Article

FOOD SCIENCE AND TECHNOLOGY INTERNATIONAL

Physical and functional properties of spray-dried powders from blackcurrant juice and extracts obtained from the waste of juice processing

Diego Archaina[1,2], Graciela Leiva[3], Daniela Salvatori[2,4] and Carolina Schebor[2,5]

Abstract

Blackcurrants contain high levels of polyphenolics, particularly flavonols and anthocyanins, which contribute to their high antioxidant activity. The aims of this work were the recovery of bioactive compounds from the remaining solid (waste) after processing blackcurrant juice and to obtain spray-dried powders from the blackcurrant juice and extracts. The extraction of bioactive compounds from the fruit pulp was performed by ultrasound-assisted extraction. Experiments were conducted to select the more suitable solvent, and citric acid was chosen. Then, to optimize the extraction conditions (time, solvent concentration, and amplitude) an experimental design using a Box–Behnken Design was done. Comparing the optimized extract with the fruit, 31% total monomeric anthocyanins, 19% total phenolic compounds, and 10% antioxidant capacity were obtained. The optimized extract and the juice were mixed and spray dried, using maltodextrin as carrier matrix. A blackcurrant powder with low hygroscopicity 14.46 ± 0.13 (g a.w./100 g d.m) and high solubility $94.25 \pm 4\%$ was obtained. High concentration of bioactive compounds and antioxidant capacity was recorded: Total monomeric anthocyanins 63.01 ± 1 (mg cyn-3-glu/100 g.d.m), total phenolic content 116.87 ± 5 (mg gallic acid/100 g d.m.), and antioxidant capacity 144.40 ± 0.11 (mg eq Trolox/100 g.d.m.).

Keywords

Bioactive compounds, blackcurrant, spray drying, ultrasound-assisted extraction

Date received: 17 February 2017; accepted: 31 July 2017

INTRODUCTION

The benefit of fruits in the human diet has received considerable attention in the recent years due to their rich amount of phenolic compounds with different biological activities (Chang et al., 2016; Li et al., 2014). Blackcurrants have been labeled as ''superfruits'' because they are an important source of health promoting phytochemicals, with strong immunomodulatory, antimicrobial, and anti-inflammatory actions, together with a reduction of cardiovascular diseases, improvement of skin condition, reduction of blood pressure, and cancer prevention (Gopalan et al., 2012; Wallace, 2011; Yonei et al., 2012).

Color is an important quality indicator that may contribute to the consumer preference and acceptance of foods (Downham and Collins, 2001). Recently, market

Food Science and Technology International 0(0) 1–9

DOI: 10.1177/1082013217729601
journals.sagepub.com/home/fst
SAGE

[1]Facultad de Bromatología, Universidad Nacional de Entre Ríos, Concepción del Uruguay, Argentina
[2]CONICET, Buenos Aires, Argentina
[3]Departamento de Química Orgánica, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Buenos Aires, Argentina
[4]PROBIEN (CONICET-Universidad Nacional del Comahue), Buenos Aires, Argentina
[5]Departamento de Industrias, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Buenos Aires, Argentina

Corresponding author:
Graciela Leiva, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón II, 3° Piso, Ciudad Autónoma de Buenos Aires 1428, Argentina.
Email: leiva@qo.fcen.uba.ar

for the application of synthetic colorants diminished since the human safety of synthetic food dyes has been legally questioned. Therefore, there is an increasing interest of food producers to replace their synthetic food colorants with natural coloring agents (Szalóki-Dorkó et al., 2015). Anthocyanins are water soluble plant pigments with attractive colors varying from red to purple (Kong et al., 2003) that could be suitable as colorants for low pH food as their molecules structure are more stable in acid conditions (Bakowska-Barczak, 2005). Anthocyanins have high antioxidant capacity (AC), so the use of these pigments obtained from berries extracts as natural colorants and natural antioxidants seems to be promising (Szalóki-Dorkó et al., 2015).

The spray-drying method offers an interesting alternative for drying fruit juices, preserving many properties of interest in the product. There have been numerous studies on drying of fruit juices with the addition of various matrices to obtain physically stable and nonsticky powders: raspberry and apricot (Bhandari et al., 1993) and blackberry (Franceschinis et al., 2014) among others. Additionally, there is growing trend in the use of berries extracts as ingredients in functional foods and dietary supplements, which may also be combined with other fruits, vegetables, and herbal extracts (Wang and Jiao, 2000). However, the main problem in extracts production is that the conventional solvent extraction methods require long times and usually have low efficiency. Also, the application of thermal extraction may deteriorate anthocyanins and the antioxidant activity of the extracts may diminish (Camel, 2000; Lapornik et al., 2005). An alternative technique is ultrasound-assisted extraction (UAE), which uses acoustic cavitation to cause increased mobility of the solvent and samples improving the efficiency, and reducing extraction time, and solvent consumption (Rostagno et al., 2003; Wu et al., 2001). Regarding the use of UAE to obtain berries extracts, Chen et al. (2007) produced an anthocyanins-rich extract from red raspberry using 1.5 M HCl–95% ethanol (15:85) as solvent, while Galvan D'Alessandro et al. (2014) produced a phenolics-rich extract from black chokeberry using water:ethanol (50:50) as extraction solvent.

The objectives of this work were (1) to optimize the extraction method by UAE to recover antioxidant compounds from the remaining solid waste after processing blackcurrant juice; and (2) to use these juices and optimized extracts to obtain spray-dried powders with the potential use as natural colorants or functional ingredients.

MATERIALS AND METHODS

Materials

Individual Quick Frozen blackcurrants (*Ribes nigrum*) Titania cultivar were purchased from local market. The used carrier matrix was a food grade maltodextrin (MD) DE 12. Analytical-grade reagents were used in all cases.

Fruit characterization

The fruit was characterized according to AOAC methods: moisture (920.62), soluble solids (932.12), acidity (945.26), pH (945.27) to AOAC (2000).

Samples preparation

Frozen fruits were thawed for 30 min at 40 °C, then they were milled with a mixer for 2 min, and finally centrifugation (10,000 r/min, 4 °C, 30 min) was applied to obtain 50% juice (supernatant) and 50% pulp (precipitate).

UAE

The pulp was sonicated using an ultrasonic processor UP100H (Teltow, Germany). A first set of experiments was carried out to select the more suitable solvent for the antioxidant compounds extraction. Then, a second set of experiments were done to optimize the extraction conditions (time, solvent concentration, and amplitude):

a. The first set of experiments, conditions: extraction time: 0, 5, and 10 min; extraction solvent: H_2O, H_2O–ethanol 96% (ETOH) (50:50), H_2O–citric acid 1.5 M and 3.0 M (85:15), and ETOH 96%–HCl 1.5 M (85:15); amplitude: 0 and 100%.
b. The second set of experiments was done applying an experimental design using a three-level and three factors Box–Behnken Design (BBD). The complete design consisted of 18 experimental points including three replications of the center point. The conditions used in UAE were extraction time: 0.50, 5.25, 10 min; citric acid concentration: 0, 1, 2 M; and amplitude: 20, 60, and 100%.

A ratio fruit:solvent (1:3) was used for ultrasonic extraction according to the procedure employed by Chen et al. (2007); later the samples were centrifuged at 10,000 r/min, 4 °C for 30 min. Finally, the supernatant "sonicated extract" was separated and frozen until use.

Spray-drying process

Considering the low yield of fruit juice obtained, juice and extract concentration of feed formulation were defined in order to take full advantage of the antioxidant content of the fruit pulp (waste). A mixture

containing 15% of blackcurrant juice and 85% of sonicated extract was prepared, and MD (40% w/w) as carrier matrix according to Franceschinis et al. (2014).

The spray drying was carried out using a laboratory-scale device, Mini Spray Dryer Büchi B290 (Flawil, Switzerland) with the following parameters: inlet air temperature of 150 °C, flow rate 8 ml/min, air pressure 3.2 bar, and 1.5 mm nozzle diameter. The obtained powders were hermetically kept and then stored at −18 °C.

Chemical and functional properties

A spectrophotometer Jasco V-630 ultraviolet-visible (Jasco International Co., Ltd, Tokyo, Japan) was used in all chemical determinations. For powder measurements, they were reconstituted as follows: 0.50 g of powder was dissolved in 25 ml distilled water. All samples were subjected to the same methodology for comparison purposes.

Extraction and determination of total monomeric anthocyanin (TMA)

TMA was extracted using an ethanolic extract prepared by homogenizing 3.00 g of sample in 35 ml of acidified ethanol (HCl 1.5 N 5%), then mixed constantly for 15 min using a magnetic stirrer and filtered by vacuum. Due to cloudiness in the solution obtained from powder samples, centrifugation at 15,000 r/min, 10 °C for 15 min was used instead of filtering. The extraction procedure was done two more times with 10 and 5 ml of acidified ethanol, respectively. The obtained extracts were combined in a 50 ml volumetric flask and brought to volume with acidified ethanol.

TMA content was measured using the pH-differential method (Giusti and Wrolstad, 2001). The results were expressed as milligram of cyanidin-3-glucoside per 100 g sample (mg cyd-3-glu/100 g s) and for powder sample as milligram of cyanidin-3-glucoside per 100 g of dry matter (mg cyn-3-glu/100 g.d.m.)

Extraction for determination of total phenolic compounds (TPCs) and AC

A methanolic extract (ME) was prepared weighing about 2.50 g of sample and then mixing with 7.5 ml of methanol for 3 min in a magnetic stirrer and filtered by vacuum. Due to cloudiness in the solution obtained from powder samples, centrifugation at 15,000 r/min, 10 °C for 15 min was used instead of filtering. The extraction procedure was done two more times with the same procedure. The obtained extracts were combined in a 25 ml volumetric flask and brought to volume with methanol.

TPC determination

TPC determination was carried out using the Folin–Ciocalteu method described by Singleton and Rossi (1965) with some modifications. 100 µl of ME was mixed with 900 µl water, 100 µl Folin–Ciocalteau reagent and 600 µl 20% sodium carbonate in NaOH 0.1 N. After incubation during 30 min at 40 °C, the absorbance was measured at 765 nm. Solutions of gallic acid (0–0.3 mg/ml) were used to construct the calibration curve ($r^2 = 0.9949$). The results were expressed as milligram of gallic acid equivalents per 100 g of sample (mg GAE/100 g s) and for powder as milligram of gallic acid equivalents per 100 g of dry matter (mg GAE/100 g.d.m.).

AC determination

AC was determined by Trolox Equivalent Antioxidant Capacity assay proposed by Re et al. (1999) using the 2,2-azinobis-[3-ethylbenzothiazoline-6-sulfonic] acid (ABTS) to produce the cationic free radical (ABTS·+). ABTS·+, was generated by the interaction of 0.0194 g of ABTS reagent, 0.0033 g of potassium persulfate, and 5.00 ml of bidistilled water and kept in the dark at room temperature for 16 h. Subsequently, the solution was diluted with phosphate buffer pH 7.40 to an absorbance of 1.00 ± 0.01 at 734 nm. Aliquots of 0.1 ml were added to 1.9 ml of ABTS·+ solution and after 30 min at 25 °C, absorbance was measured at 734 nm. Solutions of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) were used to construct the calibration curve (0.02–0.12 mg/ml of Trolox) ($r^2 = 0.9890$)). The results were expressed as milligram equivalents of Trolox per 100 g of sample (mg eq Trolox/100 g s) and for powder sample as milligram equivalents of Trolox per 100 g of dry matter (mg eq Trolox/100 g.d.m.)

Physical properties of the powder

Solubility. Solubility was measured according to Franceschinis et al. (2014). A total of 1 g of blackcurrant juice powder was hydrated in 100 ml of bidistilled water and stirred at high velocity during 5 min. Reconstituted juice was transferred to conical tubes and centrifuged at 3000 r/min during 5 min. Supernatant (20 ml) was transferred to a preweighed porcelain capsule and oven dried at 105 °C to constant weight. Solubility (%) was calculated by weight difference.

Bulk and tapped density. Bulk (δ_B) and tapped (δ_T) density were determined according to Swaminathan et al. (2015), with some modifications. Bulk density (g/ml) was determined by measuring the volume of 1 g

of powder using a 10 ml graduated cylinder. After measuring the sample volume, the cylinder was held for 1 min on a vortex mixer, and the volume was measured again. Tapped density was calculated as the relationship of mass/volume. The result was the average of three replicate measurements.

Flowability (Carr index) and cohesiveness (Hausner ratio). Carr index (C_I) was estimated as described by Jinapong et al. (2008) (equation (1)). C_I defines flowability levels of powders considering the following scale: (a) C_I values below 15% are very good, (b) C_I values between 15 and 20% are good, (c) C_I values between 20 and 35% are fair, (d) C_I values between 35 and 45% are bad, and (e) C_I values above 45% are very bad (Swaminathan et al., 2015). The cohesiveness was analyzed in terms of Hausner ratio (H_R) (equation (2)) where levels below 1.2 are considered low, between 1.2 and 1.4 are intermediate, and above 1.5 are high (Jinapong et al., 2008).

$$C_I = \frac{(\delta_T - \delta_B)x100}{\delta_T} \quad (1)$$

$$H_R = \frac{\delta_T}{\delta_B} \quad (2)$$

Thermal transitions. Glass transition was measured by differential scanning calorimetry (DSC; onset values) using a DSC 822 Mettler Toledo calorimeter (Schwerzenbach, Switzerland). The equipment was calibrated with indium (156.6 °C), lead (327.5 °C), and zinc (419.6 °C). All measurements were carried out at a heating rate of 10 °C/min from −30 °C to 50 °C. Hermetically sealed 40 µl medium pressure pans were employed (an empty pan served as reference) with 10 mg sample mass, approximately. The thermograms were evaluated using Mettler Star^e program. An average value of two replicates was reported.

Hygroscopicity. Hygroscopicity was evaluated by Swaminathan et al. (2015) method with modifications. One gram of powder was placed in a container at 25 °C with a saturated NaCl solution (75% RH). Samples were weighed during nine days, and hygroscopicity was expressed as grams of adsorbed water per 100 g of dry matter (g a.w./100 g d.m.) as an average of two replicates.

Statistical analysis. The experimental design, data analysis, and response surface plots were made with the Statgraphics Centurion XVI statistical program (Virginia, USA, 2009).

RESULTS AND DISCUSSION

Table 1 shows some physicochemical properties studied to characterize the frozen fruit and the blackcurrant juice. Regarding the whole fruits, the obtained results were within the ranges reported by other authors. Djordjevic et al. (2013) reported a soluble solids content of 13.3°Brix for blackcurrant of Titania variety. On the other hand, Rubinskiene et al. (2005) informed a range of soluble solids content between 14.01 and 16.14°Brix, and total acidity values in a range from 2.30 to 3.06 mg citric acid/100 g for fresh fruit. Stéger-Máté et al. (2011) reported a water content of 79.6% for Titania variety.

Djordjevic et al. (2013) reported a content of anthocyanins of 52.8 mg cyn-3-glu/100 g of fresh blackcurrant of Titania variety; however, they used different TMA determination methods. Regarding total polyphenols content, Djordjevic et al. (2013) reported values of 137.7 ± 2.1 mg GAE/100 g for blackcurrant fruit of Titania variety. Flores and Ruiz del Castillo (2016) studied two blackcurrant cultivars (Ben Alder and Ben Hope) and reported AC values similar to those obtained in this paper.

The blackcurrant juice was produced after milling and centrifugation of the fruit, obtaining a relatively low yield (50%). The precipitate obtained after centrifugation (50%) showed a dark red color, suggesting a

Table 1. Chemical characterization of blackcurrant fruit and juice

Property	Fruit	Juice
Water content (g H_2O/100 s)	74.1 ± 2.59	85.5 ± 0.06
Total soluble solid (°Brix at 20 °C)	16.7 ± 0.26	16.4 ± 0.06
Total acidity (mg citric acid/100 g s)	3.02 ± 0.02	3.25 ± 0.06
pH	2.83 ± 0.01	2.87 ± 0.02
Total monomeric anthocyanins (mg cyn-3-glu/100 g s)	170.41 ± 0.01	157.5 ± 0.15
Total phenolic content (mg gallic acid/100 g s)	288.0 ± 0.01	96.85 ± 0.03
Antioxidant capacity (mg eq Trolox/100 g s)	537.8 ± 1.07	352.7 ± 0.93

high concentration of bioactive compounds. Therefore, UAS was used to obtain blackcurrant extracts from the precipitate in order to add the extracts to the juice. A first set of experiments was done using different solvents, and the obtained extracts showed the following pH values: (a) water: 2.85, (b) water–ethanol: 3.60, (c) water–citric acid 1.5 M: 1.33, (d) water–citric acid 3 M: 1.04, (e) ethanol–HCl: 0.92. Figure 1 shows values of TMA (Figure 1(a)) and AC (Figure 1(b)) obtained for the different extracts. TMA values around 40% of those obtained in the juice could be reached, and the extraction was favored by acidic medium. At longer sonication times (10 min) there was a decrease in the anthocyanins concentration for water, water–ethanol, and ethanol–HCl solvents, possibly due to their destruction. However, in the presence of citric acid, the opposite behavior was observed. The best condition for the extraction of anthocyanins was the application of ultrasound during 10 min in the presence of water–citric acid solvent. The lowest AC values were obtained in the presence of water as solvent (Figure 1(b)).The behavior of AC was rather different to that of TMA, showing fewer differences between 5 and 10 min treatment. Also, the increase in acid concentration reduced the AC. When comparing with the blackcurrant juice (Table 1), AC values up to 14% were obtained.

Given that the higher TMA values were obtained in the presence of citric acid, a second set of experiments was developed in order to optimize the extraction conditions using citric acid as solvent. In this case, an experimental design was performed, using a three-level and three factors BBD. A statistical response surface analysis was performed to optimize the conditions of UAE. Table 2 shows the complete experimental design used to optimize the UAE conditions and investigate the effects of three independent variables (extraction time, citric acid concentration, amplitude) on TMA, TPC, and AC values of blackcurrant extracts.

The regression model was predicted by equations (3), (4), and (5)

$$Y_{TMA} = 12.1328 + 0.393689X_1 + 53.9483X_2 + 0.161992X_3 - 0.0700143(X_1)^2 + 0.256755X_2^1 - 0.000499822X_3^1 - 19.1909(X_2)^2 + 0.0832315X_3^2 - 0.00137848(X_3)^2, r^2 = 0.9302 \quad (3)$$

$$Y_{TPC} = 19.1157 + 5.2854X_1 + 79.2935X_2 + 0.755171X_3 - 0.694977(X_1)^2 + 0.216635X_2^1 + 0.016979X_3^1 - 29.3790(X_2)^2 + 0.0896957X_3^2 - 0.0081953(X_3)^2, r^2 = 0.9173 \quad (4)$$

$$Y_{AC} = 21.2833 - 1.57416X_1 + 21.6343X_2 + 0.119715X_3 + 0.0774451(X_1)^2 + 0.376793X_2^1 + 0.0312515X_3^1 - 8.74158(X_2)^2 + 0.0467729X_3^2 - 0.0019379(X_3)^2, r^2 = 0.7886 \quad (5)$$

Figure 2 shows the effect of extraction time and citric acid concentration on TMA (Figure 2(a)), TPC (Figure 2(b)), and AC (Figure 2(c)) at amplitude of 60%. It can be observed that extraction time did not significantly affect the amount of TMA and TPC; however, it caused an increase in AC. On the other

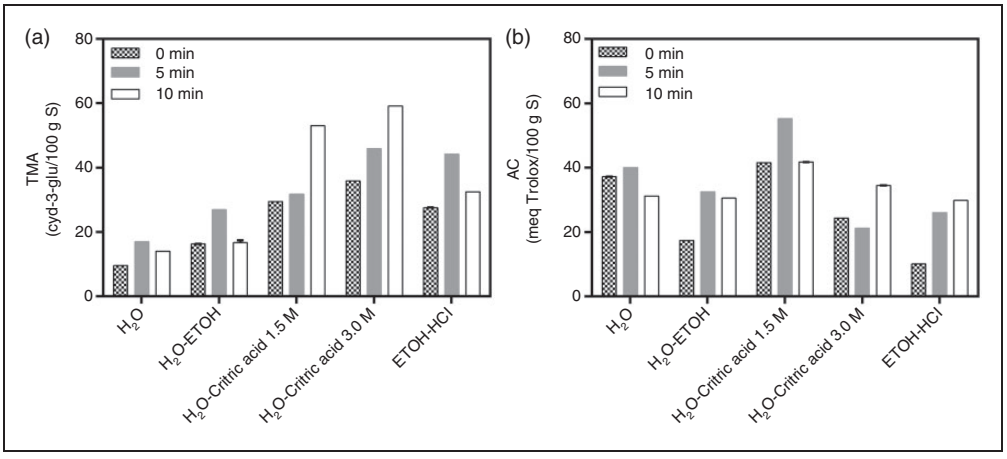

Figure 1. TMA (a) and AC (b) values obtained for the UAE extracts with different conditions (extraction time, extraction solvent, and amplitude).
AC: antioxidant capacity; TMA: total monomeric anthocyanin; UAE: ultrasound-assisted extraction.

Table 2. Experimental data and the observed responses values with different combinations of extraction time (X_1), solvent concentration (X_2), and ultrasonic amplitude (X_3) used in the Box–Behnken design (BBD)

	Factor values			Response values[a]		
Run no.	X_1 (min)	X_2 (M)	X_3 (%)	TMA (mg cyd-3-glu per 100 g s)	TPC (mg GAE per 100 g s)	AC (mg eq Trolox per 100 g s)
1	0	0	0	13.11 ± 0.007	27.35 ± 0.031	19.85 ± 0.070
2	0	1.0	0	41.07 ± 0.023	54.25 ± 0.376	30.28 ± 0.059
3	0	2.0	0	43.20 ± 0.017	68.39 ± 0.042	28.47 ± 0.041
4	5.25	0	100	15.18 ± 0.061	23.33 ± 0.144	21.96 ± 0.088
5	10.0	1.0	100	56.69 ± 0.016	74.87 ± 0.034	61.56 ± 0.039
6	0.50	1.0	20	60.06 ± 0.029	85.87 ± 0.032	43.65 ± 0.044
7	0.50	1.0	100	55.85 ± 0.061	85.86 ± 0.086	37.04 ± 0.050
8	10.0	0	60	13.99 ± 0.004	32.14 ± 0.057	32.80 ± 0.058
9	10.0	1.0	20	53.13 ± 0.005	64.74 ± 0.068	33.76 ± 0.043
10	5.25	0	20	12.06 ± 0.045	42.20 ± 0.085	25.68 ± 0.060
11	0.50	2.0	60	57.06 ± 0.025	82.61 ± 0.162	34.20 ± 0.046
12	5.25	2.0	100	67.99 ± 0.030	86.02 ± 0.046	42.67 ± 0.041
13	5.25	2.0	20	53.13 ± 0.010	90.59 ± 0.044	38.42 ± 0.045
14	10.0	2.0	60	57.06 ± 0.039	86.88 ± 0.092	55.42 ± 0.019
15	0.50	0	60	17.70 ± 0.030	31.96 ± 0.020	19.09 ± 0.026
16	5.25	1.0	60	66.01 ± 0.007	106.97 ± 0.054	48.74 ± 0.043
17	5.25	1.0	60	57.82 ± 0.024	108.13 ± 0.086	39.84 ± 0.024
18	5.25	1.0	60	46.91 ± 0.041	110.24 ± 0.026	34.06 ± 0.005

AC: antioxidant capacity; GAE: gallic acid equivalent; TMA: total monomeric anthocyanin; TPC: total phenolic compound.
[a]Data expressed in above table are the mean and standard deviations of triplicate analyses.

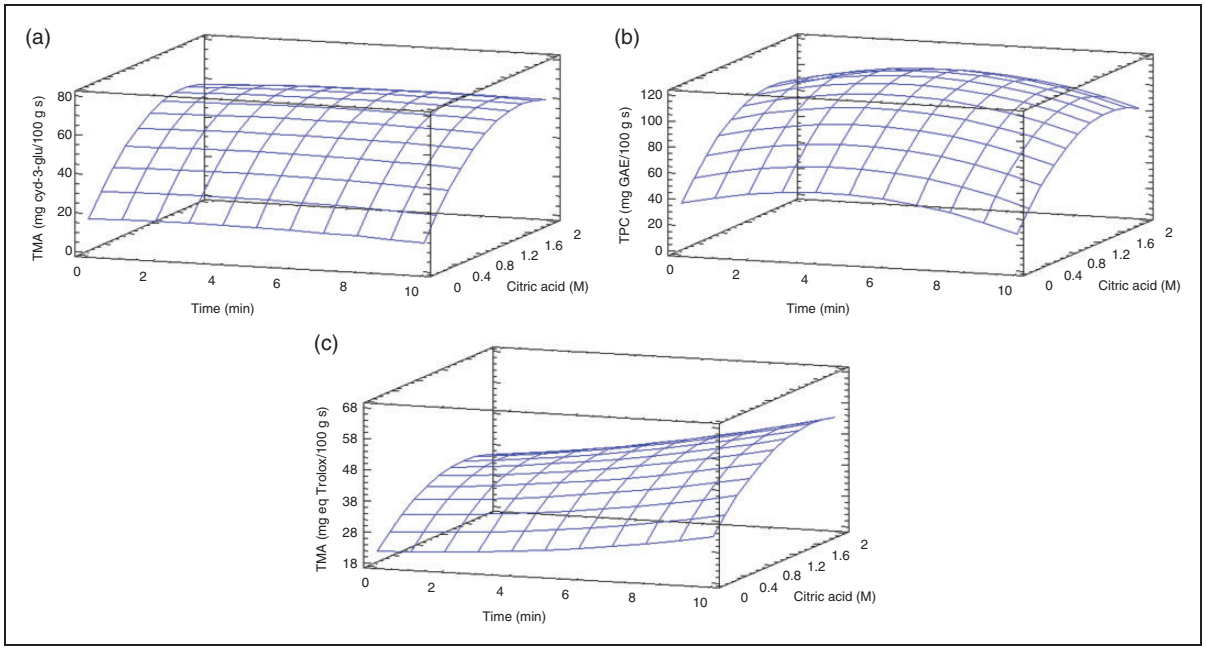

Figure 2. Response surface plot showing the effect of extraction time and citric acid concentration on TMA (a), TPC (b), and AC (c). Amplitude is constant, 60%.
AC: antioxidant capacity; TMA: total monomeric anthocyanin; TPC: total phenolic compound.

Table 3. Optimal conditions for each response value

Response values	Factor values		
	X_1	X_2	X_3
TMA	5.49	1.67	100
TPC	4.75	1.46	59
AC	10.0	1.72	100

AC: antioxidant capacity; TMA: total monomeric anthocyanin; TPC: total phenolic compound.

hand, the increase in citric acid concentration caused an increase in the three studied variables, up to a concentration close to 1.3 M at which the bioactive compounds concentration and the AC diminished. A slight increase in the three studied variables was detected with the increase in amplitude, particularly for TMA and AC (not shown).

In order to select the more appropriate extraction conditions, an optimization was performed using the statistical program (Table 3). The optimal extraction conditions suggested by the statistical program were different for the three studied variables (Table 3). For TPC, milder extraction conditions were favorable when compared to TMA and AC. We decided to prioritize high levels of anthocyanins and antioxidant activity, therefore, the extraction conditions chosen were the following: X_1: 7.45 min; X_2: 1.70 M; X_3: 100%. The concentration of bioactive compounds of the optimized extract was the following: TMA: 52.46 ± 0.01 mg cyn-3-glu/100 g s; TPC: 54.80 ± 0.01 mg gallic acid/100 g s; AC: 53.04 ± 1.13 meq Trolox/100 g s. The observed values for TMA, TPC, and AC were 33, 56.5, and 15%, respectively, with respect to the juice (Table 1). These results indicate that the obtained extract could contribute with bioactive compounds to fruit juices or other beverages.

In order to obtain a powder with good functional properties, the juice and the optimized extract obtained by UAE were mixed. This product was dried using MD as carrier. In a previous study powders of blackberry juice were obtained by spray drying and MD offered very good carrier properties (Franceschinis et al., 2014). Table 4 shows some properties of the spray-dried powder. Water activity and water content values were similar to those obtained by Franceschinis et al. (2014) for blackberry juice dried using the same MD employed in this study. The powder was in the glassy state at room temperature; however, the glass transition temperature (T_g) value was relatively low, probably due to the presence of citric acid and low molecular weight compounds present in the fruit. Fang and Bhandari (2012) spray-dried bayberry juice with MDs carrier (ratio 50:50), obtaining a T_g value of 35 °C, a_w: 0.232 and a water content of 3.74%. Regarding hygroscopicity, the obtained value was similar to that reported by Tonon et al. (2008) for açai fruit powder. These authors observed the lowest hygroscopicity values when the highest MD concentration was used. MD is a low hygroscopic material, confirming its proper use as a carrier agent. In our case, the observed low hygroscopicity value could be related to the high MD concentration in the powder.

Table 4. Physicochemical and functional properties of blackcurrant powder

Properties	Powder
Water activity (a_w measured at 25 °C)	0.153 ± 0.001
Water content (g H_2O/100 g.d.m.)	2.68 ± 0.08
Glass transition temperature (T_g, °C)	38.0 ± 1.0
Solubility (%)	94.25 ± 4.24
Bulk density (δ_B) (g/ml)	0.39 ± 0.07
Tapped density (δ_T) (g/ml)	0.41 ± 0.08
Cohesiveness. (H_R)	1.04 ± 0.00
Flowability (C_I)	4.88 ± 0.01
Hygroscopicity (g.a.w/100 g.d.m)	14.46 ± 0.13
Total monomeric anthocyanins (mg cyn-3-glu/100 g.d.m)	63.01 ± 1.01
Total phenolic content (mg gallic acid/100 g.d.m.)	116.87 ± 5.48
Antioxidant capacity (mg eq Trolox/100 g.d.m.)	144.40 ± 0.11

A powder with a high degree of solubility was obtained, with values of solubility similar to those reported by Franceschinis et al. (2014) for spray-dried blackberry juice, and Fazaeli et al. (2012) for spray-dried black mulberry juice. As it can be seen, cohesiveness in terms of H_R was low according to Jinapong et al. (2008), and flowability expressed as C_I was very good, as described by Swaminathan et al. (2015).

CONCLUSIONS

In this work we showed that it is possible to take advantage of the waste obtained from the production of blackcurrant juice to get an extract that can enrich the fruit juice, to obtain a powder with good functional properties. UAE proved to be an adequate technique to improve bioactive compounds extraction. The obtained powder had high bioactive compounds concentration, suggesting that it could result in an interesting contribution if used as a functional ingredient for the food, cosmetic, and pharmaceutical industries. Additionally, the powder presented good physical properties, in terms of hygroscopicity, solubility, cohesiveness, and flowability.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by University of Buenos Aires (UBACYT 20020150100188BA), the National Council for Scientific and Technical Research (PIP 11220120100224), and the National Agency for the Promotion of Scientific and Technical Research (PICT-2014-2250).

REFERENCES

AOAC. (2000). *Official Methods of Analysis of AOAC International*, 17th ed. Gaithersburg, MD: Association of Official Analytical Chemist.

Bakowska-Barczak A. (2005). Acylated anthocyanins as stable, natural food colorants – A review. *Polish Journal of Food and Nutrition Sciences* 14/55: 107–116.

Bhandari BR, Senoussi A, Dumoulin ED and Albert A. (1993). Spray drying of concentrated fruit juices. *Drying Technology* 11: 1081–1092.

Camel V. (2000). Microwave-assisted solvent extraction of environmental samples. *Trends in Analytical Chemistry* 19: 229–248.

Chang SK, Alasalvar C and Shahidi F. (2016). Review of dried fruits: Phytochemicals, antioxidant efficacies, and health benefits. *Journal of Functional Foods* 21: 113–132.

Chen F, Sun Y, Zhao G, Liao X, Hu X, Wu J, et al. (2007). Optimization of ultrasound-assisted extraction of anthocyanins in red raspberries and identification of anthocyanins in extract using high-performance liquid chromatography-mass spectrometry. *Ultrasonics Sonochemistry* 14: 767–778.

Djordjevic B, Savikin K, Zdunic G, Jankovic T, Vulic T, Pljevljakusic D, et al. (2013). Biochemical properties of the fresh and frozen black currants and juices. *Journal of Medicinal Food* 16: 73–81.

Downham A and Collins P. (2001). Colouring our foods in the last and next millennium. *International Journal of Food Science and Technology* 35: 1–22.

Fang Z and Bhandari B. (2012). Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. *Food Research International* 48: 478–483.

Fazaeli M, Emam-Djomeh Z, Ashtari AK and Omid M. (2012). Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder. *Food and Bioproducts Processing* 90: 667–675.

Flores G and Ruiz del Castillo ML. (2016). Accumulation of anthocyanins and flavonols in black currants (*Ribes nigrum* L.) by pre-harvest methyl jasmonate treatments. *Journal of the Science of Food and Agriculture* 96: 4026–4031.

Franceschinis L, Salvatori D, Sosa N and Schebor C. (2014). Physical and functional properties of blackberry freeze- and spray-dried powders. *Drying Technology: An International Journal* 32: 197–207.

Galvan D'Alessandro L, Dimitrov K, Vauchel P and Nikov I. (2014). Kinetics of ultrasound assisted extraction of anthocyanins from *Aronia melanocarpa* (black chokeberry) wastes. *Chemical Engineering Research and Design* 92: 1818–1826.

Giusti M and Wrolstad R. (2001). Anthocyanins: Characterization and measurement with UV–visible spectroscopy. *Current Protocols in Food Analytical Chemistry* 2: 1–13.

Gopalan A, Reuben SC, Ahmed S, Darvesh AS, Hohmann J and Bishayee A. (2012). The health benefits of blackcurrants. *Food and Function* 3: 795–809.

Jinapong N, Suphantharika M and Jamnong P. (2008). Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. *Journal of Food Engineering* 84: 194–205.

Kong JM, Chia LS, Goh NK, Chia TF and Brouillard R. (2003). Analysis and biological activities of anthocyanins. *Phytochemistry* 64: 923–933.

Lapornik B, Prošek M and Wondra AG. (2005). Comparison of extracts prepared from plant by-products using different solvents and extraction time. *Journal of Food Engineering* 71: 214–222.

Li A-N, Li S, Zhang Y-J, Xu X-R, Chen Y-M and Li H-B. (2014). Resources and biological activities of natural polyphenols. *Nutrients* 6: 6020–6047.

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M and Rice-Evans C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine* 26(9/10): 1231–1237.

Rostagno M, Palma M and Barroso CG. (2003). Ultrasound-assisted extraction of soy isoflavones. *Journal of Chromatography A* 1012: 119–128.

Rubinskiene M, Viskelis P, Jasutiene I, Viskeliene R and Bobinas C. (2005). Impact of various factor son the composition and stability of black currant anthocyanins. *Food Research International* 8: 867–871.

Singleton V and Rossi J. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal Enology Viticulture* 16: 144–158.

Stéger-Máté M, Nótin B, Juhász R, et al. (2011). Effect of vacuum drying on blackcurrant's antioxidant components. In: Taoukis PS, Stoforos NG, Karathanos VT, et al. (eds) *Proceedings of the 11th International Congress on Engineering and Food, Food Process Engineering in a Changing World*, Vol. 3, 22–26 May, pp. 2213–2214. Athens, Greece: Cosmosware.

Swaminathan S, Sowriappan JDB, Sneha F and Malela S. (2015). Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. *Powder Technology* 274: 37–43.

Szalóki-Dorkó L, Stéger-Máté M and Abrankó L. (2015). Evaluation of colouring ability of main European elderberry (*Sambucus nigra* L.) varieties as potential resources of natural food colourants. *International Journal of Food Science and Technology* 50: 1317–1323.

Tonon R, Brabet C and Hubinger MD. (2008). Influence of process conditions on the physicochemical properties of acai (*Euterpe oleracea* Mart.) powder produced by spray drying. *Journal of Food Engineering* 88: 411–418.

Wallace TC. (2011). Anthocyanins in cardiovascular disease. *Advances in Nutrition* 2: 1–7.

Wang SY and Jiao HJ. (2000). Scavenging capacity of berry crops on superoxide radicals hydrogen peroxide hydroxyl radicals and singlet oxygen. *Journal of Agricultural and Food Chemistry* 48: 5677–5684.

Wu J, Lin L and Chau F-T. (2001). Ultrasound-assisted extraction of ginseng saponins from ginseng roots and cultural ginseng cells. *Ultrasonics Sonochemistry* 8: 347–352.

Yonei Y, Ashigai H, Ogura M, Yagi M, Kawachi Y and Yanai T. (2012). Effect of consumption of a cassis polysaccharide-containing drink on skin function: A double blind randomized controlled trial of 9-week treatment. *Anti-Aging Medicine* 9: 34–42.