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Research Paper / Araştırma Makalesi

Optimization of Drying Parameters in the Production of Purple Carrot Puree Powder

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ABSTRACT

Purple carrots are an important source of phenolic compounds and spray drying is the most advantageous method to make purple carrots more stable. Optimization analysis was carried out to determine the effects of inlet temperature, pump rate, and maltodextrin concentration on the process yield, antioxidant activity, total phenolic and anthocyanin content in the purple carrot puree powder. The optimum drying parameters obtained by maximizing the dependent variables (desirability=0.809) were determined as 16.51% (w/v) maltodextrin concentration, 180.16°C inlet temperature, and 30.39% pump rate. Process yield was 83.64%. Under optimum conditions, the dependent variables were 81.20% DPPH scavenging antioxidant activity, 5332.87 ppm total phenolic content as gallic acid equivalent, and 449.71 ppm total anthocyanin content as cyanidin-3-glucoside, and results indicated that they were preserved at 92.66, 90.43 and 83.79%, respectively.

Keywords: Experimental design, Antioxidant activity, Total phenolic content, Anthocyanin content

Mor Havuç Püresi Tozu Üretiminde Kurutma Parametrelerinin Optimizasyonu

ÖZ

Mor havuç, önemli bir fenolik bileşik kaynağıdır ve mor havucu daha stabil hale getirmek için püskürterek kurutma en avantajlı yöntemdir. Mor havuç püresi tozunda giriş sıcaklığı, pompa hızı ve maltodekstrin konsantrasyonunun proses verimi, antioksidan aktivite, toplam fenolik ve antosiyanin içeriği üzerindeki etkilerini belirlemek için optimizasyon çalışması yapılmıştır. Bağımlı değişkenlerin (arzu edilebilirlik=0.809) maksimize edilmesiyle elde edilen optimum kurutma parametreleri şu şekilde belirlenmiştir: maltodekstrin konsantrasyonu %16.51 (a/h); giriş sıcaklığı 180.16°C, pompa hızı %30.39. Proses verimi %83.64 olarak bulunmuştur. Optimum koşullarda, bağımlı değişkenler şu şekildedir: antioksidan aktivite (DPPH) %81.20; toplam fenolik madde (gallik asit eşdeğeri olarak) 5332.87 ppm; toplam antosiyanin içeriği (siyanidin-3-glukozit olarak) 449.71 ppm. Buna göre optimum koşullarda, incelenen bu parametreler sırasıyla %92.66, %90.43 ve %83.79 oranlarında korunmaktadır.

Anahtar Kelimeler: Deneysel tasarım, Antioksidan aktivite, Toplam fenolik içeriği, Antosiyanin içeriği

INTRODUCTION

Carrot (*Daucus carota*) is a biennial of the *Umbelliferae* family that contains vitamins and dietary fiber and is widely used in daily diet. The consumption rate of purple carrots greatly varies among countries. Turkey is the world's leading purple carrot producing country and its production of purple carrots is constantly increasing due to demand by the pigment and functional food industries [1-3].

Purple carrots with an attractive red-purple color are particularly used in the production of anthocyanin-rich concentrates for the pigment industry [4]. Purple carrot extracts have a wide range of uses as a healthy alternative to synthetic colorants used in fruit juices, candies, ice creams, jams, marmalade, Turkish delights, beverages, sauces, and soup mixes [5].

Purple carrots contain high amounts of, mainly acylated, anthocyanins (45.4- 17400 mg/kg dry matter) and other phenolic acids that are excellent sources of functional compounds [5]. In this context, it has been reported that the purple carrot has approximately 3 times more antioxidant capacity than the orange carrot [6]. Anthocyanins are pigments sensitive to environmental factors, they are highly unstable components and have first-order degradation kinetics, and therefore, they decrease exponentially over time and must be stabilized and protected against adverse conditions. Additionally, purple carrots have high moisture content in fresh or mashed form, so they are susceptible to microbial spoilage in the cold and even under controlled atmosphere storage conditions [7]. To prolong the shelf life, the high moisture content should be reduced using various methods [6]. As a result, the dried product is valued as an important source for many processed ready-made food products.

Various methods are suggested for drying vegetables in the literature, among which the spray drying method, which offers the opportunity to produce a quality product with low water activity, weight, and ease of storage and transportation, stands out due to its advantages. By adjusting spray drying conditions according to raw material properties, both heat-resistant and heat-sensitive components can be sufficiently preserved. The properties of the vegetable powders obtained using this process mainly depend on the air inlet temperature, feed flow rate, and carrier agent concentration [8]. However, when drying vegetables with high organic acid and sugar content with this method, the product sticks to the cyclone walls, decreasing quality, and yield. To eliminate this negativity and to obtain the powder with high efficiency, the most appropriate approach is to use drying aids that can increase the glass transition temperature of the product. Among these substances, maltodextrin (MD) stands out in terms of cost and effectiveness [9].

Response surface methodology (RSM) is a modeling method used to find the optimum values of independent variables within the scope of dependent variables, especially in studies for optimization [10-12]. In this research, the process parameters (air inlet temperature, pump rate, and MD concentration) were optimized by RSM within the scope of the powder obtained by spray-drying purple carrot puree on antioxidant activity, total phenolic, and anthocyanin content.

There is a lack of literature on the production of a high-content powder with elevated antioxidant activity, total phenolic content, and anthocyanin content through the spray drying process of purple carrot puree. Thus, the novelty of this study is manifested in filling this research gap. By examining the impacts of optimized spray drying conditions on the aforementioned parameters, this research seeks to enhance the knowledge regarding the utilization of purple carrot powder as a valuable resource in the realm of processed food products.

MATERIALS and METHODS

Materials

Purple carrot puree (91.07% wb. moisture content, 7.99 °Brix, 6.39 pH, 0.11% titratable acidity, and 2.5 Bostwick) and MD (NutriDex-18, produced by Omnia Starch, Adana, Turkey) with 18-20 dextrose equivalents (DE) used in the research were kindly donated by Tunay Foods, Erzincan, Turkey, and Durukan Confectionery, Ankara, Turkey, respectively. BUCHI B-290 Mini Spray Dryer (BÜCHI Labortechnik AG, Switzerland) with drying gas flow 40 kg/h, evaporation capacity 1 L.H_2O/h, particle-size diameter 1-25 µm, smallest sample 30 mL, collection system cyclone. All of the chemicals were analytical grade and purchased from Sigma-Aldrich.

Preparing the Feed

The mash was first diluted with 1/4 water and filtered to obtain a consistency suitable for feeding into the spray dryer. 100 mL of the prepared solution was taken into glass bottles, MD was added at the rates determined in the trial plan, and mixed at 600 rpm for 10 min (Heidolph MR Hei-Standard), and the MD was completely dissolved. All of the samples were fed into the instrument at room temperature.

Experimental Design

A 3-factor and 3-level Box-Behnken Design consisting of 15 experimental runs with 3 replicates at the center point (Table 1) to be used for powdering purple carrot puree in a spray dryer were created with RSM in Design Expert 11.0 software (Stat-Ease Inc., ABD). The experimental study order was completely randomized. A quadratic Eq. (1) is used to express the dependent variables as a function of the independent variables.

$$Y_k = ß_{k0} + \sum_{i=1}^{n} ß_{ki}x_i + \sum_{i=1}^{n} ß_{kii}x_i^2 + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} ß_{kij}x_ix_j \qquad (1)$$

where Y_k = dependent variable, Y_1 = Process yield (%), Y_2 = Antioxidant activity, Y_3 = Total phenolic content, Y_4 = Total anthocyanin content; x_1 = concentration of MD, x_2 = inlet air temperature, x_3 = pump rate; β_{ko} was the value of the fitted response at the center point of the design, $\beta_{ki,kii,kij}$ are the regression coefficients, respectively. Statistical significance was determined by analysis of variance (ANOVA) at a 95% confidence level. The adequacy of the model was checked with R^2 values. The desired targets were (Y_1 is within range and all other responses max) selected for each variable and response.

In the trial plan, MD concentration (15%-35% w/v), inlet temperature (170-190°C), and pump rate (20%-40%) were independent variables; process yield, antioxidant activity, total phenolic substance content, and total anthocyanin content were dependent variables. The constant process parameters in the spray dryer were used as 100% aspirator rate (35 m^3/h) and 40 mm airflow volume (667 L/h).

Analysis of Powder

The following analyses were performed in 3 replications-3 parallel to 15 different purple carrot powders obtained with the trial plan in Table 1. The same analyses were performed on the purple carrot puree feed, and the protection levels of the chemical parameters determined in the final product were revealed.

Extract Preparation for Antioxidant Activity and Total Phenolic Content Analysis

One gram of powder was mixed with 10 mL of distilled water in an orbital shaker (Heidolph Unimax 2010) at 350 rpm for 15 min. At the end of the period, the samples were kept in an ultrasonic water bath (ISOLAB Laborgerate GmbH) at 20°C for 30 min and then centrifuged (Hettich Zentrifugen-Universal 320R) at 5000 rpm at 20°C for 10 min and the supernatants were used as extracts [13].

Total Phenolic Content

Total phenolic content (TPC) in powder extracts was determined using the Folin-Ciocalteu method described by Slinkard and Singleton [14]. After vortexing (Heidolph D-91126) 60 µL of extract, 4.75 mL of distilled water, 300 µL of Folin-Ciocalteu reagent, and 750 µL of 20% (w/v) sodium carbonate mixture, was incubated (Nüve, EN 400) at 40°C for 30 min. At the end of the period, absorbances were read at 765 nm in the UV-Vis spectrophotometer (Shimadzu UV-1602). The total phenolic content of the samples was expressed as ppm gallic acid equivalent (GAE) by using the calibration chart (y = 0.0011x + 0.0808, R^2 = 0.9989) prepared with 25, 50, 100, 200, 300, 400 and 500 ppm gallic acid standard solutions.

Antioxidant Activity

The antioxidant activity (AOA) was determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method determined by Brand-Williams et al [15]. 100 µL of extract and 3.9 mL of 6×10^{-5} M DPPH solution were vortexed and after 30 min of incubation in the dark, the absorbances of the samples were read in a UV-Vis spectrophotometer at 515 nm. The DPPH scavenging activity (%) was calculated with Eq. (2).

$$DPPH\ scavenging\ activity\ (\%) = \frac{(Abs_{control} - Abs_{sample})}{Abs_{control}} * 100 \quad (2)$$

Total Anthocyanin Content

Total anthocyanin content (TAC) was determined according to the method described by Wang and Xu [16]. 0.5 g of powder was diluted in 50 mL of 2 different buffers (0.025 M potassium chloride (pH = 1.0) and 0.4 M sodium acetate (pH = 4.5)) and it was incubated for 2 h in the dark at room temperature. Absorption (A) was measured at 521.5 and 700 nm. The total anthocyanin content was calculated as ppm cyanidin-3-glucoside (Cn-3G) equivalent according to Eq. (3).

$$Total\ anthocyanin\ content\ (ppm) = \frac{A * MW * DF * 1000}{\varepsilon * l} \quad (3)$$

where A = $(Abs_{@521.5\ nm} - Abs_{@700\ nm})_{pH\ 1.0} - (Abs_{@521.5\ nm} - Abs_{@700\ nm})_{pH\ 4.5}$, MW is the molecular weight of Cn-3G, DF is the dilution factor, 1000 is the conversion factor, ε is the molar extinction coefficient of Cn-3G, and l is the path length (cm).

Process Yield

The yield (PY) of the powder product obtained according to the amount of feed was determined as a percentage on a dry matter basis.

RESULTS and DISCUSSION

Processing purple carrot puree under different spray drying conditions has resulted in different values for the measured dependent variables (PY, AOA, TPC, and TAC). According to the results presented in Table 1, purple carrot puree processed under different drying conditions exhibited variable ranges for PY (82.59% to 97.14%), AOA (76.575% to 83.213%), TPC (2777.58 to 5929.09 ppm GAE), and TAC (279.628 to 461.02 ppm Cn-3G). These findings indicate that different drying methods have diverse effects on the antioxidant activity, total phenolic, and anthocyanin content of purple carrot samples, in comparison with studies reported in the literature. While there are numerous articles in the literature on drying orange carrots or encapsulating their carotenoid content, studies on purple carrots are comparatively limited [17-21].

Janiszewska et al [18] investigated the effect of different drying methods (convective, microwave-convective, infrared-convective, and freeze) on the physical properties of purple carrot puree and found that vacuum drying method preserved the physical properties of the puree the best. Macura et al [19] examined the effect of freeze-drying and air-drying on purple carrots during the storage process. The research results showed that both freeze-drying and air-drying had similar effects on the carotenoid and anthocyanin content of purple carrots. Both methods were effective in preserving the levels of carotenoids and anthocyanins in purple carrots. In a different study, Wright et al [20] demonstrated that consumption of dried purple carrots led to significant improvements in weight, lipids, blood pressure, body composition, and inflammatory markers. The group consuming dried purple carrots showed weight loss, reduction in fat mass, decrease in lipid levels, and decrease in inflammatory markers. Additionally, Kidoń and Uwineza [21] focused on the potential of dried purple carrots as a source of bioactive compounds in new smoothie products based on pumpkin, banana, and purple carrot. The research findings indicated that adding dried purple carrot to smoothie products increased their bioactive compound content. Dried purple carrots contain high levels of antioxidants, phenolic compounds, and anthocyanins, which provide health benefits. These findings emphasize the significance of selecting appropriate drying methods for preserving the antioxidant activity and nutritional components of purple carrot puree. Furthermore, a study conducted by Uyan et al [22] addresses the impact of the drying process on the antioxidant activity of purple carrots.

Table 1. Design of experiment and results of dependent variables*

Std	Run	MD concentration (%)	Inlet temperature (°C)	Pump rate (%)	PY (%)	AOA (%DPPH scavenging activity)	TPC (ppm GAE)	TAC (ppm Cn-3G)
3	1	15	190	30	86.26	80.36	5929.09	380.26
8	2	35	180	40	88.84	78.40	2959.39	326.26
9	3	25	170	20	91.16	78.11	3865.45	348.78
11	4	25	170	40	86.96	81.77	3762.42	368.96
7	5	15	180	40	82.59	79.26	5592.73	380.35
13	6	25	180	30	84.92	82.87	3904.85	401.36
10	7	25	190	20	94.10	81.38	3650.30	377.06
5	8	15	180	20	89.17	76.57	5923.03	439.26
12	9	25	190	40	80.26	77.87	3816.97	341.26
15	10	25	180	30	84.26	83.21	3413.94	460.03
14	11	25	180	30	85.01	82.92	3777.58	461.02
2	12	35	170	30	92.36	82.06	2844.24	282.26
1	13	15	170	30	84.60	79.65	5556.36	417.93
6	14	35	180	20	97.14	81.38	2877.58	279.62
4	15	35	190	30	89.07	80.26	2777.58	297.66

*: PY: Process Yield, AOA: antioxidant activity, TPC: Total phenolic content, TAC: Total anthocyanin content

The main distinction of this study lies in the direct processing of purple carrot puree using the spray drying method. This approach minimizes the exposure time of the puree to high temperatures, thus reducing the degradation and loss of components through a rapid drying process. Spray drying creates a thin spray layer, increasing the surface area and facilitating the rapid evaporation of water. As a result, valuable components in purple carrot puree, such as anthocyanins and phenolic compounds, are preserved more effectively. Additionally, the spray drying method offers advantages such as short processing time and low energy consumption. This study demonstrates the positive impact of spray drying on the antioxidant activity, phenolic, and anthocyanin content of purple carrot puree. Consequently, spray drying can be considered as a more efficient and effective option for processing purple carrot puree.

To improve the properties of the powder obtained by spray-drying purple carrot puree, the optimization of the processing conditions was carried out with BBD. Significant model terms, including A, B, C, AB, AC, BC, A^2, B^2, and C^2, were identified for each dependent variable (see Eq. 4-7), and the ANOVA results of these quadratic models are presented in Table 2.

Here, the F and p values associated with the models were utilized to determine statistically significant factor effects. The model F-values of PY, AOA, TPC, and TAC indicated that the model was significant. For statistical models, an F value less than 0.05 indicates the importance of the terms, a P value less than 0.05 indicates the significance of the terms, the lack of fit value indicates the suitability of the model, and the R^2, AdjR^2, Pred R^2>0.80 values indicate the statistical significance of the designed model (Table 3).

The second-order polynomial equations obtained from the experiments, along with their respective coefficients, for PY (Eq. 4), AOA (Eq. 5), TPC (Eq. 6), and TAC (Eq. 7) are provided below.

$$Y_1 = 84.73 + 3.10 * A - 0.67 * B - 4.11 * C - 1.24 * AB - 0.43 * AC - 2.41 * BC + 2.33 * A^2 + 1.01 * B^2 + 2.38 * C^2 \quad (4)$$
$$Y_2 = 83.00 + 0.78 * A - 0.21 * B - 0.02 * C - 0.63 * AB - 1.42 * AC - 1{,}79 * BC - 1.65 * A^2 - 0.77 * B^2 - 2.45 * C^2 \quad (5)$$
$$Y_3 = 3698.79 - 1{,}44 * A + 18{,}18 * B - 23{,}11 * C - 11.85 * AB + 103.03 * AC + 67.42 * BC + 571.21 * A^2 + 6.82 * B^2 + 68.18 * C^2 \quad (6)$$
$$Y_4 = 440.80 - 53.99 * A - 2.71 * B - 3.49 * C + 13.27 * AB + 26.39 * AC - 13.99 * BC - 49.45 * A^2 - 46.82 * B^2 - 34.97 * C^2 \quad (7)$$

where, A is the MD concentration, B is the inlet ait temperature, and C is the pump rate.

Optimization criteria A, B, C, and Y_1 "in range"; $Y_{2,\ 3,\ 4}$ were determined at the same level of importance as "maximize". Optimum processing parameters (desirability=0.809) were obtained as 16.5101% MD concentration, 180.155°C inlet temperature and 30.387% pump rate. Thus, these processing conditions were determined as the optimum levels of the independent variables in the experimental plan. Under these conditions, the results of the analysis were determined as 83.6414% PY, AOA value 81.19% DPPH scavenging activity, TPC value 5332.87 ppm GAE, and TAC value 449.714 ppm Cn-3G. Purple carrot puree, the powder produced with this puree under optimum spray drying conditions, and the aqueous and acidic aqueous solutions of this powder are given in Figure 1.

Table 2. ANOVA of quadratic model terms of responses*

	Sum of Squares	df	Mean Square	F-value	p-value	Inference
PY						
Model	285.66	9	31.74	41.58	0.0004	significant
Residual	3.82	5	0.7634			
Lack of Fit	3.48	3	1.16	6.89	0.1293	not significant
Pure Error	0.3365	2	0.1683			
AOA						
Model	58.64	9	6.52	72.52	<0.0001	significant
Residual	0.4492	5	0.0898			
Lack of Fit	0.3828	3	0.1276	3.84	0.2135	not significant
Pure Error	0.0665	2	0.0332			
TPC						
Model	46605.00	9	5178.33	10.77	0.0088	significant
Residual	2403.57	5	480.71			
Lack of Fit	69.30	3	23.10	0.0198	0.9951	not significant
Pure Error	2334.27	2	1167.14			
TAC						
Model	1.798E+07	9	1.998E+06	57.59	0.0002	significant
Residual	1.735E+05	5	34695.62			
Lack of Fit	43670.89	3	14556.96	0.2243	0.8737	not significant
Pure Error	1.816E+07	14				

*: PY: Process Yield, AOA: antioxidant activity, TPC: Total phenolic content, TAC: Total anthocyanin content

Table 3. Model summary statistics*

Dependent variables	Model	R^2 value	Adj R^2	Pred R^2
PY	quadratic	0.9868	0.9631	0.8050
AOA	quadratic	0.9924	0.9787	0.8938
TPC	quadratic	0.9510	0.8627	0.8702
TAC	quadratic	0.9904	0.9732	0.9454

*: PY: Process Yield, AOA: antioxidant activity, TPC: Total phenolic content, TAC: Total anthocyanin content

The final moisture content of the powder produced from purple carrot puree, which initially had a moisture content of 91.07%, has been reduced to 6.01% with optimal spray drying conditions. It can be observed that the moisture content has been reduced by 93.40% through spray drying, and the powdered product has become more stable. The AOA, TPC, and TAC contents in purple carrot puree were determined as 87.63%, 5896.97 ppm, and 536.69 ppm, respectively. These results indicate that under the recommended conditions, they were preserved at 92.66%, 90.43%, and 83.79%, respectively. BBD and comparison percentage results showed that the value ranges used in the research were statistically significant on yield, antioxidant activity, total phenolic, and total anthocyanin content of the purple carrot puree powder.

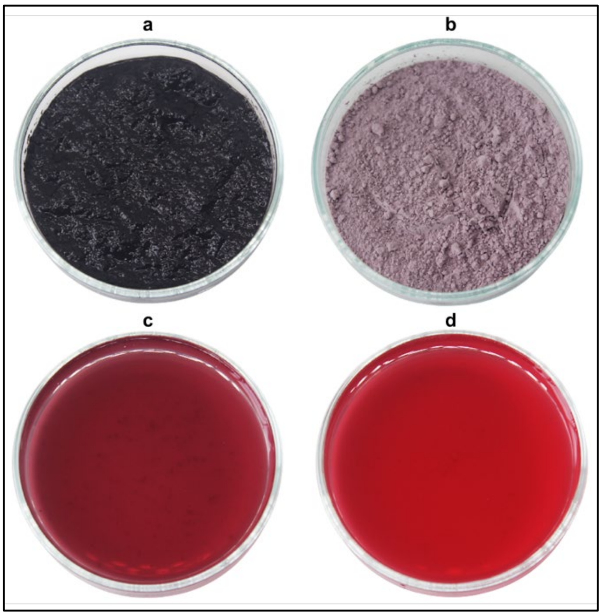

Figure 1. Purple carrot puree (a), purple carrot puree powder (b), rehydrated powder (1%) in distilled water (c), rehydrated powder (1%) in distilled water containing 0.1% acetic acid (d).

In this research, the PY increased and decreased depending on the inlet temperature and other parameters. Temperature is not a factor that can be evaluated on its own. The effect of MD concentration on PY was related to other factors, but in general, PY decreased with increasing MD concentration. The results revealed that, as the pump rate increased, PY generally decreased, but still changed with other factors (Figure 2).

AOA and TPC generally decreased with increasing inlet temperature. Additionally, AOA increased at low temperatures and decreased at high temperatures with the increase of MD concentration (Figure 3). The effect of MD alone on TPC is unclear, however, it is effective along with other parameters. Additionally, AOA and TPC decreased as the pump rate increased (Figure 4).

According to the results, anthocyanin losses increase at high temperatures. It indicates, TAC generally increased as the MD concentration increased and as the pump rate increased, TAC increased and decreased depending on the temperature (Figure 5).

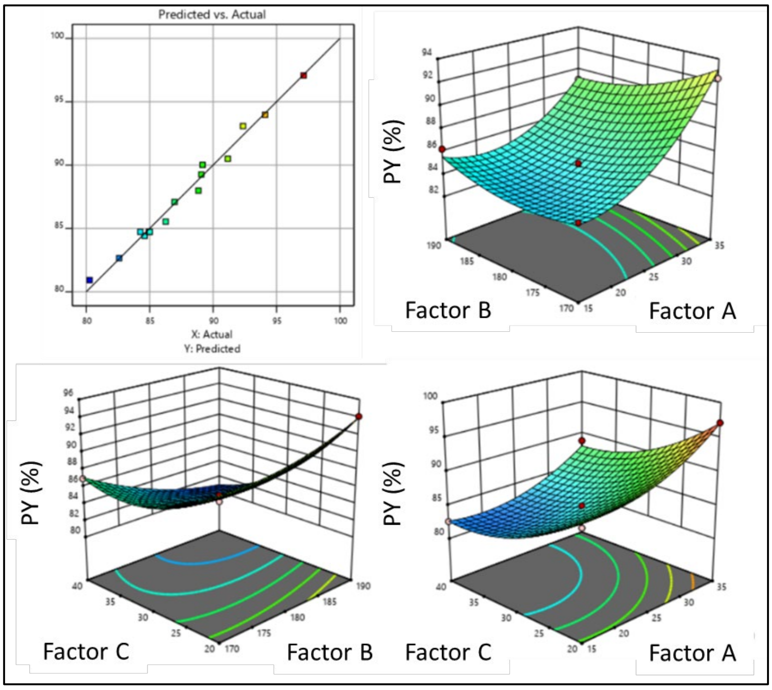

Figure 2. 3D plots of the relevance between the independent variables and process yield (PY)

Effect of Inlet Temperature

Product yield

There are controversial results in the literature on the effect of inlet temperature on product yield in spray drying [23, 24]. To achieve successful drying, it is critical to determine the process yield at different inlet temperatures. Simultaneously, the outlet temperature also has a significant effect on the powder properties. The general judgment on this issue is that the yield increases due to the decrease in the moisture content of the final product because of the high inlet temperature increasing the outlet temperature.

Antioxidant activity and total phenolic content

Polyphenols and other antioxidants can be easily degraded during various heat treatments, including drying. Additionally, losses are likely to occur because of possible oxidation that occurs during drying [25]. The inlet air temperature had a significant effect on the phenolic compounds. At higher inlet temperatures, the total loss of phenolic compounds is generally higher, because of the heat sensitivity of phenolic and other bioactive compounds [26]. About phenomena with this situation, antioxidant activity decreases when phenolics are exposed to high temperatures. According to many researchers, high-temperature spray drying is considered an intense thermal process despite a very short drying time, and the antioxidant activity may decrease after this process. Although the effects of heat treatment on antioxidant activity are controversial in the literature, the general judgment is that the antioxidant activity can be preserved by lowering the spray drying temperature. The opposite situation is explained by the fact that compounds produced during heat treatment have antioxidant properties such as Maillard reaction products [25].

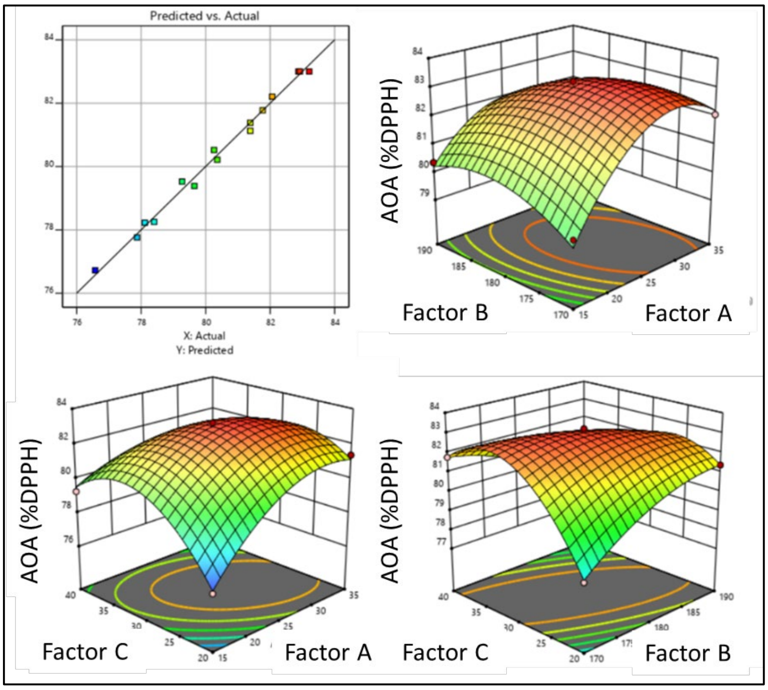

Figure 3. 3D plots of the relevance between the independent variables and antioxidant activity (AOA)

Total anthocyanin content

Pigments are compounds sensitive to thermal processing conditions, and in general, they are damaged by increased temperature in thermal processes. This has been proven on different heat-sensitive compounds such as anthocyanins and various phenolics in different fruit and vegetable powders. Another perspective is based on the high degree of agglomeration occurring due to the higher moisture content of the powders produced at lower inlet air temperatures. The agglomeration process reduces the powder's exposure to oxygen, protecting the anthocyanin pigments from oxidation. A lower exit temperature, on the other hand, causes heat-sensitive compounds such as anthocyanins protected better from heat [27].

Effect of Carrier Agent Concentration

Product yield

Stickiness, which is the most important problem in spray drying of vegetable-based feeds, is due to the presence of sugars (fructose, glucose, sucrose) and organic acids (malic, citric, and tartaric acid) with a very low glass transition temperature (T_g). Feeds rich in these compounds are very difficult to spray dry directly without a carrier agent and it is the key factor in the spray-drying process. To increase T_g in vegetable-based feeds, MD is the most widely used [28-31] and is a successful agent that protects sensitive compounds from environmental factors [3]. As the amount of MD increases, the T_g of the product also increases, so the yield increases. Since the viscosity of the feed is lower at low MD concentrations, the feed comes into contact with the drying surface longer after atomization, and more sediment is formed on the drying surface, reducing the yield [33]. As these results indicate, a generally applicable fixed carrier concentration cannot be recommended for spray drying [8].

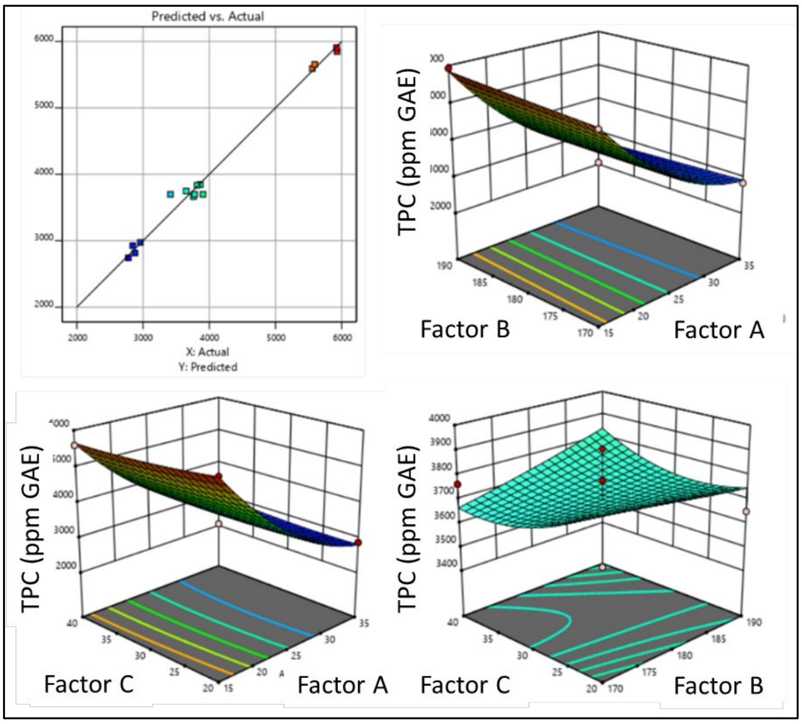

Figure 4. 3D plots of the relevance between the independent variables and total phenolic content (TPC)

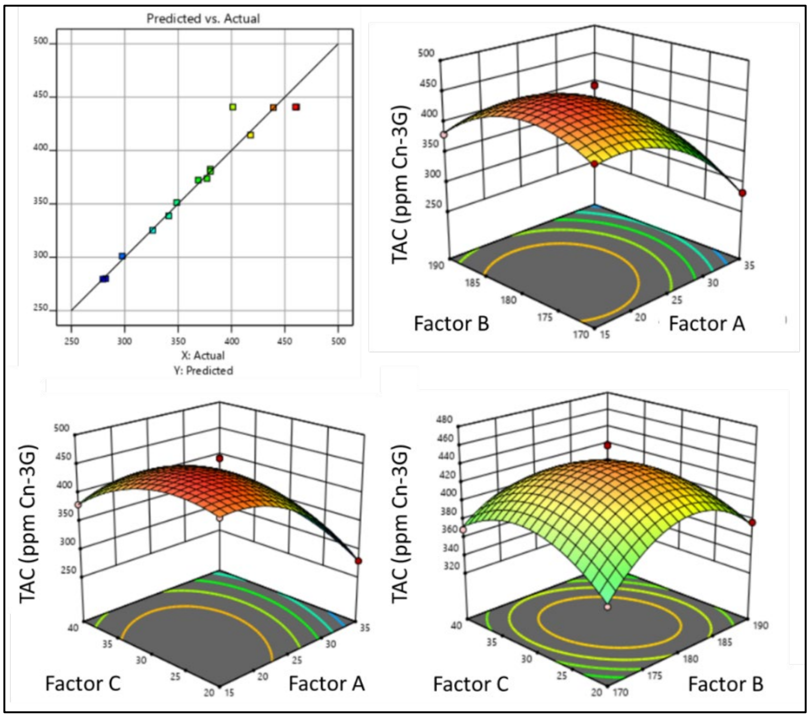

Figure 5. 3D plots of the relevance between the independent variables and total anthocyanin content (TAC)

Antioxidant activity and total phenolic content

In the spray drying process, phenolic compounds are better extracted because of changes in chemical structures, and this increases the total phenolic content. Additionally, the applied heat treatment can also increase the total phenolic content by breaking the glycosidic bonds between aglycone-sugar [34]. MD, a polysaccharide, interacts with phenolics to form complexes that can increase the stability of polyphenols. Thus, the use of higher amounts of carrier agents encapsulates the phenolic compounds better, thus maintaining the phenolic content and antioxidant activity. The mechanism is that the chemical functional groups in the carrier agents interact with the chemical groups in the feed and affect the stability of the bioactive compounds [35]. However, conflicting results have also been reported in the literature. According to several researchers, as the MD concentration increases, the total phenolic content and antioxidant activity decrease. This situation was explained as the increase in MD concentration, which does not have antioxidant activity on its own, dilutes the feed and decreases the phenolic content and antioxidant activity [36].

Total anthocyanin content

The best way to improve the bioavailability of anthocyanins, which are highly unstable and susceptible to degradation due to their chemical structure, is the encapsulation method. For this purpose, MD is a successful carrier in spray drying to preserve the structure of anthocyanins [7]. The DE value of MD is also critical here; MD with high DE increases anthocyanin and antioxidant content, while MD with low DE contains many long-chain saccharides, creating an oxygen-permeable barrier during microencapsulation, reducing the anthocyanin and antioxidant content [37]. MD with higher DE creates a denser mixture and creates a barrier effect, protecting anthocyanins from oxygen [38]. However, if the MD concentration is too high, the anthocyanin content decreases because as the total solids content increases, the amount of anthocyanin in the feed decreases relatively, that is, the pigments are diluted [36].

Effect of Pump Rate

Product yield

Previous studies reported that an increased feed flow rate has a negative effect on product yield. A higher pump rate means a higher feed flow rate. At a higher feed flow rate, the interaction time between the feed droplets and hot air decreases, and heat and mass transfer occurs less [27]. As a result, because the product becomes difficult to dry, wet particles are formed that adhere to the wall of the drying chamber, so the moisture of the final product increases, and thus the process efficiency decreases.

Antioxidant activity and total phenolic content

Increasing the feed flow rate decreases antioxidant activity and total phenolic content. When the feed is given more slowly, there will be enough time for the heat mass transfer in the drying chamber, so the final product exit temperature will increase and the phenolic components will be damaged. In parallel with this, antioxidant activity decreases [39].

Total anthocyanin content

At a high feed flow rate, higher moisture content and a thin dry layer are formed in the powder product, that is, anthocyanin pigments are damaged because there is no adequate barrier against oxygen. Additionally, at a low pump rate, the product will stay in the drying chamber for a longer time, the final product outlet temperature increases, and this results in decreased anthocyanin content with increasing temperature [40].

CONCLUSION

In case of the relationship between all tested parameters is considered in detail, it was seen that each factor has different effects on the final product. The spray drying process is more advantageous for obtaining functional powder products from purple carrot puree. With this process, purple carrot powder, which has high antioxidant activity, total phenolic, and anthocyanin content, can be used in different industries. In this research, it was found that inlet temperature, carrier agent concentration, and pump rate were effective on tested chemical properties of purple carrot powder in the spray drying process. Finally, the optimum drying conditions were determined as 16,52% MD concentration, 180,16°C inlet temperature, and 30.40% pump rate. With drying under these conditions, the content of purple carrot puree can be preserved above 83%, despite heat treatment.

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DECLARATION OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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