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Optimization of Process Parameters for Microwave Drying of Yellow- and Purple-Fleshed Potatoes

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Abstract
The main objective of the present work was to study the optimization of microwave drying of potatoes that have different flesh colors. The effects of independent variables of microwave power (300, 450, 600 W), slice thickness (2–4, 6 mm), and steam blanching time (2, 5, 8 min) on the color, total phenolic content (TPC), antioxidant activity, starch ratio, and total monomeric anthocyanin content (TMA) were investigated by using the Response Surface Methodology (RSM). Before drying, potato slices that had different thicknesses were blanched in steam at 90 °C for indicated times. Optimization was applied to improve bioactive compounds, starch ratio, and color. The optimum drying parameters were determined as 300 W, 6 mm, and 8 min for purple-fleshed potatoes, and 450 W, 6 mm, and 2 min for yellow-fleshed potatoes. This study is beneficial to the development of the processing of potatoes in the food industry and provides more insights into the application of microwave drying technology.

Keywords Microwave drying · Potato · Response surface methodology · Total phenolic content · Total monomeric anthocyanin content

Introduction

Potato as an annual plant, is rich in vitamins and minerals as well as high in starch content. After being harvested, fresh potato tubers comprise roughly 80% water and 20% dry matter, of which starch makes up between 60 and 80 percent. Potatoes are rich in minerals including potassium, phosphorus, and magnesium as well as vitamins B1, B3, and B6. They also contain riboflavin, folate, and pantothenic acid (Ekin 2011; FAO 2008). In addition to these essential nutrients, some colored potato varieties contain phytonutrients such as polyphenols and anthocyanins. Purple and red-fleshed potatoes can be used as a new food source as antioxidants and colorants,

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and they also have many effects on human health, such as brain development and strengthening immunity (Yu et al. 2018; Zhang et al. 2020). Potatoes can be used directly as raw material, and also drying is applied to prevent quality losses and deterioration during post-harvest storage. While the moisture content of the potato decreases with the drying process, the microorganism activity that causes spoilage stops, while the enzyme activity slows down (Sidhu et al. 2019). In addition, the obtained potato powder can be used to produce both commercial and functional products (Waseem et al. 2022).

Potato powder is used in ready-to-eat products because it provides a great advantage compared to its raw form in terms of mixing homogeneously with the product and saving time. Therefore, interest in different drying techniques is increasing to minimize the quality losses that may occur in the final product after drying. Especially since microwave drying is fast and efficient, it has been preferred in food processing in recent years (Luo et al. 2019).

For long-term storage, potatoes are often dried to a low moisture level (Chen 2002). Three different methods were used to dry sweet potatoes: hot air drying (AD), microwave-vacuum drying (MVD), and microwave-spouted bed drying (MSBD). As a result of these methods, when the drying kinetics and product quality were examined, it was observed that MSBD and MVD were faster and product color was better preserved compared to AD (Yan et al. 2013). In another drying study on increasing microwave power and decreasing potato slice thickness, a significant yield was obtained in terms of time and quality characteristics (Azimi-Nejadian and Hoseini 2019). Purple cabbage's combined microwave and hot air drying process parameters (microwave density, hot air temperature, and dry moisture content) were optimized with the Response Surface Methodology (RSM). To determine the drying conditions of purple cabbage, DPPH antioxidant capacity, the anthocyanin content, rehydration ratio, chewiness, ΔE, and average drying rate were chosen as responses. The microwave density at 2.5 W/g, the moisture content of the conversion point at 4.0 g/g, and the hot air temperature at 55°C were determined as optimum process parameters of combined drying (Liu et al. 2021). It was studied that the optimization of hot air and microwave drying of *Asparagus officinalis* using the RSM, the microwave power, and slice thickness were chosen as process parameters in microwave drying, and reported that less drying time was obtained in microwave drying compared to hot air drying (Baltacıoğlu 2017). In addition, some pre-treatments are applied before drying to make the drying process most effective and to minimize the functional and physical negative effects. One of them is the blanching process. Drying of purple sweet potato in a drum dryer was examined and blanching with steam and water was applied as pre-treatments before drying. It was determined that functional compounds were better preserved during drying by applying pre-treatment, and browning, an important parameter, was found to be less (Nevara et al. 2019). It was observed that different drying techniques and pre-treatments yielded quite different results when the functional properties and quality of potato powders were examined by applying pre-treatments such as blanching and boiling in three different potato varieties before freeze-drying and oven drying (Buzera et al. 2022). Blanching, ultrasound, and ohmic heating were also used as physical pre-treatments to enhance the functional properties of purple-fleshed potatoes during drying (Karacabey et al. 2023).

In recent years, the application of different drying techniques and optimization of the process conditions in drying have gained importance to eliminate the quality loss of the final product and as well as to increase the shelf life of the product for commercial use (Maisnam et al. 2017). Microwave is a new technique compared to existing drying techniques. It is used both alone and in combination with combined drying methods, especially in fruit, vegetable, and grain products, to obtain high-quality final products (Baltacıoğlu 2017). The main purpose of this study is to provide the optimization of microwave drying for two different potato cultivars by using RSM, depending on three different independent variables of slice thickness, steam blanching time, and microwave power.

Materials and methods

Sample Preparation

Potatoes (*Solanum tuberosum* L.) fresh yellow (cv. Agria) and purple-fleshed potatoes (cv. İlkmor) were supplied from Nigde Omer Halisdemir University, Faculty of Agricultural Sciences and Technologies, and stored in a storage room at +4°C. After washing, potatoes were peeled and sliced with a household manual slicer (Sinbo Sto-6510, Turkey) according to the slice thicknesses obtained in the experimental design (Table 1). To prevent enzymatic browning in yellow-fleshed potatoes and to preserve anthocyanins in purple-fleshed potatoes, the potatoes were immersed in 1% citric acid solution and after making sure that the surface was completely wetted with the solution for a while, the potatoes were removed from the solution and steam blanched

Table 1 Box-Benkhen experimental design for microwave drying application

Experiment number	Microwave power (Watt)	Slice thickness (mm)	Steam blanching time (min)
1	600	6	5
2	450	4	5
3	600	4	2
4	450	2	8
5	300	4	8
6	300	6	5
7	300	4	2
8	300	2	5
9	450	2	2
10	450	6	8
11	600	2	5
12	450	6	2
13	450	4	5
14	450	4	5
15	600	4	8

at a temperature of 90 ± 2°C that provides enzyme inactivation as determined in the literature (Baltacıoglu and Coruk 2021). Then, according to the microwave power determined in the experimental design (Table 1), the samples were dried in a microwave oven (Samsung MS23K3515AW, Turkey) by opening the microwave door for 5 seconds every 30 seconds to prevent a sudden temperature rise (<70°C) to reduce the moisture level below 10%. After microwave drying according to the experimental design (Table 1), yellow and purple-fleshed potatoes were ground with the help of a kitchen grinder (HC100, Lavion, Turkey) and powder was obtained by sieving through a 150μm sieve (Marzuki et al. 2021). Potatoes dried at 40 °C in a laboratory oven (Termal, Turkey) without any pretreatment were used as control samples.

Experimental Design

RSM was used to optimize drying conditions. The box-Behnken model was selected for RSM analysis. The effect of three independent process parameters: thickness (X_1, mm), microwave power (X_2, W), and steam blanching time (X_3, t) were examined using RSM. The total number of microwave-drying of yellow and purple-fleshed potato experiments was 30, and three replicates at the center point of the design were conducted (Table 1). Minitab 17.1.0.0 was used for the experimental design, data analysis, and regression modeling. The independent variables were; X_1 (2, 4, and 6 mm), X_2 (300, 450, and 600 W), and X_3 (2, 5, and 8 minutes). The proposed model was shown in Eq.(1).

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_{11} + b_{22}X_{22} + b_{33}X_{33} + b_{12}X_{12} + b_{13}X_{13} + b_{23}X_{23} \quad (1)$$

where Y was the response of equation, b_0 was the constant coefficient, b_1, b_2, and b_3 were the linear coefficients, b_{11}, b_{22}, and b_{33} were the quadratic coefficients, b_{13}, b_{23}, and b_{12} were the interaction coefficients. The values of R^2, adjusted-R^2, and lack-of-fit of models were evaluated to check the model adequacies.

Solvent extraction

Bioactive compounds from potato powders were extracted using methanol (80 %, Sigma) containing 1% HCl (Honeywell, Germany). Yellow-fleshed powders were mixed with extraction solution at a dilution rate of 0.25 g/10 mL, and purple-fleshed samples were mixed with extraction solution at a dilution rate of 1 g/50 mL. The mixture was shaken at 40 rpm for 4 hours and centrifuged (Nüve brand NR 800R model NR 800R, Turkey) at 9000 g 4°C for 15 minutes to remove the clear part. The clear part was used for analysis (Coruk and Baltacıoğlu 2022).

Total phenolic content (TPC)

The method proposed by Baltacıoğlu et al. (2021) was used to determine and calculate the total amount of phenolic compounds in the extracts. 50 μL of the prepared extracts was taken and 50 µL of distilled water was added and vortexed. Then 0.75 mL of Folin-Ciocalteu solution (10%) was added and vortexed once more. Subsequently, 0.75 mL of saturated sodium carbonate (Na_2CO_3, 75 g/L) was added to the resulting mixtures and incubated for 1 h in the dark. Samples' absorbances were measured with a spectrophotometer (Evolution 300 UV-Vis spectrophotometer, Thermo Fisher, ABD) at 765 nm wavelength. Total phenolic content (TPC) results of samples were calculated in terms of "mg equivalent gallic acid/g dry matter". The total phenolic contents of the samples were determined in three parallels.

Antioxidant activity (AA)

In order to determine the antioxidant activity (AA) of the samples, the method used by Horuz et al. (2018) was applied. 100 µL of the extract was put into a test tube. Then, 3.9 mL of DPPH (2,2-diphenyl-1-picrylhydrazyl) solution was added and left for 30 min incubation in the dark. The absorbance of samples was measured with a spectrophotometer (Evolution 300 UV-Vis spectrophotometer, Thermo Fisher, ABD) at 515 nm. The percentage inhibition of samples was calculated using the following Eq. (2).

$$\%\text{Inhibition} = \frac{\text{Acontrol} - \text{Asample}}{\text{Acontrol}} x100 \tag{2}$$

$\mathbf{A_{control}}$: Absorbance of control
$\mathbf{A_{sample}}$: Absorbance of sample

Total Monomeric Anthocyanin (TMA) Content

The total monomeric anthocyanin (TMA) contents of dried potato powders were determined by the pH differential method (Coruk and Baltacıoğlu 2022). The absorbance value of the extract was measured at 520 and 700 nm using the UV–VIS spectrophotometer (Evolution 300 UV-Vis spectrophotometer, Thermo Fisher, ABD) for pH 1 (KCl buffer) and pH 4.5 (CH_3COONa buffer). Anthocyanin content was calculated by the following Eq. (3).

$$W = \frac{[(\text{A}_{520} - A_{700})_{pH_{1.0}} - (\text{A}_{520} - A_{700})_{pH4,5}] \times \text{Mw} \times \text{DF}}{\varepsilon \times \text{Wt}} \tag{3}$$

where W is the total monomeric anthocyanin content, Mw is molecular weight (449.2 g/mole for cyanidin-3-glucoside), DF is the dilution factor, ε is molar extinction coefficient (26,900/cm/mg for Cy-3G), A was obtained from measured absorbance values at 520 and 700 nm for pH 1 (KCl buffer) and pH 4.5 (CH_3COONa buffer), Wt is sampling volume, mL. The total monomeric anthocyanin content of the sample was calculated as "mg equivalent of cyanidin-3-glucoside/g dry matter". The total monomeric anthocyanin contents of the samples were assessed in two repetitions

Color

L*, a*, and b* values were determined using the Konica-Minolta (CR400, Osaka, Japan) colorimeter (Horuz et al. 2017).

Browning index (BI) is an important parameter in processes where enzymatic browning takes place and the brown color represents the deterioration of the product. BI values were calculated using equations (4) and (5) to determine the effect of drying on the browning of the yellow-fleshed potatoes (Maskan 2006). Furthermore, chroma values were calculated using equation (6) to determine the effect of drying on the purple-fleshed potatoes.

$$\mathrm{BI} = [100(\mathrm{x} - 0.31)]/0.172 \tag{4}$$

$$\mathrm{x} = (\mathrm{a}^* + 1.75\mathrm{L}^*)/(5.645\mathrm{L}^* + \mathrm{a}^* - 3.012\mathrm{b}^*) \tag{5}$$

$$\mathrm{Chroma} = \mathrm{C}^* = [(\mathrm{a}^*)^2 + (\mathrm{b}^*)^2]^{1/2} \tag{6}$$

Determination of Starch Ratio

In order to determine the starch ratio of the samples, the method used by Coruk and Baltacıoğlu (2022) was applied. Weighed 2.5 g of the dried sample with a precision balance and placed it in a 250 mL glass flask. Acid hydrolysis of starch was carried out for 15 min by adding 50 mL of 1.128 N HCl solution and keeping it in a beaker with boiling water. After the end of the time, 30 mL of water was added and left to cool in cold water. Then 5 mL Carrez I (Potassium hexacyanoferrate (II) trihydrate: 15%) and 5 mL Carrez II (Zinc sulfate heptahydrate: 30%) were added and mixed again. Then 10 mL of distilled water was added and the mixture was completed to 100 mL. The solution was filtered through filter paper and the filtrate was recorded by reading the optical rotation angle (α) observed with sodium D line light (589.3 nm) at 20°C with a polarimeter (Krüss, P 3000, Germany). The degree of optical conversion determined by polarimetry was substituted in Minitab (7) and % starch was calculated.

The starch ratio was measured as described previously (Coruk and Baltacıoğlu 2022). The determined optical rotation degree was substituted in equation (7) to calculate the starch ratio (%).

$$\%Starch = \frac{\alpha.2000}{(a)_{20}^{D}.L} \tag{7}$$

α: The degree of rotation read on the polarimeter

$(a)_{20}^{D}$: Specific degree of conversion of potato starch

L: Polarimeter tube length

Statistical Analysis

Minitab (Minitab 17.1.0.0, State College, PA, USA) statistical software was used for experimental design and optimization. Tukey's multiple comparison test was performed to determine whether there was a significant difference between the groups. As a result, optimum conditions for microwave drying of yellow and purple-fleshed potatoes were obtained from the experimental data.

Results and Discussion

When the physicochemical properties of fresh yellow-fleshed potato samples were analyzed, total phenolic content, antioxidant activity, browning index, and starch ratio (%) were found as 1298.29 ± 44.13 mg GAE / kg DW, 22.03 ± 0.21 % inhibition, 15.71 ± 0.72, 67.24 ± 0.19 %, respectively. In addition to this, total phenolic content, antioxidant activity, chroma value, starch ratio (%), and total monomeric anthocyanin amounts of purple-fleshed potato samples, were found as 2891.44 ± 4.88 mg GAE / kg DW, 25.9 ± 0.47 % inhibition, 11.25 ± 4.12, 72.41 ± 2.78 %, 2172.05 ± 204.31 mg cyanidin-3-glucoside / kg DW, respectively. The starch value in both yellow and purple-fleshed potatoes was found to be in the range of 13.5 – 15% on a fresh weight basis but on a dry weight basis, it is approximately 75 – 80% in the literature, which was similar to our study (Dupuis and Liu 2019). In the literature, the amount of total phenolic content in potato flesh ranged from 0.54 to 3.59 mg GAE / g DW for 60 potato varieties with different flesh colors (Valcarcel et al. 2015). It was observed that the values found in our study were in this range. Similarly, in similar studies, total monomeric anthocyanin amounts varied from 0.00126 to 0.436 g cyanidin-3-glucoside / kg DW depending on the variety (Tierno et al. 2016). Depending on the treatment applied to the potato, the chroma value was generally seen in the range of 10 to 20 in the studies (Rytel et al. 2019). The value found in our study was in this range, which was similar to the literature. Furthermore, in our study, the browning index value in the control sample was found to be lower than many studies in the literature (Bußler et al. 2017; Krishnan et al. 2010). It was thought that the browning index value may be different due to many variable factors depending on the type of raw material, slice thickness, pre-treatment applied, and drying temperature. The antioxidant activity values in yellow and purple-fleshed potato varieties were examined, purple-fleshed potatoes had higher antioxidant activity value than yellow-fleshed potatoes, and although it varied according to potato varieties, similar results were found in the literature with our study (Ru et al. 2019).

The physicochemical properties of microwave-dried powders of yellow and purple-fleshed potatoes were summarized in Tables 2 and 4. The optimization process was carried out with these obtained data. At the same time, the model coefficients were shown in Tables 3 and 5 which were created for each experimental data for optimization. The variety of potatoes had a significant effect on the TPC and AA of the powder. It was higher in microwave-dried purple-fleshed potato powder than in yellow-fleshed potato powder. It was expected to be high due to the anthocyanin contents of purple-fleshed potato powders.

Table 2 Experimental data on total phenolic content, antioxidant activity, browning index, and starch ratio of yellow-fleshed potato powders obtained for the required conditions

Experiment number	Microwave power (Watt)	Slice thickness (mm)	Steam blanching time (min)	Total phenolic content (mg GAE / kg dry weight)	Antioxidant activity (% inhibition)	Browning index (BI)	Starch ratio (%)
1	600	6	5	1083.02 ± 140.92	25.28 ± 3.62	40.11 ± 1.19	51.66 ± 0.05
2	450	4	5	824.25 ± 141.88	23.66 ± 3.45	43.65 ± 10.87	63.71 ± 4.99
3	600	4	2	760.05 ± 16.07	24.03 ± 3.46	39.28 ± 4.28	64.99 ± 0.61
4	450	2	8	851.22 ± 92.57	22.93 ± 4.29	33.51 ± 2.91	77.83 ± 14.52
5	300	4	8	1105.69 ± 263.30	22.67 ± 3.44	37.43 ± 0.50	58.70 ± 9.06
6	300	6	5	1161.42 ± 47.47	23.04 ± 0.71	46.56 ± 2.33	64.70 ± 6.85
7	300	4	2	1144.58 ± 135.38	23.78 ± 2.5	44.09 ± 7.91	63.81 ± 3.72
8	300	2	5	923.41 ± 29.30	22.39 ± 1.28	37.71 ± 0.26	64.99 ± 8.75
9	450	2	2	834.02 ± 170.88	22.00 ± 0.42	38.67 ± 0.39	74.98 ± 9.65
10	450	6	8	1065.42 ± 176.01	22.25 ± 0.57	49.98 ± 8.59	68.32 ± 4.62
11	600	2	5	752.24 ± 172.51	22.58 ± 1.14	37.28 ± 1.92	73.00 ± 9.35
12	450	6	2	1237.46 ± 24.79	25.30 ± 1.40	44.12 ± 2.49	61.43 ± 10.61
13	450	4	5	909.578 ± 83.20	23.07 ± 0.4	46.26 ± 11.48	59.41 ± 7.80
14	450	4	5	905.38 ± 170.86	23.39 ± 0.41	44.71 ± 0.08	59.96 ± 10.91
15	600	4	8	1112.48 ± 260.58	22.09 ± 0.93	42.90 ± 5.79	70.11 ± 2.15

Table 3 Estimated Regression Coefficients for total phenolic content, antioxidant activity, BI values and starch ratio of yellow-fleshed potato powders

Symbols	Total phenolic content (mg GAE / kg dry weight)		BI		Antioxidant activity (% inhibition)		Starch ratio (%)	
	Coefficients	p	Coefficients	p	Coefficients	p	Coefficients	p
β_0 Constant	879.7	0.000*	44.88	0.000*	23.375	0.000*	61.03	0.000*
β_1 Microwave Power (W)	-78.4	0.044*	-0.778	0.374	0.263	0.204	0.94	0.484
β_2 Slice Thickness (L)	148.3	0.004*	4.199	0.003*	0.746	0.009*	-5.59	0.006*
β_3 Steam Blanching Time (t)	19.8	0.529	-0.293	0.728	-0.648	0.016	1.22	0.372
β_{11} W*W	67.0	0.181	-2.55	0.082	-0.013	0.964	-1.84	0.361
β_{22} L*L	33.3	0.475	-1.91	0.165	-0.035	0.900	4.39	0.062
β_{33} t*t	84.0	0.109	-1.40	0.288	-0.214	0.455	5.22	0.036*
β_{12} W*L	-23.2	0.600	-1.51	0.239	0.513	0.100	-5.27	0.030*
β_{13} W*t	97.8	0.065	2.57	0.071	-0.207	0.453	2.56	0.206
β_{23} L*t	-47.3	0.306	2.76	0.058	-0.997	0.011	1.01	0.592
The Importance of the Model	0.043*		0.038*		0.033*		0.040*	
R^2 (%)	90.27		90.83		91.39		90.55	
R^2_{adj} (%)	72.76		74.32		75.88		73.55	

Table 4 Experimental data on total phenolic content, antioxidant activity, chroma, starch ratio and total monomeric anthocyanin content of purple-fleshed potato powders obtained for the required conditions

Experiment no	Microwave power (Watt)	Slice thickness (mm)	Steam blanching time (min)	Total phenolic content (mg GAE / kg dry weight)	Antioxidant activity (% inhibition)	Chroma	Starch ratio (%)	Total monomeric anthocyanin content (mg cyanidin-3-glucoside / kg dry weight
1	600	6	5	3740.51 ± 174.74	36.58 ± 3.96	10.01 ± 1.13	74.58 ± 0.39	2347.98 ± 153.30
2	450	4	5	4228.90 ± 285.97	38.72 ± 6.05	10.78 ± 0.68	69.83 ± 0.79	2371.25 ± 285.32
3	600	4	2	3949.33 ± 90.48	41.59 ± 3.39	10.00 ± 0.11	78.70 ± 6.50	2451.55 ± 97.64
4	450	2	8	4272.32 ± 34.00	37.53 ± 6.35	12.02 ± 1.92	80.93 ± 4.95	1511.71 ± 127.69
5	300	4	8	3979.85 ± 202.03	41.50 ± 1.50	11.47 ± 0.95	86.17 ± 9.98	2813.27 ± 36.96
6	300	6	5	4469.90 ± 412.25	44.39 ± 2.79	12.45 ± 3.09	75.59 ± 4.98	2303.54 ± 161.44
7	300	4	2	4570.60 ± 158.90	39.39 ± 4.13	11.43 ± 2.38	77.56 ± 8.62	2159.34 ± 9.90
8	300	2	5	3439.73 ± 214.91	37.31 ± 0.18	14.12 ± 1.41	80.29 ± 0.41	2735.94 ± 145.26
9	450	2	2	4047.95 ± 455.73	39.02 ± 2.20	12.94 ± 1.27	78.45 ± 3.70	2422.17 ± 145.69
10	450	6	8	4802.91 ± 71.00	41.38 ± 0.23	12.07 ± 3.73	66.59 ± 3.68	2328.28 ± 87.15
11	600	2	5	3801.06 ± 150.65	42.03 ± 8.25	11.07 ± 0.03	71.94 ± 9.62	1591.38 ± 77.73
12	450	6	2	4165.59 ± 153.48	36.48 ± 1.63	8.06 ± 1.24	74.95 ± 12.62	1673.30 ± 12.15
13	450	4	5	4663.94 ± 890.47	38.09 ± 1.56	10.50 ± 0.31	68.47 ± 12.78	2274.42 ± 42.71
14	450	4	5	4310.58 ± 347.48	38.25 ± 3.84	10.57 ± 0.68	67.47 ± 3.48	2376.57 ± 165.87
15	600	4	8	4823.45 ± 63.26	36.19 ± 2.09	10.05 ± 1.64	63.22 ± 8.0	2199.49 ± 15.87

Table 5 Estimated regression coefficients for total phenolic content, chroma, antioxidant activity, starch ratio and total monomeric anthocyanin content of purple-fleshed potato powders

Symbols	Total phenolic content (mg GAE / kg dry weight)		Chroma		Antioxidant activity (% inhibition)		Starch ratio (%)		Total monomeric anthocyanin content (mg cyanidin-3- glucoside / kg dry weight)	
	Coefficients	p	Coefficients	p	Coefficients	p	Coefficients	p	Coefficients	p
β_0 constant	4401	0.000*	10.622	0.000*	38.360	0.000*	68.59	0.000*	2340.7	0.000*
β_1 Microwave Power (W)	-18.2	0.809	-1.044	0.009*	-0.776	0.098	-3.90	0.020*	-177.7	0.032*
β_2 Slice Thickness (L)	202.2	0.037*	-0.943	0.014*	0.366	0.383	-2.49	0.084	49.0	0.452
β_3 Steam Blanching time (t)	143.1	0.102	0.397	0.180	0.015	0.971	-1.59	0.226	18.3	0.773
β_{11} W*W	-265	0.054*	0.380	0.358	1.392	0.056*	4.10	0.061	163.0	0.125
β_{22} L*L	-273	0.049*	0.917	0.058*	0.331	0.583	2.92	0.147	-259.0	0.033*
β_{33} t*t	195	0.124	-0.261	0.517*	-0.081	0.892	3.72	0.080	-97.8	0.319
β_{12} W*L	-273	0.043*	0.152	0.690	-3.132	0.002*	1.83	0.312	297.3	0.017
β_{13} W*t	366	0.015*	0.004	0.991	-1.877	0.018*	-6.02	0.014	-226.5	0.045*
β_{23} L*t	103	0.355	1.235	0.019*	1.596	0.032*	-2.71	0.158	391.4	0.006*
The Importance of the Model	0.036*		0.033*		0.021*		0.041*		0.022*	
R^2 (%)	90.98		91.29		92.92		90.44		92.75	
R^2_{adj} (%)	74.74		75.61		80.17		73.22		79.69	

Steam blanching had significant effect on the color of samples due to the inactivation of enzymes that affect color. In addition, starch ratios (%) showed similar results in both cultivars. The data obtained in the study showed similar results to other studies conducted on different sweet potato powders, indicating consistency with previous findings (Castro-Mendoza et al. 2022).

Effect of Process Parameters on TPC

The TPC of yellow-fleshed potato powders was found in the range between 752.24 to 1237.46 mg GAE/kg DW (Table 2). RSM analysis showed that the individual effects of microwave power and slice thickness on TPC were found to be significant (Table 3). High microwave power had a negative effect ($p<0.05$) on TPC of yellow-fleshed potato powder (Table 3) whereas slice thickness had a positive effect ($p<0.05$) on TPC of yellow-fleshed powder (Table 3). It can be said that low microwave power has a more protective effect on phenolic compounds because phenolic compounds are thermal-sensitive. A study reported that low microwave power had a protective effect on phenolic compounds. The TPC of the carrot samples dried with lower microwave power levels of 150 and 200 W was found to be relatively better preserved (Keser et al. 2020).

At the same time, the TPC of microwave-dried purple-fleshed potato powders was in the range of 3439.7 to 4823.4 mg GAE / kg (Table 4). According to the RSM analysis (Table 5), the linear term of slice thickness was found to have a significant ($P<0.05$) impact on TPC. Previous studies (Song et al. 2009; Azimi-Nejadian and Hoseini 2019) have shown that slice thickness has a significant effect on drying kinetics. In addition, quadratic terms of microwave power and slice thickness had a significant ($P<0.05$) effect on TPC. Moreover, the interaction between microwave power and slice thickness, microwave power, and steam blanching time had significant effects ($P<0.05$) on TPC. When the interaction between microwave power and slice thickness was examined, it was observed that high slice thickness and low microwave power increased TPC of samples (Fig. 1a). Similarly, low microwave power and high slice thickness increased the total phenolic content of quince. This could be due to the waves emitted from the microwave gradually passing into the potato pieces at high slice thickness and low microwave power, and in this way, the phenolic compounds were more protected (Baltacioglu et al. 2015). When the interaction between microwave power and steam blanching time (Fig. 1b) was examined, it was observed that high blanching time and microwave power increased TPC of samples. This could be because high blanching time increased the moisture removal from the tissues so high microwave power may not cause damage to phenolic compounds during microwave drying (Fig. 2). In addition, high steam blanching time may preserve phenolic compounds by inactivating enzymes that use phenolic compounds as substrates (Horuz et al. 2017).

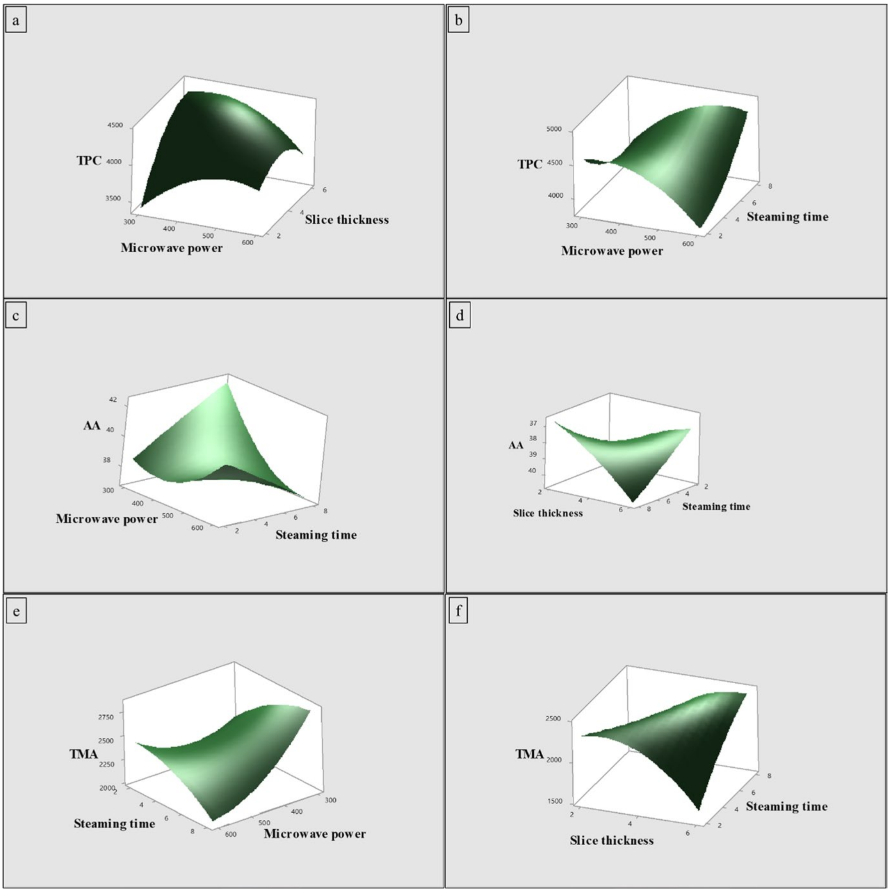

Fig. 1 Response surface plots showing the effect of microwave power and slice thickness (**a**), microwave power and steam blanching time (**b**) on total phenolic content; the effect of microwave power and steam blanching time (**c**), slice thickness and steam blanching time (**d**) on antioxidant activity; the effect of microwave power and steam blanching time (**e**), slice thickness and steam blanching time (**f**) on total monomeric anthocyanin content

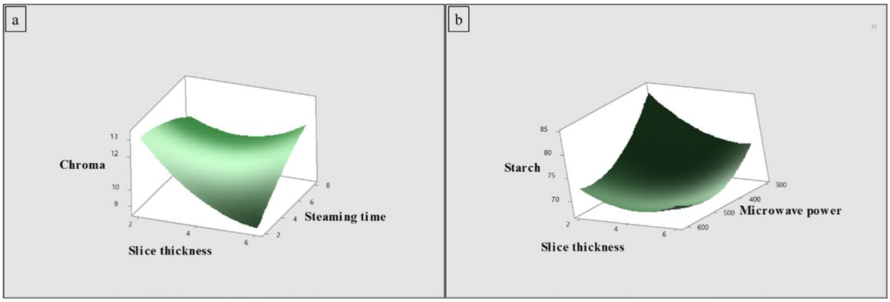

Fig. 2 Response surface plots showing the effect of steam blanching time and slice thickness (**a**) on chroma value, the effect of microwave power and slice thickness (**b**) on starch ratio

Effect of Process Parameters on AA

The antioxidant activity of the samples has been tested by DPPH. Antioxidant activity (inhibition %, measurements of the capacity of antioxidants to scavenge DPPH radicals) of microwave-dried yellow-fleshed potato powder was from 22 to 25.3% (Table 2). According to the RSM analysis (Table 3) linear term of slice thickness had a significant ($P<0.05$) impact on AA. This effect was shown in Figure 3a. For yellow-fleshed potatoes, as the slice thickness increased, the amount of antioxidants also increased. This increase can be explained by the amount of surface area. As the slice thickness increased, similar results were obtained for the antioxidant activity of kumquat during drying (Özkan Karabacak et al. 2022).

For example, values of AA for microwave-dried purple-fleshed potato powder varied between 36.19 and 44.39 % (Table 4). The interactions between factors changed the results more than the individual effects. For yellow-fleshed potato powder, slice thickness alone was found to be high in terms of AA, whereas, for purple-fleshed potato powder samples, the interactions between factors were more important. When the interaction between microwave power and steam blanching time (Fig. 1c) was examined, AA increased at high steam blanching time and low microwave power. This was due to the high steam blanching time loosened the tissues, low drying energy was sufficient and the preservation of bioactive components increased, which was a factor that increased AA. In a study, similar results were reported that microwave vacuum drying, as an application at low powers, was more effective in preserving the antioxidant content in citrus peels compared to hot air drying (Shu et al. 2020). When the interaction between slice thickness and steam blanching time on the AA of purple-fleshed potato powder (Fig. 1d) was examined, the interaction of high slice thickness and long steam blanching time increased antioxidant activity ($P<0.05$). The increase in antioxidant content due to the interaction of high slice thickness and long steam blanching time suggested that both the quantitative amount in slice thickness and the lower energy input during drying with long blanching time helped to preserve bioactive components (Azizah and Febrianto 2022).

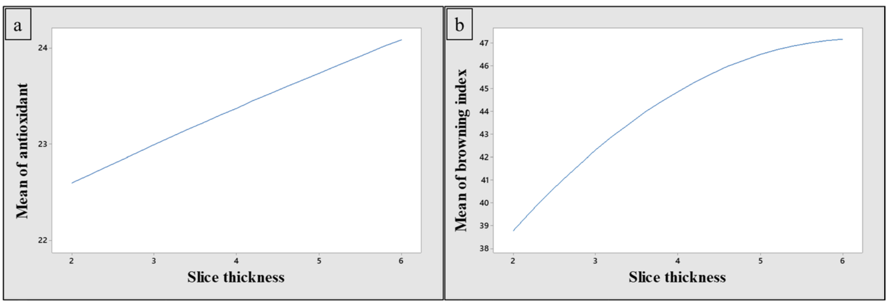

Fig. 3 Main effect plot showing the effect of slice thickness on antioxidant activity for microwave-dried yellow-fleshed powder (**a**), Main effect plot showing the effect of slice thickness on browning index for microwave-dried yellow-fleshed powder (**b**)

Effect of Process Parameters on TMA Content for Purple-Fleshed Potato Powder

Since anthocyanin is a heat-sensitive compound, it can be degraded during the drying of foods. For this reason, the drying process should be carried out in such a way that anthocyanins do not break down. The anthocyanin amounts of microwave-dried purple-fleshed potato powder were in the range from 1511.71 to 2813.27 mg cyanidin-3-glucoside / kg DW (Table 4). According to the RSM analysis (Table 5) linear term of microwave power was found to have a significant ($P<0.05$) impact on TMA content. The reason why microwave power was found to be important on anthocyanins can be said to be due to the interaction between microwave power and drying time (Zia and Alibas, 2021). In addition to the interaction between microwave power and steam blanching time, slice thickness and steam blanching time interaction had a significant effect ($P<0.05$) on TMA content. When the interaction between microwave power and steam blanching time (Fig. 1e) was examined, it was observed that high blanching time and low microwave power increased (~2750 mg cyanidin-3-glucoside / kg DW) TMA content of the powder. High blanching time preserved anthocyanins by enzyme inactivation (Jiang et al. 2020). When at the same time interaction between steam blanching time and slice thickness (Fig. 1f) was examined, it was observed that high steam blanching time and high slice thickness increased TMA content. Similarly, both steam blanching and thick slice thickness provide low-power microwave drying, minimizing the negative effects of temperature and protecting the anthocyanin components (Zhang et al. 2019; Zhang et al. 2014).

Effect of Process Parameters on BI for Yellow-Fleshed Potato Powders

The BI of microwave-dried yellow-fleshed potato powder was changed from 33.51 to 49.98 (Table 2). According to the RSM analysis (Table 3), linear terms of slice thickness were found to have a significant ($P<0.05$) impact on BI. As the slice thickness increased, an increment in BI value was observed (Fig. 3b). As the slice thickness increased, the distance required for water molecules to leave the cell increased, so the drying time could be longer and this caused an increment in BI value (Ndisya et al. 2020).

Effect of Process Parameters on Chroma Value for Purple-Fleshed Potato Powders

Color protection is important in the drying process. The color change can be given in different ways for dried products. In this study, color was given as chroma value which is related to color's purity, intensity, or saturation for microwave-dried purple-fleshed potato powder which ranged from 8.06 to 14.12 (Table 4). According to the RSM analysis (Table 5), linear terms of microwave power and slice thickness were found to have a significant ($P<0.05$) impact on chroma value. The chroma value is related to the anthocyanin (natural pigment) value for purple flesh-colored potatoes. Therefore, the breakdown of anthocyanins affects the chroma value. Chroma value is significantly impacted by variables that affect drying time, such as microwave power and slice thickness during drying, which also affects anthocyanins (Kasim et al. 2011). In addition, the interaction between slice thickness and steam blanching time had a significant effect (P<0.05) on chroma. The interaction between steam blanching time and slice thickness was examined (Fig. 2a): as the slice thickness and steam blanching time decreased, the chroma value increased, and vice versa. The chroma value was preserved because long blanching time inactivated the enzymes that damaged anthocyanins. Similar behaviors were also reported in bitter gourds (Zahoor et al. 2023).

Effect of Process Parameters on Starch Ratio (%)

Starch is one of the main nutrients in products such as potatoes. The starch ratio of microwave-dried yellow-fleshed potato powder was from 51.66 to 77.83 % (Table 2). According to the RSM analysis (Table 3) the linear term of slice thickness was found to have a significant (P<0.05) impact on the starch ratio. In addition, slice thickness and microwave power interaction had a significant effect (P<0.05) on the starch ratio. When the interaction between microwave power and slice thickness (Fig. 2b) was examined, it showed that low microwave power and low slice thickness increased the starch ratio of the powder. Drying at high microwave power had a positive effect on starch by minimizing the deformation of starch granules and the disintegration of the cell wall since it was carried out in a shorter time (Bondoruk et al. 2007).

On the other hand, the starch ratio of microwave-dried purple-fleshed potato powder was changed from 63.22 to 86.17 % (Table 4). The effect of microwave power alone during the drying of purple-fleshed potato was found to be significant and the starch ratio decreased with the increase of microwave power. It has been observed through a lot of studies that the structure of starch granules was influenced by various factors (Yao et al. 2020). In yellow-fleshed potatoes, low slice thickness combined with high microwave power had a positive effect on starch content, while the sole effect of microwave power caused the fragmentation of starch granules, resulting in a decrease in starch content (Kumar et al. 2020).

Optimum Drying Conditions

Optimum drying conditions were chosen to improve the quality of powders. For this purpose TPC, AA, TMA content, starch ratio, and chroma values were maximized, and BI values were minimized. Optimum drying conditions for yellow-fleshed potatoes were determined as 450 W, 6 mm, and 2 minutes; that of purple-fleshed potatoes were determined as 300 W, 6mm, and 8 minutes for microwave power, slice thickness, and steam blanching time. TPC, AA, BI, and starch ratio (%) values that should be in optimum conditions for yellow-fleshed potato were found as 1208.28 mg GAE / kg DW, 25.30 % inhibition, 44.22, and 64.20, respectively. For purple-fleshed potatoes, the expected TPC, AA, TMA content, starch ratio, and chroma values under optimum conditions were found as 4430.61 mg GAE / kg DW, 47.76 % inhibition, 2712.47 mg cyanidin-3-glucoside / kg DW, 80.61 %, 13.23, respectively.

Similarly, the functional properties of sweet potatoes were optimized during convective drying (Savas 2022). Response surface methodology (RSM) was used in this study to estimate changes in water activity (aw), moisture content (MC), rehydration capacity (Rc), shrinkage (Sb), and color qualities to optimize drying parameters (temperature, thickness, and time). Optimum parameters were found to be 63.79 ◦C, 4.78 h, 3 mm.

Conclusion

In this study, yellow and purple-fleshed potatoes were dried under several conditions according to experimental design in a microwave dryer. RSM was used to analyze and optimize the effect of microwave drying parameters on product quality. Optimized parameters were microwave power, slice thickness, and steam blanching time. It was seen that individual effects and interactions of drying parameters affected the drying process in different directions. Optimization with RSM was a suitable option to determine the effects of multiple factors affecting the drying conditions and to aggregate these conditions under a single parameter. From the results obtained in this study, the optimum points for microwave drying conditions of yellow and purple-fleshed potatoes were found. In addition, although the drying conditions had independent effects, the optimization evaluated these effects as a triple parameter, and a clear conclusion was reached. At the same time, it was thought that the optimization made by microwave drying has given a new perspective to the literature.

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Author contributions Katibe Sinem Coruk: Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal).

Hande Baltacıoğlu: Conceptualization (equal); funding acquisition (equal); project administration (equal); methodology (equal); supervision (equal); writing – original draft (equal); writing – review and editing (equal).

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Data Availability The data that support the findings of this study are available from the corresponding author, Hande Baltacioglu, upon reasonable request.

Declarations

Conflicts of Interest The authors declare no conflict of interest.

Ethical statement Ethics approval was not required for this research.

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