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Optimization of Sour Cherry Juice Spray Drying as Affected by Carrier Material and Temperature

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Summary

Response surface methodology was applied for optimization of the sour cherry Marasca juice spray drying process with 20, 30 and 40 % of carriers maltodextrin with dextrose equivalent (DE) value of 4–7 and 13–17 and gum arabic, at three drying temperatures: 150, 175 and 200 °C. Increase in carrier mass per volume ratio resulted in lower moisture content and powder hygroscopicity, higher bulk density, solubility and product yield. Higher temperatures decreased the moisture content and bulk density of powders. Temperature of 200 °C and 27 % of maltodextrin with 4–7 DE were found to be the most suitable for production of sour cherry Marasca powder.

Key words: sour cherry juice, spray drying, optimization, physicochemical properties

Introduction

Economic and industrial development influenced changes in consumer trends, focusing on the consumption of fresh fruits and vegetables as the healthy, nutritive and biologically valuable food, rich in biologically active components. However, fruits and vegetables are highly perishable products, so in order to answer to market demands and ensure their longer period of availability, industry offers different preservation and processing techniques. The main problem regarding the storage of fruit products is high water content, which makes them susceptible to elevated enzymatic activity and microbial growth, leading to quality degradation and deterioration. The prolongation of fruit product shelf life and stability can be achieved by drying as one of the most commonly used preservation techniques for reduction of the water content of food, and subsequently for reduction of microbial growth as well as enzymatic activity. Furthermore, drying reduces the mass and volume of food products resulting in lower storage and transportation costs and making the product easier to handle (*1*). Numerous drying methods have been developed aiming to increase productivity, processing control as well as the quality of the final product. Spray drying is a widely spread technique for drying of liquid products, such as fruit juices, into powder form. However, during drying of fruit juices, stickiness on the drier wall, wet, plastic appearance, agglomeration and clumping occur, resulting in operational problems and increased losses (*2*). Low glass transition temperature of sugars, which make about 90 % of juice dry matter, is the main cause of the stickiness (*3*). Common approaches for a solution to this problem involve modifying the sticky characteristics of the material most frequently through the addition of carrier agents and controlling the inlet and outlet temperature of the dryer (*4*). Advantages of this method mainly include short drying period because of a large heat transfer surface, low product surface temperature, no direct contact of food with heated metal surface, stability and high quality of the final product. As fruit powders have a variety of potential uses in food industry, as semi-products or final products

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with high nutritive and functional benefits, optimizing the spray drying process is a worthwhile step.

Sour cherry Marasca (*Prunus cerasus* var. Marasca) is a cultivar characterized by high content of dry matter (21.0–27.3 %) (*5*), biologically active compounds (polyphenols, melatonin and vitamin C), dark red colour and intense sweet-sour aroma (*5–8*). Although it is rarely consumed fresh, the possibilities for processing are numerous: jams, juices and concentrated juices, frozen and dried products, among which fruit powders are recognized. Because of its intense colour, flavour and high dry matter content, sour cherry Marasca juice is a great material for production of spray-dried fruit powders. However, Marasca juice is a demanding material for spray drying and preservation of its natural attributes such as colour, aroma and flavour. Moreover, the characteristics of spray-dried sugar-rich juices, especially the hygroscopicity and thermoplastic behaviour, put additional requirements on the selection of processing parameters. Sour cherry Marasca juice has high content of low-molecular-mass sugars such as glucose and fructose, which cause stickiness and caking during the spray drying and therefore disable the production of free-flowing dry powder (*9*). In practice, this problem is solved by the addition of carrier materials, such as polymers and gums, which prevent the stickiness, and by the careful selection of processing parameters such as drying temperature, air flow and material flow (*10*). Most frequently used carrier materials are maltodextrins (MD) of different dextrose equivalents (DE). Vardin and Yasar (*11*) optimized the spray drying process of pomegranate juice with 40 % dry matter using MDs of 7 and 18 DE added in ratios of juice dry matter and MD of 1:1, 3:4 and 1:2, at temperatures of 110, 140 and 170 °C. At the ratio 1:2, product yield was over 72 % at temperatures of 110–140 °C and about 67 % at 170 °C. At the ratio 1:1, yield was significantly lower, 25–51 %. Dextrose equivalent was also found to be significant, as maltodextrin with lower dextrose equivalent gave higher yields at higher mass per volume ratios and lower temperatures. Moisture content of the powders decreased with the increased inlet and outlet air temperature, while solubility increased. The hygroscopicity of spray-dried powders increased with increased DE value of MD and slightly decreased with increased inlet air temperature. Solval *et al*. (*12*) researched the effect of temperature (170, 180 and 190 °C) on the properties of melon juice produced with MD 9–13 DE added in the ratio of juice and MD of 9:1. The increase in temperature caused the reduction of moisture content from 5.39 to 3.81 %. According to these literature reports, it can be concluded that spray drying parameters as well as the carrier addition highly depend on the material that is to be dried and therefore should be carefully optimized. Because of the differences between Marasca and other sour cherry cultivars, especially regarding the significantly higher dry matter content, sour cherry Marasca is a challenging material for spray drying. Therefore, the aim of this research is to optimize the spray drying process of sour cherry Marasca juice in terms of carrier material selection, its concentration and drying temperature and to determine the influence of the above-mentioned parameters on physicochemical properties of sour cherry Marasca fruit powders.

Materials and Methods

Material

Sour cherry juice (15 °Brix) used for experiment was obtained from Maraska d.d. factory (Zadar, Croatia). Industrial juice production included following steps: fruit washing, heating at 45–50 °C, one-hour treatment with 20–40 mL/t of pectolytic and amylolytic enzymes (Endozym Pectofruit PR, AEB Group, Brescia, Italy), pressing with Bucher press (Bucher Vaslin SA, Chalonnes sur Loire, France), 2-minute pasteurisation at 85 °C, cooling to 50 °C, two-hour treatment with 2–3 g/hL of pectolytic enzyme (Endozym Pectofruit), precipitation and vacuum and plate filtration. The juice was stored in dark glass bottles at 4 °C until analysis.

Three different carriers were used for production of spray-dried juice, namely maltodextrin with dextrose equivalent of 4–7 (MD 4–7 DE), maltodextrin with dextrose equivalent of 13–17 (MD 13–17 DE) and gum arabic (GA). All carriers were obtained from Sigma-Aldrich (Taufkirchen, Germany).

Spray drying process

Sour cherry Marasca juice powders were produced on a laboratory scale spray dryer SD 06 (Labplant, North Yorkshire, UK). During the process the following parameters were kept at constant level: air flow 3.5 m/s, feed flow 485 mL/h and deblocking speed at medium level. Spray drying process was carried out according to the experimental design as follows: three different carriers (MD 4–7 DE, MD 13–17 DE and GA) were added at 20, 30 and 40 % (by mass per volume) to the 100 mL of sour cherry Marasca juice (15 °Brix). The slurry was stirred and preheated to 50 °C on a magnetic stirrer (HSC Ceramic Hot Top-Plate Stirrer, VELP Scientifica Srl, Usmate Velate (MB), Italy) for 10 min in order to achieve homogeneous dispersion of carrier material in juice. The slurries were spray dried at three different inlet temperatures, 150, 175 and 200 °C. The corresponding outlet temperatures were 78–80, 87–90 and 99–102 °C, respectively. All powders were produced in duplicate and stored in dark plastic containers in a desiccator at 20 °C until analysis.

Analytical methods

Product yield

Product yield was calculated as the ratio of the dry matter content of the collected powder to the dry matter content of the slurry according to the following equation:

$$\text{Product yield} = \frac{m_p}{m_d + m_c} \cdot 100 \qquad /1/$$

where m_p is the mass (g) of produced spray-dried sour cherry Marasca juice powder, m_d is dry matter content (g) of juice in the slurry and m_c is the mass (g) of the carrier in the slurry.

Moisture content

Moisture content (%) of the sour cherry Marasca powders was calculated as the difference in the mass before and after drying in an oven at 105 °C (FN 500; Nüve, Ankara, Turkey) until the constant mass was obtained (*13*).

Hygroscopicity

Hygroscopicity of powders was analysed according to Tonon *et al.* (*14*). Duplicates of 1 g of each sample were placed in open Petri dishes in a desiccator containing saturated NaCl solution (RH=75.3 %) and stored for one week at room temperature. Hygroscopicity was determined by measuring the mass of water adsorbed by the sample, and was expressed in g of adsorbed water per 100 g of powder using the following equation:

$$\text{Hygroscopicity}=\left(\frac{m_7-m_0}{m_0}\right)\cdot 100 \qquad /2/$$

where m_7 is the mass (g) of the powder after 7 days of storage and m_0 is the mass (g) of the powder before storage.

Solubility

Solubility was determined according to the method described by Anderson *et al*. (*15*), with some modifications. The mass of 1 g of powder was placed in a glass test tube with 10 mL of distilled water and stirred vigorously at vortex vibrator for 1 min, termostated in a water bath (B-490; Büchi, Flawil, Switzerland) at 37 °C for 30 min and centrifuged at 5500×*g* for 20 min (Rotafix 32; Hettich, Tuttlingen, Germany). Later on, the obtained supernatant was collected and dried in a laboratory oven at 105 °C (FN 500; Nüve) until constant mass was obtained. Solubility was calculated according to the following equation:

$$\text{Solubility}=\frac{m_s}{m_p}\cdot 100 \qquad /3/$$

where m_s is the mass (g) obtained by drying of the supernatant and m_p is the mass (g) of the powder taken into analysis.

Bulk density

Bulk density (g/mL) was determined by adding 2 g of sour cherry Marasca powder into an empty 10-mL graduated cylinder and holding the cylinder on a vortex vibrator for 1 min. The ratio of the powder mass and the volume occupied in the cylinder determines the bulk density value (*16*).

Experimental design and statistical analysis

The experimental design and statistical analysis were done using STATISTICA v. 10 Experimental design (DOE) software (StatSoft Inc., Tulsa, OK, USA). A full factorial design comprising nine experimental trials for each carrier material used was chosen to evaluate the combined effect of two factors, carrier mass per volume ratio and drying temperature, termed X_1 and X_2, respectively (Table 1), giving in total 27 experimental runs. Experiments were performed in duplicate, starting with the lowest carrier mass per volume ratio and the lowest temperature. The operating variables were considered at three levels, namely low (–1), central (0) and high (1). The values of carrier mass per volume ratio were set at 20 (–1), 30 (0) and 40 % (1) and of temperature at 150 (–1), 175 (0) and 200 °C (1). Repetition experiments were carried out immediately after the corresponding original experiments designed by the program. The responses obtained from the experimental design were product yield (%), moisture content (%), hygroscopicity (g/100 g), solubility (%) and bulk density (g/L).

The design matrix for the experiment and the regression model for each response were calculated as follows (*17*):

$$Y=\beta_0+\sum\beta_i X_i+\sum\beta_{ii}X_i^2+\sum\beta_{ij}X_iX_j \qquad /4/$$

where Y is predicted response, β_0 is the fixed response, β_i, β_{ii} and β_{ij} are the linear, quadratic and interaction coefficients, and X_i and X_j are independent factors, respectively.

Analysis of variance (ANOVA) was carried out to determine any significant differences ($p<0.5$) among the applied treatments. The model was fitted by multiple linear regressions (MLR). The validity of the quadratic empirical model was tested using the analysis of variance (ANOVA). The confidence level used was 95 %.

For optimization purposes a prediction and profiling tool was used. Preferences were set for each response as follows: for product yield, solubility and bulk density preference was high (1.0), while for moisture content and hygroscopicity it was low (0.0). Factors were set at optimum value and were observed at 20 steps for more precise optimization.

Results and Discussion

Fruit juices are one of the most demanding materials for spray drying because of the high content of low-molecular-mass sugars and organic acids. Therefore, it is necessary to optimize the spray drying process in order to obtain the product with good physical and chemical properties, rehydration capacity and with characteristic sensory attributes. The use of drying aids, specifically the carrier materials, is mandatory as they prevent stickiness during the process and also may act as a protection of heat-sensitive compounds because of their role as microencapsulating agents (*18*).

In sour cherry Marasca juice powders produced according to the experimental design, the following physical and chemical parameters were determined and observed for the optimization: product yield, moisture content, hygroscopicity, solubility and bulk density (Table 1).

Product yield of powders containing MD 4–7 DE ranged from 27.7 to 59.1 %, of powders containing MD 13–17 DE from 6.0 to 60.4 % and of powders containing GA from 34.1 to 54.3 %. According to the previous report by Bhandari *et al.* (*19*) the criterion for successful drying is product yield higher than 50 %. Almost all experimental drying conditions with MD 4–7 DE resulted in powders with product yield over 50 %, while with MD 13–17 DE product yield was over 50 % only when using powders with higher carrier mass per volume ratio (30 and 40 %) dried at higher temperatures (175 and 200 °C). On the other hand, GA powders had yield higher than 50 % only at the lowest carrier addition (20 %).

Losses during spray drying can occur as the result of different factors: residue on the dryer walls, fine particle loss through the outlet air filter and losses due to hand manipulation with powder (*20*).

Analysis of variance (ANOVA) results for carrier mass per volume ratio and temperature effect on the observed physical and chemical parameters are shown in

Table 1. Results of physicochemical parameters of sour cherry Marasca juice powder produced with the addition of 20, 30 and 40 % of maltodextrin (MD) with 4–7 and 13–17 dextrose equivalent (DE) and gum arabic (GA) at different drying temperatures

Carrier	$\left(\frac{m(\text{carrier})}{V(\text{juice})}\right)/\%$	Temperature / °C	Product yield / %	Moisture content / %	Hygroscopicity / (g/100 g)	Solubility / %	Bulk density / (g/mL)
MD 4–7 DE	20	150	50.8±0.5	2.3±0.1	19.8±0.4	95.0±0.9	0.25±0.00
		175	53.0±1.0	1.81±0.08	21.1±0.4	81.8±0.4	0.28±0.01
		200	27.7±0.8	1.36±0.06	22.9±0.7	89.5±1.5	0.48±0.01
	30	150	56.0±0.7	3.60±0.06	26.3±0.9	94.9±0.9	0.30±0.01
		175	50.9±1.2	2.27±0.08	19.5±0.7	93.3±0.6	0.28±0.01
		200	55.8±0.8	1.39±0.04	19.6±0.5	96.0±0.2	0.28±0.01
	40	150	43.1±0.4	3.23±0.01	22.1±0.5	85.2±0.5	0.34±0.01
		175	59.1±0.2	2.49±0.04	20.9±0.2	86.5±0.4	0.40±0.00
		200	58.6±0.5	1.87±0.04	18.3±0.4	96.1±0.2	0.23±0.00
MD 13–17 DE	20	150	19.4±0.8	2.23±0.06	30.8±0.7	95.8±0.3	0.36±0.00
		175	12.1±0.5	7.69±0.05	39.0±1.0	91.1±0.4	0.33±0.01
		200	6.0±0.5	6.41±0.06	39.6±0.4	90.5±0.3	0.34±0.01
	30	150	31.1±0.6	3.01±0.04	28.4±0.6	97.8±0.8	0.29±0.01
		175	55.7±0.8	1.53±0.05	21.9±0.5	97.4±0.4	0.28±0.00
		200	51.1±1.1	1.76±0.06	36.8±0.5	95.2±0.3	0.28±0.01
	40	150	46.8±0.6	2.59±0.04	22.9±0.7	96.0±1.0	0.32±0.00
		175	59.5±0.8	1.55±0.04	23.2±0.7	97.7±0.8	0.25±0.01
		200	60.4±1.4	1.41±0.04	26.0±0.4	81.6±2.9	0.32±0.01
GA	20	150	54.3±0.6	5.71±0.05	23.1±0.1	88.2±0.8	0.28±0.01
		175	51.6±0.6	3.70±0.08	32.5±0.4	88.2±0.6	0.26±0.01
		200	52.0±0.3	3.26±0.06	34.2±1.0	88.4±0.7	0.24±0.01
	30	150	39.6±0.8	5.12±0.07	32.0±0.2	88.2±0.7	0.34±0.00
		175	47.8±0.6	4.31±0.09	33.1±0.7	86.2±0.9	0.35±0.01
		200	45.1±0.7	3.35±0.06	29.8±0.4	89.0±0.9	0.30±0.00
	40	150	46.0±0.8	5.12±0.05	23.0±1.0	81.6±0.6	0.45±0.03
		175	49.8±0.6	3.64±0.08	29.0±0.7	81.1±0.2	0.39±0.01
		200	34.1±0.2	3.82±0.06	20.8±0.5	85.9±0.9	0.28±0.00

Results are expressed as mean value±standard deviation (N=4)

Table 2. Both carrier mass per volume ratio and temperature, as well as combined effect of these two factors had significant influence on product yield of powders with all three carriers.

With maltodextrin carriers, regardless of dextrose equivalent, the highest carrier mass per volume ratio (40 %) and higher temperatures (175 and 200 °C) resulted in the highest product yield. With 20 % MD 13–17 DE, the stickiness problem occurred, so resulting yields were very low (6.0–19.4 %), decreasing with the increase in drying temperature. The cause of the stickiness during drying is the presence of low-molecular-mass sugars, namely sucrose, glucose and fructose, which have low glass transition temperature (*19*,*21*) and therefore tend to stick to the dryer walls, leading to low product yield and technical difficulties during process. Low glass transition temperature, high hygroscopicity, low melting point and high water solubility characterize juice dry matter and make them highly sticky products. These problems are solved by the addition of carrier materials, polymers and gums, which have the ability to increase the glass transition temperature of juice and consequently decrease or inhibit the stickiness phenomenon (*22*). Carrier efficiency primarily depends on its ratio to the juice dry matter and drying temperature. According to our results, it can be concluded that the use of MD 13–17 DE demands higher carrier ratio as with 20 % carrier addition to the juice with 15 % dry matter, the stickiness problem occurred, being more expressed with the rise of the drying temperature.

On the other hand, with gum arabic, the highest product yields were obtained with the lowest carrier ratio, regardless of the drying temperature. Vardin and Yasar (*11*) optimized the spray drying process of pomegranate juice and reported the highest yield at juice to MD ratio 1:2 and temperatures from 110 to 140 °C with decreasing trend at higher temperatures. Dextrose equivalent was also found to be significant as MD with lower DE gave higher yields at higher ratios and lower temperatures. In the present study, both maltodextrins gave similar yields at higher ratios and temperatures, regardless of the dextrose equivalent. Other authors showed compara-

Table 2. Analysis of variance (ANOVA) for the effect of carrier mass per volume ratio (X_1) and temperature (X_2) on the observed physicochemical parameters of spray-dried sour cherry Marasca juice powder produced with the addition of maltodextrin (MD) of 4–7 and 13–17 dextrose equivalent (DE) and gum arabic (GA) at 95 % confidence level

Carrier	Source of variation	Product yield		Moisture content		Hygroscopicity		Solubility		Bulk density	
		F-ratio	p-value	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
MD 4–7 DE	X_1	371.60	0.00	203.81	0.00	9.81	0.01	122.50	0.00	75.98	0.00
	X_2	135.74	0.00	793.48	0.00	37.43	0.00	128.93	0.00	32.42	0.00
	X_1X_2	458.49	0.00	51.97	0.00	52.20	0.00	86.51	0.00	428.38	0.00
MD 13–17 DE	X_1	4282.37	0.00	10129.56	0.00	577.60	0.00	36.45	0.00	125.74	0.00
	X_2	218.07	0.00	609.57	0.00	206.48	0.00	79.73	0.00	35.08	0.00
	X_1X_2	272.15	0.00	3550.71	0.00	100.72	0.00	33.55	0.00	17.51	0.00
GA	X_1	435.30	0.00	1.49	0.28	228.00	0.00	103.59	0.00	119.83	0.00
	X_2	144.02	0.00	1186.55	0.00	118.75	0.00	19.92	0.00	67.78	0.00
	X_1X_2	161.94	0.00	71.71	0.00	33.73	0.00	7.23	0.01	19.93	0.00

ble results regarding the carrier ratio, while the ones dealing with the effect of drying temperature are diverse. Peng *et al.* (*23*) researched the influence of MD 20 DE addition on the product yield of spray-dried purple sweet potato. The addition of 30 % MD 20 DE increased product yield from 23.32 to 39.85 %, while further addition gave no effect. The importance of carrier use is in the formation of outer layer, the 'wall' surrounding the material and increase of glass transition temperature which results in prevention of stickiness and increase in product yield (*24*). For effective spray drying of concentrated blackcurrant, apricot and raspberry juices, the addition of minimally 35 % of MD 6 DE was necessary (*9*), while Righetto and Netto (*25*) reported the minimum addition of 50 % of MD 25 DE to acerola juice.

Fazaeli *et al.* (*26*) reported the effect of drying temperature similar to our conclusions. They observed the positive effect of temperature increase on spray-dried black mulberry juice yield, explained by more effective energy and mass transfer at elevated temperatures (*14*,*27*).

Moisture content of sour cherry Marasca powders varied from 1.36–2.49 % in those containing MD 4–7 DE, from 1.41–7.69 % in those containing MD 13–17 DE and from 3.26–5.71 % in those containing GA. This is one of the most important indicators of spray drying effectiveness and final product quality (*28*).

According to the ANOVA results (Table 2) both carrier mass per volume ratio and drying temperature had significant effect on moisture content of sour cherry Marasca powders produced with MD carriers, while in powders produced with GA there was no significant effect of carrier mass per volume ratio.

Generally, powders produced with MD 4–7 DE had the lowest moisture content, while those with GA had the highest. The exception are powders produced with 20 % of MD 13–17 DE at 175 and 200 °C, which had high moisture residue due to the stickiness that occurred during the process. It can also be observed that increase in MD 13–17 DE carrier mass per volume ratio had evidently positive effect on moisture content decrease, which reduced the stickiness problem. These findings are in accordance with other authors' reports.

At higher drying temperatures, the resulting moisture content is lower thanks to more effective mass and heat transfer, namely intensive water evaporation (*29*). Fazaeli *et al.* (*26*) also reported the reduction of moisture content in black mulberry juice powder with temperature increase as well as with the increase in carrier concentration. Rodríguez-Hernández *et al.* (*30*) observed lower moisture content in *Opuntia* powders produced with maltodextrins with higher dextrose equivalent, while Fazaeli *et al*. (*26*) and Goula and Adamopoulos (*27*) reported adverse findings for sweet potato and orange juice powders. These authors explained their findings with the structure of maltodextrin with high dextrose equivalent characterized by more short chains and hydrophilic groups which consequently adsorb more water molecules. The results of our research showed that there was no significant difference in the moisture content of powders produced with MD 4–7 DE and MD 13–17 DE at higher mass per volume ratios (30 and 40 %), but results with the addition of 20 % MD are in accordance with the above mentioned studies.

Hygroscopicity of sour cherry Marasca juice powders containing MD 4–7 DE ranged from 18.3 to 26.3 g/100 g, in powders containing MD 13–17 DE from 21.9 to 39.6 g/100 g and in powders containing GA from 20.8 to 34.2 g/100 g. Hygroscopicity is a parameter that describes the flowability of powders very well, as more hygroscopic powders are less free flowing due to more adsorbed moisture (*31*). Both hygroscopicity and flowability depend on the glass transition temperature. The higher the glass transition temperature, the lower the hygroscopicity and the higher the flowability (*32*).

According to the ANOVA results, all observed parameters individually, as well as combined, had a significant influence on hygroscopicity of powders with all three carriers used. Powders produced with the MD 4–7 DE had the lowest hygroscopicity, followed by the MD 13–17 DE and the GA with the highest hygroscopicity. Vardin and Yasar (*11*) also reported higher hygroscopicity of powders produced with maltodextrin with higher dextrose equivalent (18 DE) in comparison with 7 DE. Low-molecular-mass maltodextrins are more susceptible to water adsorption due to more hydrophilic groups (*33*).

Higher mass per volume ratio of carrier material and higher drying temperatures had positive effect on hygroscopicity decrease, which is in accordance with previous findings. Moreira *et al.* (*34*) reported the decrease in hygroscopicity of acerola powders with an increase in temperature from 170 to 200 °C, explained by the lower moisture content. Tonon *et al.* (*14*) observed the influence of higher maltodextrin concentration on the decrease of hygroscopicity of acai powders.

The solubility of powders ranged from 81.8 to 96.1 % in those containing MD 4–7 DE, from 81.6 to 97.8 % in those with MD 13–17 DE and from 81.1 to 89.0 % in powders containing GA. It can be observed that regardless of the drying conditions, the powders with GA had significantly lower solubility than the ones with MD, which is related to the different structure and properties of gums and maltodextrins, although the GA is considered as the gum with high water solubility.

Both carrier mass per volume ratio and temperature significantly influenced the water solubility of powders with all carriers used (Table 2). General observation is that powders containing 30 % carrier mass per volume ratio have better solubility. Fazaeli *et al*. (*26*) also observed the positive effect of higher maltodextrin mass per volume ratio on the solubility of powders due to the high maltodextrin solubility in water. Contrary to these findings, Selvamuthukumaran and Khanum (*35*) reported the negative effect of higher maltodextrin mass per volume ratios on the solubility of sea buckthorn powder, caused by the higher amount of insoluble residue and more lumps formed during the dissolution. MD 13–17 DE carrier showed opposite behaviour under the influence of different temperatures compared to MD 4–7 DE and GA; its solubility decreased at higher drying temperatures. Quek *et al*. (*29*) reported the negative effect of temperature on the solubility of watermelon powders, similar to the behaviour of powders containing MD 13–17 DE in our study, while temperature increase favoured the solubility of black mulberry and pomegranate powder (*11,26*).

Bulk density of powders ranged from 0.23 to 0.48 g/mL in powders containing MD 4–7 DE, from 0.25 to 0.36 g/mL in powders containing MD 13–17 DE and from 0.24 to 0.45 g/mL in powders containing GA. Compared to the sour cherry Marasca juice powders, the bulk density of other powder juices was generally higher (in g/mL): pomegranate powder 0.579–0.687 (*11*), lime powder 0.41–0.69 (*36*), except for pitaya powder, which was lower, 0.29–0.34 (*37*).

Generally, the heavier the powder is, the more easily it fills the space between the particles, resulting in higher bulk density. Therefore, the bulk density includes the particles and the space between them and can be related to the powder porosity which includes only the space between the particles (*38*).

All observed drying parameters had a significant influence on bulk density of sour cherry Marasca juice powders regardless of the carrier used. In powders containing maltodextrin, bulk density was higher with lower carrier mass per volume ratio, contrary to powders containing GA. Regarding the drying temperature, powders produced with MD 4–7 DE had higher bulk density when dried at higher temperatures, while powders produced with MD 13–17 DE and GA had higher bulk density at lower temperatures.

The increase in drying temperature also caused lower bulk density of black mulberry powders in the study of Fazaeli *et al.* (*26*). Particularly, at higher temperatures the water evaporation rate is faster, dried powder has more porous and fragmented structure, larger particles are formed and therefore the bulk density is lower. Higher temperature usually results in larger particles with more inside cavities (*39*). The same trend is confirmed in studies on gac fruit aril powder (*2*) and pomegranate powder (*11*). Goula and Adamopouls (*40*) reported the increase in bulk density of powders with higher dextrose equivalent of maltodextrin while our results show no significant difference between MD 4–7 DE and MD 13–17 DE.

Table 3 shows the equations of regression models for product yield, moisture content, hygroscopicity, solubility and bulk density of sour cherry Marasca juice powders produced with MD 4–7 DE, MD 13–17 DE and GA. In these models, studied spray drying parameters (carrier mass per volume ratio and temperature) are combined in linear, quadratic and interaction coefficients, enabling the prediction of response variable values for any desired carrier mass per volume ratio and drying temperature. The adequacy of the model was checked by calculating the coefficient of determination, R^2, which is the proportion of variation in the response attributed to the model rather than to random error. It has been suggested that a good-fitting model should have R^2 no less than 80 %. As it can be observed, all models had the R^2 higher than 0.9, which implicates the adequacy of the models to predict the physicochemical properties of powders. While R^2 indicates how much of the observed variability in the data was accounted for by the model, R^2_{adj} modifies R^2 by taking into account the number of covariates or predictors in the model. An R^2_{adj} close to the R^2 values insures a satisfactory adjustment of the quadratic models to the experimental data. As it can be observed, all R^2_{adj} values were close to the R^2, implying that the models explained the observed powder properties very well. Results of the optimization of spray drying with each carrier are shown in Table 4. Optimization was carried out using the response surface methodology in order to obtain the drying parameters resulting in the powder with high production yield, low moisture content and hygroscopicity, high solubility and high bulk density. Optimal drying conditions are almost similar for powders with MD 4–7 DE and GA, the highest drying temperature of 200 °C, and about 30 % of carrier, twice higher than juice dry matter content, namely 27 % of MD 4–7 DE and 31 % of GA. For powders produced with MD 13–17 DE, required carrier addition is higher, 40 %, while drying temperature is lower, 150 °C. These differences are the result of the influence of maltodextrin with higher dextrose equivalent on the powder stickiness at higher temperatures when applied in lower mass per volume ratio.

The optimal conditions for spray drying depend primarily on the material that is to be dried. Therefore, Vardin and Yasar (*11*) reported the optimal temperature for pomegranate juice drying in the range from 125 to 145 °C, optimal juice dry matter to carrier ratio of 0.6–0.8 and car-

Table 3. Regression models for the physicochemical parameters of spray-dried sour cherry Marasca juice powder produced with the addition of maltodextrin (MD) with 4–7 and 13–17 dextrose equivalent (DE) and gum arabic (GA), and corresponding values of coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj})

Carrier	Response	Model	R^2	R^2_{adj}
MD 4–7 DE	Product yield	$-6814.82+466.84X_1-7.66X_1^2+80.72X_2-0.24X_2^2-5.45X_1X_2+0.02X_1X_2^2+0.09X_1^2X_2$	0.997	0.994
	Moisture content	$-102.45+8.012X_1-0.13X_1^2+1.011X_2-0.002X_2^2-0.077X_1X_2+0.001X_1^2X_2$	0.995	0.992
	Hygroscopicity	$-1571.24+120.16X_1-2.02X_1^2+17.14X_2-0.05X_2^2-1.3X_1X_2+0.02X_1^2X_2$	0.971	0.946
	Solubility	$2875.015-160.806X_1+2.381X_1^2-32.637X_2+0.093X_2^2+1.906X_1X_2-0.005X_1X_2^2-0.029X_1^2X_2$	0.990	0.980
	Bulk density	$2.53375+0.317177X_1-0.012493X_1^2-0.046082X_2+0.000201X_2^2-0.002655X_1X_2+0.000004X_1X_2^2+0.000133X_1^2X_2$	0.995	0.991
MD 13–17 DE	Product yield	$5509.751-397.496X_1+6.32X_1^2-61.203X_2+0.163X_2^2+4.441X_1X_2-0.012X_1X_2^2-0.071X_1^2X_2$	0.999	0.998
	Moisture content	$-1333.47+82.13X_1-1.20X_1^2+15.05X_2-0.04X_2^2-0.93X_1X_2+0.01X_1^2X_2$	0.999	0.999
	Hygroscopicity	$-4945.96+351.6X_1-5.65X_1^2+58.09X_2-0.17X_2^2-4.11X_1X_2+0.01X_1X_2^2+0.07X_1^2X_2$	0.995	0.991
	Solubility	$-88.88+34.8542X_1-0.9953X_1^2+2.7954X_2-0.0111X_2^2-0.4522X_1X_2+0.0015X_1X_2^2+0.0125X_1^2X_2$	0.976	0.955
	Bulk density	$16.7336-1.20783X_1+0.02196X_1^2-0.18481X_2+0.00053X_2^2+0.01367X_1X_2-0.00004X_1X_2^2-0.00025X_1^2X_2$	0.978	0.958
GA	Product yield	$1583.251-95.192X_1+1.151X_1^2-15.357X_2+0.039X_2^2+0.926X_1X_2-0.002X_1X_2^2-0.01X_1^2X_2$	0.995	0.991
	Moisture content	$395.26-25.792X_1+0.4283X_1^2-4.4448X_2+0.0124X_2^2+0.2968X_1X_2-0.0008X_1X_2^2-0.0049X_1^2X_2$	0.997	0.994
	Hygroscopicity	$-1574.97+106.22X_1-1.87X_1^2+16.65X_2-0.04X_2^2-1.11X_1X_2+0.02X_1^2X_2$	0.991	0.984
	Solubility	$-468.38+39.269X_1-0.567X_1^2+6.149X_2-0.017X_2^2-0.429X_1X_2+0.001X_1X_2^2+0.007X_1^2X_2$	0.968	0.940
	Bulk density	$9.9057-0.70614X_1+0.011482X_1^2-0.104354X_2+0.000271X_2^2+0.00759X_1X_2-0.00002X_1X_2^2-0.00012X_1^2X_2$	0.981	0.963

Table 4. Predicted and experimental values of physicochemical parameters of spray-dried sour cherry Marasca juice powder produced with the addition of maltodextrin (MD) with 4–7 and 13–17 dextrose equivalent (DE) and gum arabic (GA) at optimal conditions for each carrier used

	Optimal drying conditions			Product yield	Moisture content	Hygroscopicity	Solubility	Bulk density
	$\left(\frac{m(\text{carrier})}{V(\text{juice})}\right)/\%$	t/°C		%	%	g/100 g	%	g/mL
MD 4–7 DE	27	200	Predicted value	50.06	1.33	20.39	94.72	0.32
			Experimental value	51.17	1.30	20.04	95.08	0.32
MD 13–17 DE	40	150	Predicted value	46.79	2.59	22.94	96.04	0.32
			Experimental value	47.23	2.75	22.16	96.97	0.32
GA	31	200	Predicted value	44.18	3.37	29.06	88.88	0.30
			Experimental value	44.65	3.53	28.84	89.01	0.30

rier MD 7 DE rather than MD 18 DE. Krishnaiah *et al*. (*41*) used temperature of 95 °C and maltodextrin to dry matter ratio of 1.5 for drying of the noni extract, while Selvamuthukumaran and Khanum (*35*) applied temperature of 162.5 °C and 25 % carrier for optimized spray drying process of sea buckthorn juice. Having in mind the differences among the dried materials, all these results are comparable and in accordance with the findings in our study. On the other hand, Karaca *et al*. (*42*) researched similar material, sour cherry concentrate, and reported the optimal spray drying conditions to be 150 °C, 25 % sour cherry content with carrier MD 12 DE, resulting in yield higher than 85 %. The temperature effect findings are in accordance with our conclusions on higher dextrose equivalent maltodextrins but resulting yields are higher than in our study. These differences may derive from the higher carrier mass per volume ratio applied in the reported study as well as from the different spray dryers used, as construction differences, especially those regarding the outlet temperature control and outlet filters, influence the yield losses to a high extent. At defined optimal conditions, physicochemical parameters were predicted by the model and confirmed in experimental trials. Experimental results support the adequacy of the models for prediction of powder properties. It can be observed that powders produced with MD 4–7 DE had the highest product yield, the lowest moisture content and hygroscopicity, and the highest bulk density. On the other hand, powders containing GA had the lowest yield and solubility and the highest moisture content and hygroscopicity. Taking into account the above mentioned, it can be concluded that the MD 4–7 DE is the most suitable carrier for production of the spray-dried sour cherry juice Marasca powder with the best physicochemical properties.

Conclusions

This study confirmed that carrier material, its mass per volume ratio and drying temperature significantly affect the physical and chemical properties of spray-dried sour cherry Marasca juice powder. Generally, higher maltodextrin carrier amounts caused the increase in product yield, increase of both maltdextrin and gum arabic mass per volume ratio up to 30 % positively affected the powder solubility, while bulk density was highest at 40 % carrier addition. High carrier mass per volume ratio decreased the moisture content and hygroscopicity of powders. Higher drying temperature decreased their moisture content and bulk density. Maltodextrin with low dextrose equivalent showed better stickiness reduction properties than the one with higher dextrose equivalent, while gum arabic, although with good stickiness reduction properties, produced powders with lower yield and solubility, and with high moisture content and hygroscopicity.

According to the obtained results, it can be concluded that the sour cherry Marasca juice powder with the optimal physicochemical properties is produced with the addition of 27 % of maltodextrin with dextrose equivalent of 4–7 at drying temperature of 200 °C. Further studies have to be done regarding the influence of the abovementioned parameters on the phenolic content of the obtained powders in order to design the final product.

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