

Characterization, Optimization, Physicochemical Properties, and Bioactive Components of Drum-Dried Apple Puree

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ABSTRACT

The aim of this study was to detect the effect of drum-drying parameters on certain physical and chemical properties of apple puree powder. Optimum drying conditions were determined using the Response Surface Methodology (RSM). The qualities of apple puree powder products were investigated in terms of water activity, pH, color, phenolics, antioxidant activity and sensory properties. Apple puree (13 Bx[°]) and maltodextrin (10 DE) were used as the raw material and carrier agent, respectively. Steam pressure, rotational speed and the puree/maltodextrin ratio were chosen as variable parameters. The effects of three of the parameters mentioned were found to be statistically significant: water activity, pH, and the a* and b* parameters of the powders (P < 0.05). In this study, the results showed that the optimum drying parameters and the highest desirability could be obtained for a treatment using a 60/40 apple puree/malodextrin ratio at 3.5 bar steam pressure and a 1 rpm drum rotation speed.

Keywords: Apple powder, Drum drying, Drying, Maltodextrin, Response Surface Methodology.

INTRODUCTION

Apple (*Malus domestica*) is a delicious fruit with many different varieties, and this fruit species is widely consumed throughout the world (Faramarzi *et al.*, 2014). It is one of the most extensively produced and cultivated fruit species, thus it is available on market shelves throughout the year. Turkey is among the top five countries in terms of world apple production (Ozkan *et al.*, 2016; Kıpçak and Akköprü, 2017). A group of compounds that has acquired scientific attention due to its effects on human health and its antioxidant properties are called phenolic compounds. Phenolic compounds are rich in terms of hydroxyl groups and among the most effective compounds in disrupting oxidation processes (Raudone *et al.*, 2016). Also, apple fruit plays a significant role in the human diet in that it is

a rich source of phytochemicals including phenolic compounds like phenolic acids and flavonoids; it also possesses a high antioxidant capability. This high antioxidant concentration can play a role in decreasing the risk of different diseases arising from oxidative stress, namely, coronary disease, immune system damage, diabetes and asthma (Kalinowska *et al.*, 2014; Karaman *et al.*, 2010). Also, raw apple is found to inhibit cancer cell production, decrease lipid oxidation and lower cholesterol levels (Oszmiański *et al.*, 2011, Grigoras *et al.*, 2013, Faramarzi *et al.*, 2014; Henríquez *et al.*, 2014).

In recent years, many techniques have been developed to improve food quality and extend the shelf life of foods (Massah *et al.*, 2017). One of these technologies involves drying techniques. The first target of the drying process is to remove the water so that

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microbial degradation reactions are reduced. It is a process that includes mass and heat transfer in which water is transformed into vapor and then removed. This makes the food product suitable to safely store. Nevertheless, the drying process may uncover some physicochemical, structural and biological differences, and these differences may affect the quality and organoleptic attributes like texture, color, nutritional value, and flavor (Vega-Gálvez *et al.*, 2009; Henríquez *et al.*, 2013). For the food industry, drum-drying technology is a continuous economical system. As well as this sector, this drying system is used in the paper, medical, and chemical industries. Basically, a drying unit has a cylindrical shape, and the processing solutions, liquid materials, and suspensions are laid onto the drum dryer and heated with steam. The material is uniformly applied in a thin layer, averaging 0.5 to 2.2 mm thick, onto the drum surface. A big proportion of the moisture is removed by boiling the water. In order to reach a moisture level less than 5% (wet basis), the duration time of the final product on the drum ranges from a few seconds to tens of seconds. Then, a scraper knife pulls the drying product away from the drum (Tang *et al.*, 2003; İlhan *et al.*, 2003). Nowadays, the drum-dryer system is an economical device extensively used in factories for the production of a variety of foods, such as powdered milk, fruit purees, dry soup mixtures, breakfast cereals, baby foods, mashed potatoes, and cooked starch, and fruit and vegetable pulp (Kalogianni *et al.*, 2002; Pua *et al.* 2010; Henríquez *et al.*, 2014).

In coating technology, carbohydrates that are semi-synthetic derivatives of cellulose and synthetic polymers have been used as encapsulating agents, as drying-aid materials and as carrier agents (Davidov-Pardo *et al.*, 2013; Otálora *et al.*, 2015). Maltodextrin is a hydrolyzed form of starch and may be produced by the acid method and by the combined use of acids and enzymes. The problems with the acid method may be overcome by using enzyme methods (Hobbs, 2009). Maltodextrin is formed from D-glucose units linked basically by glycosidic bonds (β -

1,4) and is generally classified according to its Dextrose Equivalent (DE). The dextrose equivalent of maltodextrin determines its reducing capacity and is related to its molecular weight (Otálora *et al.*, 2015; Farahnaky *et al.*, 2016). The level of starch hydrolysis necessary to produce maltodextrin is represented by the DE value. High DE values can be obtained with higher levels of hydrolysis because of the lower molecular mass of the maltodextrin components. The maltodextrin agent is extensively used in products that are difficult to dry and in food products with a high sugar content, such as fruit juices, flavorings and sweeteners (Koc and Ertekin, 2014; Otálora *et al.*, 2015). Furthermore, maltodextrin is classified as a GRAS (Generally Recognized as Safe) ingredient and is used as fat replacers and texturizing agents (Hobbs, 2009). Maltodextrin can be used for advancing the dehydration characteristics of dried materials with high sugar contents (Nurhadi *et al.*, 2016).

In published literature, there are no investigations on drum-drying parameters and characterization of apple puree. In other studies examined, there were no chemical evaluations for drum-technology fruit powder production. Thus, in this study, we aimed to investigate the particular physical, chemical, and sensory properties of apple powders produced by drum drying, and use the Response Surface Methodology (RSM) program for modeling purposes. The objective was to evaluate the effect of three independent variables: Steam pressure (Bar), the apple puree/maltodextrin ratio (w/w), and the rotation speed (rpm).

MATERIALS AND METHODS

Preparation of Coated Apple Puree Samples

In this study, apple puree was purchased from a commercial company in Turkey. Maltodextrin (10 DE) was used as the carrying agent. Apple puree samples were

coated with maltodextrin. The puree/maltodextrin mixtures were prepared at different concentrations with the same apple puree brix at 40/60, 50/50 and 60/40 (w/w), respectively.

Drying Conditions and Apple Powder Production

Production of the apple puree mixture powder is demonstrated in the flowchart in Figure 1. Samples were dried by using the drum-drying system. A drum dryer with two hollow cylinders was used in this study. The length of each cylinder was 20 cm and they had a diameter of 10 cm. The drying parameters were chosen to be steam pressure, rotational speed, and the puree/maltodextrin ratio. Steam pressures were 1.5, 2.5 and 3.5 Bar. Rotation

speeds were 1, 2, and 3 rpm. The concentrations of the apple puree and maltodextrin mixtures were 40/60, 50/50 and 60/40. The distance between drums was kept stable at 1 mm, and their temperatures were measured. The temperatures at 1.5, 2.5 and 3.5 Bar were 99.1, 105.0, and 112.6°C, respectively. Apple puree was preserved at -25°C until the drying operation. Frozen apple puree samples were dissolved before preparing the apple/maltodextrin mixtures. After feeding these mixtures into the dryer, the first products obtained from it were flakes. These products were ground in a coffee grinder, and then the powdered samples were stored in laminated aluminum bags at -18°C. Samples in aluminum bags were placed into glass jars to exclude oxygen and moisture until the physical and chemical analyses were conducted.

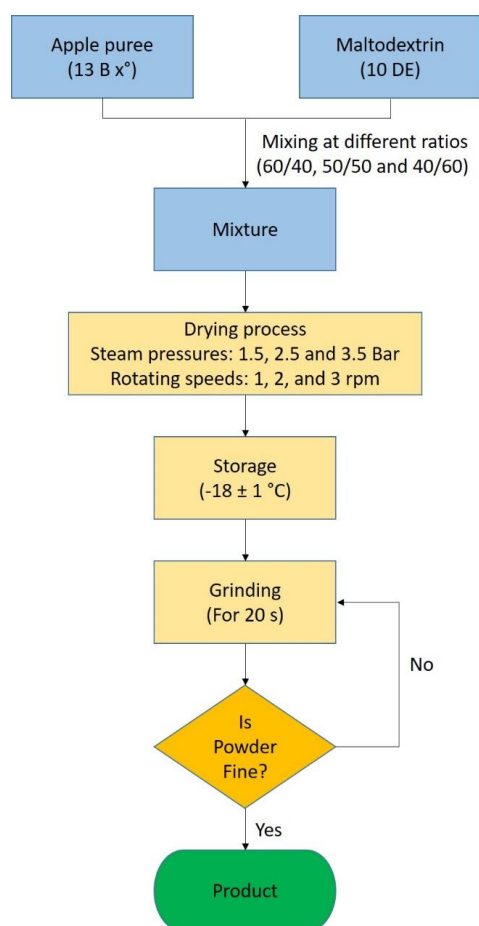


Figure 1. The flowchart for apple puree powder production.

Water Activity and pH Analysis of the Apple Powder

The water activity of samples was measured with Testo instrumentation (AG Electronics, Germany, 1999). Four grams of each raw materials and powder samples were weighed. After 30 minutes, the results of the water activity measurements reached equilibrium and the results were noted. For pH measurement, 2 grams of the samples were dissolved in 50 mL of puree water and the pH value was recorded.

Water Solubility Measurement of Apple Samples

Apple purees were purchased from a commercial firm. The amount of water-soluble dry matter of the apple puree was measured with a refractometer (Greinorm Refractometer, Germany).

Color Properties

All samples were dried to prevent caramelization in a vacuum oven at a temperature of 65°C (Ozdikicierler *et al.*, 2014). The color properties were measured by a HunterLab, Colourflex Spectrophotometer (2009). Samples were put onto quartz glass and the L*, a* and b* values were determined at four different places on the glass.

Total Phenolic Content (TPC) and Antioxidant Activity

The phenolic content was measured according to Singleton *et al.* (1999), except that a low extraction temperature was chosen and Folin solution was used without dilution (Otlés and Yalcin, 2012). Solutions of 80% methanol/water and 7% NaCO₃ were used as extracts. Extraction time was determined to be 1 hour at 50°C. Different gallic acid solution concentrations were prepared at 5, 10, 15, 20, 25, 30, 35, and 40 ppm to create standart curve. Standards and sample extracts were measured at a wavelength of 700 nm by a spectrophotometer, and antioxidant activity was determined by the DPPH method (2,2-DiPhenyl-1-PicrylHydrazyl). Samples were extracted before analysis for 1 hour at 50°C, and the DPPH extraction solution was prepared daily at a concentration of 1 mM and preserved at 4°C until needed. The DPPH radical was prepared daily with pure methanol. Two mL methanolic DPPH was added to both 100 µL sample and the standard. The mixture was kept in the dark for 20 minutes. The antioxidant capacity of the extracts was calculated according to the calibration curve obtained with different concentrations of gallic acid solutions (10-150 ppm). Standards and extracts were measured by a

spectrophotometer at a wavelength of 517 nm (Otlés and Yalcin, 2012).

Sensory Evaluation

Sensory evaluation of apple puree powders was performed as described in Altuğ and Elmacı (2005). The results of the sorting test were statistically evaluated by rank analysis at a significance level of P< 0.05 according to Kramer and Twigg (1984). Sensory evaluation was performed by semi-educated panelists where the samples were made based on the concentration of apple puree/maltodextrin. Each group was evaluated on its own. The sorting test was performed by taking into consideration the flavor and color characteristics of the samples.

Statistical Evaluation

The RSM (Response Surface Methodology) was used for modeling. This program was used to find the optimum conditions for the apple powder samples. Modeling of the trial plan was carried out using the Design-Expert 7.0 program. The variables used and their levels for apple powder modeling are shown in Table 1. Variance analysis (ANOVA) was used for comparing the experimental data of the model.

RESULTS AND DISCUSSION

Creating the Model to Optimize the Drum-Drying Parameters

The optimization modeling of the roller

Table 1. Variables and their levels for the trial plan.

Factors	Independent variables	Variable levels		
		-1	0	+1
x ₁	Steam pressure (Bar)	1.5	2.5	3.5
x ₂	Drum rotation speed (rpm)	1.0	2.0	3.0
x ₃	Puree/Maltodextrin ratio (w/w)	40/60	50/50	60/40

drying parameters was carried out in Design-Expert 7.0 software according to a Central Combined Design (CCD) approach. It was seen that the model was highly compatible with quadratic terms for water activity, pH, and a^* and b^* values. As the model was unsuitable for analysis of the other results, these responses were not modeled and, therefore, not optimized. The statistical significance of the linear, quadratic and interaction effects of each factor on the responses was found by applying the Fischer (F test) test at a 95% confidence interval. These four analyses showing the compatibility of the model defined the maximum and minimum targets for the response. The aim was to minimize the pH and water activity responses and maximize the responses of the a^* and b^* values for the apple puree powders.

Results for Water Activity and pH

The amount of water-soluble dry matter of apple puree was measured as 13 brix. In this study, the water activity, pH, L^* , a^* and b^* values of drum-dried apple puree powder samples were measured (Table 2). It was concluded that two drying parameters (steam pressure and puree concentration) were significant for the final product. When the results were analyzed, the water activity had lower values with increasing maltodextrin

concentration in the powder samples. The water activity and pH of the samples were statistically significant ($P < 0.05$) and this is shown in Figures 2a and 2b, respectively. Milczarek and Liu (2015) investigated certain physical properties of drum-dried Condensed Distillers Solubles (CDS). The water activity of materials was measured and the drying trials that used high temperature and low steam pressure exhibited a better drying performance. Moisture content also showed parallel results to water activity. Pua *et al.* (2010) produced jackfruit powder by using a drum dryer. According to the results of that study, the rotation speed and steam pressure of the drums strongly ($P < 0.05$) affected the overall acceptability, water activity, moisture content ($P < 0.05$) and quality of the final product. Özturan *et al.* (2014), in their study on the drying characteristics of olive pomace, determined that the water activity of the samples decreased as the steam pressure increased in the drum dryer. Also, it was found that the water activity of the samples that were dried in a drum dryer was lower than in a tray dryer.

Color Property Results

According to a study by Carillo *et al.* (2012), a single-drum dryer from Gouda, in

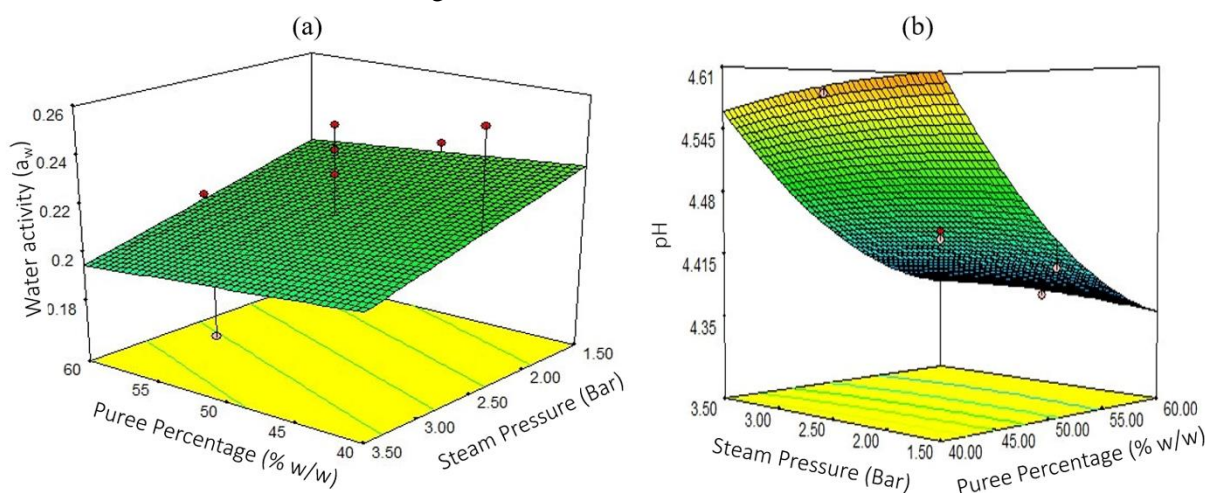


Figure 2. Results of water activity and pH of samples.

The Netherlands, was used in an investigation into producing potato powder. Potato puree was spread onto the surface of the drum and then the dry coat obtained was cut with the aid of a knife and taken carefully from the rollers. Different steam pressures of 0.2, 0.3 and 0.4 mPa were chosen to dry the potato puree at temperatures of 118, 130, and 139°C, respectively. Three drum rotation speeds of 0.5, 1.0, and 2.0 rpm, corresponding to times of 90, 45, and 22.5 seconds, were selected for the production process. The L* value was statistically and significantly ($P < 0.05$) dependent on the effect of the steam pressure, but did not show the same dependence on the drum rotation speed ($P > 0.05$).

The color of samples treated at 0.2 mPa showed similar results to the color of fresh puree. Application of high-pressure steam created a brownish color on the products because of thermal efficiency (burning), which was represented by a lower L* color value. Also, the color properties a* and b* were determined to produce values corresponding to the lower L* value. In other research, mango powder was produced by spray drying and drum drying (Caparino

et al., 2012) When comparing the two drying methods, the mango powder obtained by spray drying had the higher L* value, while the drum-dried mango powder appeared to have the lower L* value (indicating a darker color). For this study, a* and b* values were determined to be statistically significant ($P < 0.05$) and the results are shown in Figures 3a and 3b. According to another study, it was determined that the a* and b* values of drum-dried tomato powders were not statistically significant ($P > 0.05$).

Results for Phenolic Concentration and Antioxidant Activity

There are many studies on antioxidant activity and the phenolic content of apple, apple peel, and fresh apple in published literature. In this study, both the antioxidant activity and the total phenolic compounds of apple powders were found to be statistically insignificant ($P > 0.05$). The results for the phenolic and antioxidant content of the powder samples are shown in Figure 4. With an increase in steam pressure, the total phenolics and antioxidant concentrations

Table 2. Central composite design and experimental data taken for the response variables.

Run no	Independent variables				Response variables			
	Steam pressure (Bar)	Rotation speed (rpm)	Puree mixings (w/w)	Water activity (a_w)	pH	L*	a*	b*
1	0	0	0	0.22	4.4	75.92 ± 0.03	5.94 ± 0.03	18.18 ± 0.07
2	-1	-1	+1	0.27	4.6	79.47 ± 0.04	4.71 ± 0.02	17.08 ± 0.05
3	-1	-1	-1	0.14	4.6	79.86 ± 0.02	5.49 ± 0.04	18.95 ± 0.05
4	-1	0	0	0.26	4.6	80.28 ± 0.04	3.87 ± 0.02	14.51 ± 0.05
5	0	-1	0	0.23	4.4	76.94 ± 0.04	6.17 ± 0.02	18.24 ± 0.05
6	+1	+1	+1	0.20	4.4	76.20 ± 0.03	7.51 ± 0.02	21.52 ± 0.07
7	-1	+1	-1	0.17	4.6	78.07 ± 0.02	5.38 ± 0.02	16.77 ± 0.04
8	-1	+1	+1	0.27	4.6	78.68 ± 0.01	5.31 ± 0.01	16.32 ± 0.03
9	+1	-1	+1	0.30	4.3	71.87 ± 0.05	8.89 ± 0.04	25.57 ± 0.07
10	+1	-1	-1	0.18	4.4	78.66 ± 0.02	6.93 ± 0.02	20.64 ± 0.03
11	0	0	-1	0.16	4.4	78.62 ± 0.02	6.19 ± 0.03	18.70 ± 0.07
12	0	+1	0	0.18	4.4	76.00 ± 0.02	6.36 ± 0.01	18.58 ± 0.05
13	+1	0	0	0.21	4.4	77.06 ± 0.01	7.08 ± 0.02	21.47 ± 0.04
14	0	0	+1	0.19	4.4	81.12 ± 0.02	3.92 ± 0.04	12.20 ± 0.08
15	+1	+1	-1	0.19	4.5	80.92 ± 0.01	5.85 ± 0.02	16.39 ± 0.05

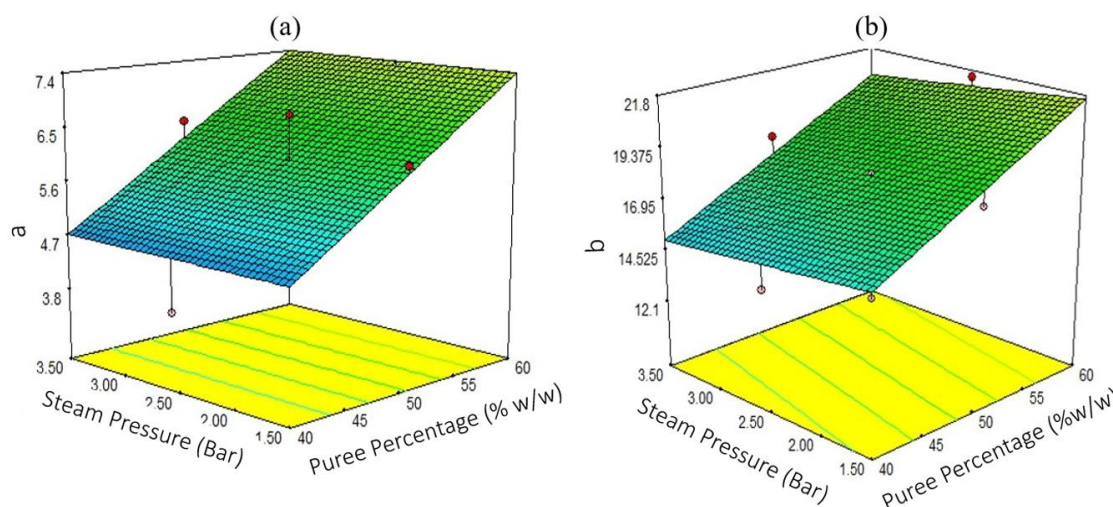


Figure 3. Results for the a* and b* values of the samples.

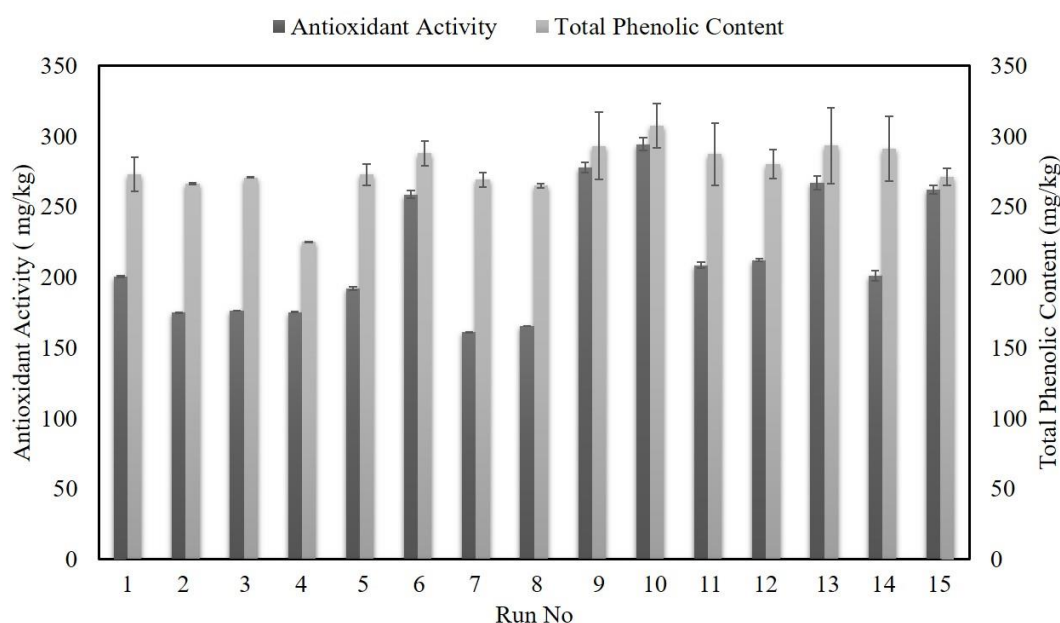


Figure 4. Total phenolic content and antioxidant activity results for apple powder.

had low values compared to the raw material. Phenolic compounds of apple types (yellow, red, green) were determined to be 99.7, 125.4 and 118.1 mg GAE 100 g⁻¹, respectively (Marinova *et al.* 2005). Awad and Jager (2000) found phenolic compounds ranged from 4.42 to 14.66 mg g⁻¹ in the dried matter. For this investigation, it was observed that the heat treatment applied to

apple powders caused a general decrease in the total phenolic content.

There are a limited number of studies in published literature on drum-drying technology. There are also no studies available on the drying of apple puree in a drum dryer, so, the chemical composition of apple puree powder was investigated for the first time. As a result of the study, it was determined that the phenolic content and amount of antioxidant

substances decreased in apple powder at high temperature and low rotation speeds. Therefore, the bioactive content of the dried samples was found to be low. The phenolic and antioxidant content of apple puree was found to be higher than in the dry samples. Otles and Yalcin (2012) determined that raw materials had a higher concentration of phenolics and antioxidants, and that a compound's content was reduced by applying thermal operations to produce the final products. According to a study, the Total Phenolic Content (TPC) measured in fresh apple peels and in drum-dried apple peel at 110, 120, 130, and 140°C was measured at 35.74 ± 3.0 mg GAE g⁻¹ and the phenolic content of dried apples was determined to be between 7.54 to 26.14 mg GAE g⁻¹. This study showed that the retention of TPC was higher when lower temperatures were used and longer times were spent on the drums. Lower temperatures may ensure suitable conditions for processing apple peel using drum-drying technology (Henríquez *et al.*, 2014).

The amount of antioxidant capability and antioxidants are higher in apple peel than in the whole fruit or in a pulp fraction. Also, many studies have shown that apple peel is a good source of valuable compounds such as dietary fiber and minerals (Henríquez *et al.*, 2013). The antioxidant activity of dried apple was found using the DPPH method to be 875 mg 100 g⁻¹ and 4.82 ± 0.84 (mmol L⁻¹ dried matter) (Leyva-Corral *et al.* 2016).

For this research, a similar result was observed in terms of the antioxidant activity and the amount of phenolic substances. The antioxidant activity of apple powders decreased with increasing vapor pressure.

Results of the Sensory Evaluation

Steam pressure, rotational speed, and maltodextrin ratio were effective in

determining color properties. It was seen that panelists gave a low ranking score to dark-colored products, and that the powder product trials were given higher-ranking points by panelists as the rotation speed decreased. As the different ratios of added maltodextrin increased, it was seen that the panelists gave a higher ranking score (Coşkun, 2014; Coşkun and Pazır, 2017). Apple puree/maltodextrin mixtures (50/50), which were placed in the same amount in terms of flavor, received higher-ranking points. Mixtures containing high amounts of maltodextrin (40/60) received low ranking points. In terms of color properties, 60/40 3.5 bar 1 rpm, 50/50 2.5 bar 3 rpm, 50/50 3.5 bar 2 rpm, and 40/60 2.5 bar 2 rpm powder trials were found statistically significant. Also, flavor characteristics for 50/50, 3.5 bar, 2 rpm and 40/60, 3.5 bar, 3 rpm powder trials were found to be statistically significant. In a similar study, Pua *et al.* (2010) found that the steam pressure and the rotational speed for the jackfruit obtained from the dryer were found to be statistically significant ($P < 0.05$). As a result of sensory evaluation, it was determined that the flavor scoring was higher with an increase in the steam pressure and a decrease in the rotational speed. The desired criteria in apple powders were determined as light colored and high maltodextrin concentration. These results were taken into consideration with preliminary evaluations and panelist reports.

Results of the Confirmation Test

In this study, the analyses demonstrated above showed model compatibility for optimum drying parameters for a 60/40 puree/maltodextrin mixture, 3.5 bar of steam pressure, and a 1 rpm rotational speed. At the end of the research, a confirmation test

Table 4. Results of the verification test.

	a _w	pH	a*	b*
60/40 3.5 (Bar) 1 (rpm)	0.19	4.47	7.45 ± 0.01	22.39 ± 0.02

was applied to these parameters and results are shown in Table 4. For optimum drying parameters, the results of the verification test and the production parameters were found to be consistent.

CONCLUSIONS

In this study, it was seen that drum-dried apple puree could be obtained with the use of maltodextrin and optimal drying parameters. Also, it was thought that different maltodextrin concentrations and suitable compounds other than maltodextrin (such as modified starch, and modified cellulose) may be used. The physical results for the powder were similar to former trials, but chemical results were found to have lower values because of the use of higher steam pressure and temperature, and remaining longer on the drum surface. At the end of the research, the steam pressure, physical, chemical and sensory properties of the final product were affected by the puree/maltodextrin concentration and the rotational speed of the drum. Moreover, according to this study, apple puree powder can be used as a functional additive in other food products (like puddings, yogurt, biscuits, cake, and bread) because of a fairly high phenolic and antioxidant content and significant physical and sensory properties. It is also thought that different fruits with high sugar content may be successfully dried with maltodextrin by using a drum dryer. Thus, these fruit powders can be used in the food applications mentioned before.

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تشخیص ویژگی‌ها، بهینه‌سازی، خواص فیزیکی‌شیمیایی و ترکیبات زیست‌فعال پوره سیب خشک شده با خشک‌کن غلتکی

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چکیده

هدف این پژوهش شناسایی اثر پارامترهای خشک‌کن غلتکی روی برخی خواص فیزیکی و شیمیایی پودر پوره سیب بود. به این منظور شرایط خشک کردن بهینه با استفاده از روش سطح پاسخ (RSM) تعیین شد. کیفیت‌های پودر پوره سیب برحسب مواردی شامل فعالیت آب، pH، رنگ، فنول‌ها، فعالیت آنتی‌اکسیدانی و خواص حسی (sensory properties) بررسی شد. پوره سیب (13 Bx°) و مالتودکسترین (10 DE) به ترتیب به عنوان مواد خام و حامل (carrier) استفاده شدند. همچنین، فشار بخار، سرعت چرخش، و نسبت پوره به مالتودکسترین به عنوان متغیرها انتخاب شد. اثر سه پارامتر فعالیت آب، pH، و پارامترهای a^* و b^* از نظر آماری معنادار بود (در سطح $p < 0.05$). در این پژوهش، نتایج نشان داد که بهینه پارامترهای خشک کردن و بالاترین پسندیدگی را می‌توان از تیماری شامل نسبت ۶۰ به ۴۰ پوره سیب به مالتودکسترین، در فشار بخار ۳/۵ بار و سرعت چرخش غلتک برابر ۱ دور در دقیقه به دست آورد.