. Optimization of osmotic dehydration of cauliflower. J Food Process Preserv, 19: 229-242. https://doi.org/10.1111/j.1745-4549.1995.tb00291.x

Wang J, Liu C, Zheng L. 2024. Effect of ultrasound-assisted osmotic dehydration on the drying characteristics and quality properties of goji. J Food Process Eng, 47(5): e14620. https://doi.org/10.1111/jfpe.14620

Zhang Z, Wang S, Pan M, Lv J, Lu K, Ye Y, Tan D. 2024. Utilization of hydrogen-diesel blends for the improvements of a dual-fuel engine based on the improved Taguchi methodology. Energy, 292: 13047. https://doi.org/10.1016/j.energy.2024.130474

Zolgharnein J, Asanjarani N, Shariatmanesh T. 2013. Taguchi L16 orthogonal array optimization for Cd (II) removal using Carpinus betulus tree leaves: Adsorption characterization. Int Biodeterior Biodegrad, 85: 66-77. https://doi.org/10.1016/j.ibiod.2013.06.010