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Riječ gostujuće urednice

Poštovani čitatelji Glasila Future,

Iznimno mi je zadovoljstvo predstaviti Vam poseban broj časopisa čija je tematika posvećena ispitivanju kvalitete, funkcionalnosti te specifičnosti uvjeta procesiranja različitih vrsta hrane i pića. Osobita vrijednost ovog broju su radovi vezani uz funkcionalnu hranu. Funkcionalni prehrambeni proizvodi su posljednjih godina u posebnom fokusu kako znanstvenika tako i potrošača prvenstveno zbog njihovog blagotvornog i pozitivnog utjecaja na zdravlje. Rad autora izv. prof. dr. sc. Ante Lončarić i suradnika prikazuje istraživanje učinaka prerade i skladištenja na nutritivna i antioksidativna svojstva batata. Rezultati istraživanja ukazuju kako pojedini uvjeti procesiranja omogućuju proizvodnju batata kao sigurne prerađene funkcionalne hrane. Doc. dr. sc. Mladenka Šarolić i suradnici su ispitivali kako vrijeme skladištenja (čuvanja) utječe na aromatični profil djevičanskih maslinovih ulja analizirajući sastav hlapljivih spojeva svako tri mjeseca kroz period od godine dana. U radu Emilije Friganović, v. pred. i suradnika prikazana je senzorska procjena četiri različite recepture čajnog peciva obogaćenog šipkom (*Rosa canina* L.) kroz ispitivanje prihvatljivosti proizvoda od strane potrošača. Rad Nikole Marića i suradnika prikazuje postupak proizvodnje funkcionalnog napitka na bazi ječmenog slada kao i promjene koje se događaju tijekom pojedinih faza procesa proizvodnje. Klice i mikrozelenje - novi trendovi u prehrani, rad autora Koloper i Gaćina opisuje kemijski sastav i nutritivnu vrijednost ove namirnice koja je posljednjih godina sve popularnija u gastronomiji i prehrambenoj industriji. Aromu kao važan segment kvalitete ispitivali su Svalina i suradnici analizirajući kako primjena različitih vrsta kvasaca utječe na formiranje arome vina Pošip.

Doc. dr. sc. Mladenka Šarolić

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SADRŽAJ:

Effect of processing and storage on the quality of the purees made from different sweet potato cultivars

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Abstract

This study aimed to elucidate the effects of processing and storage on the nutritional and antioxidant properties of three sweet potato cultivars from Croatia. The sweet potato purees (SPP) were analyzed for proximate composition and properties, antiradical activity (AA), total phenolic content (TPC), starch content, free sugars (FS), β-carotene, total anthocyanins (TA), and color. The highest TPC (2.55 µg GAE/mg) and starch content (596.9 g/kg DW) are in the purple cultivar, while the highest AA (21.76 mol TE/g) and total and reducing sugars (50.7 and 30.9 g/kg, respectively) were in the white cultivar. During processing, the sucrose, glucose, and fructose content decreased, leading to an increase in maltose content. The AA, TPC, and FS were higher in baked and steamed SPP, while the starch, β-carotene, and TA contents were lower. These results suggest that processing can enhance some of the properties (TPC, AA, and reducing sugars) of sweet potatoes making a processed sweet potato a desirable food ingredient with physio-chemical and nutritional attributes that has a future beyond home usage for the production of safe processed functional foods. Storage resulted in a decrease in AA, β-carotene, and TA, while TPC, starch, and soluble solids were stable during 6 months of storage.

Key words: sweet potato, freezing, freeze-drying, antioxidant activity, polyphenols, β-carotene.

Introduction

One of the most widely consumed tubers in the world is sweet potato [*Ipomoea batatas* (L.) Lam.]. It is an important staple food worldwide since it has a high nutritional value – about 50% higher than the potato (Dincer et al., 2011). More than 90% of the 105 million metric tons produced each year are

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produced in developing countries. The production of sweet potatoes in Croatia is very low. Estimated production in 2016 amounted to 500 tons, of which 350 tons are processed into first-class goods that are marketed as fresh produce. The other 150 tons are a good raw material for processing, which due to its nutritional composition has immense potential to prevent and reduce food insecurity and malnutrition (Bovell-Benjamin, 2007). Sweet potatoes contain high levels of polysaccharides, disaccharides, minerals, vitamins, polyphenols, and in some cultivars carotenoids (Oke and Workneh, 2013). Sweet potato varieties come in many types of skin and flesh colors, ranging from almost pure white through cream, yellow, orange, or pink, to a very deep purple, although white and yellow-orange flesh are the most common (Bovell-Benjamin, 2007). The most common ways of preparing sweet potato tubers are baking, boiling, steaming, or frying. Furthermore, the sweet potato could be processed into a puree that can be preserved by freezing, pasteurization, or dehydration (Collins and Pangloli, 2013). These processing and preservation methods change the physico-chemical characteristics of sweet potato tubers. However, by carefully managing these processes, we can get the best out of the sweet potato. Some of these changes that we can influence are starch hydrolysis, maltose yield, increase in AA and TPC, and control of β-carotene and anthocyanins (Dincer et al., 2011; Truong Van et al., 1986; Zhang et al. 2002; Takenaka et al.; 2006; Wu et al., 2008; Tao et al., 2010; Troung and Ramesh, 2010). During the last decade, the demand for value-added foods has increased. The sweet potato [*Ipomoea batatas (L.) Lam.]* in the form of puree could be considered as an excellent novel source of natural health-promoting compounds such as anthocyanins, β-carotene, etc. for the functional food market. Ultimately, this could increase utilization and demand for the crop by the food industry as well as consumers.

This study aims to elucidate the effects of baking and steaming as well as freezing and freeze-drying on the physicochemical properties of purees obtained from three sweet potato cultivars.

Materials and methods

The analysis was conducted at the Faculty of Food Technology Osijek, at the Department of Food Technology, in 2022.

Preparation of sweet potato purees

The sweet potato cultivars (orange, white, and purple) used in this study were a gift from a local producer (Višnjica, Slatina, Osijek-Baranja County, Croatia). Before the experiment, the tubers were cleaned with water. The untreated (raw) puree was prepared after peeling and disintegration of the sweet potato tubers. Baked sweet potato puree was prepared by baking the tubers in a foil pouch at 120 °C for 60 min. After baking, the tubers were peeled and disintegrated. Steamed sweet potato tubers were prepared from the peeled tubers, which were cut into 2 cm thick slices and steam-cooked for 20 min. The process parameters for both, steamed and baked sweet potato were determined in a

preliminary study (Loncaric et al., 2016). The raw, baked, and steamed tubers were disintegrated into a puree using a laboratory mill IKA M 20 (IKA-Werke GmbH & Co. KG, Staufen, Germany). Obtained purees were preserved by freezing at -20 °C and freeze-drying in a freeze-dryer (Christ Freeze Dryer, Gamma 2-20, Germany) with a sublimation temperature of -35 °C to 0 °C at 0.220 bar. Frozen sweet potato purees were stored at -20 °C for 3 and 6 months. Freeze-dried sweet potato purees (SPPs) were milled into powders and stored in darkened glass containers at room temperature for 3 and 6 months.

Extraction procedure

For the analysis of bioactive compounds from all the purees, 1 g of purees was extracted with 10 mL of acidified methanol (1% w/w HCl) at 25 °C for 15 min using ultrasound (Bandelin Sonorex Digitech, Berlin, Germany). After extraction, the samples were centrifuged (Microspin, Grant-bio, England) for 15 min (6596.2 x g) and filtrated through 0.45 mm PTFE syringe filters (Labex Ltd., Hungary).

Determination of antioxidant activity

The antioxidant activity was measured with a DPPH radical according to the method described by Lončarić et al. (2014). The reaction mixture consisted of 0.2 mL of the extract and 3 mL of DPPH radical solution 0.5 mM in ethanol. The color change of the radical from deep violet to light yellow was measured at 517 nm using a UV-VIS spectrophotometer (Jenway 6300, Bibby Scientific, UK) and the results were expressed as moles of Trolox equivalents (TE) per gram of sample.

Determination of total polyphenolic content and monomeric anthocyanin content

Total phenolic content (TPC) was determined using Folin-Ciocalteu reagent (FC) according to a procedure described by Lončarić et al. (2014). Briefly, 0.2 mL of the extract was mixed in a test tube with 1.8 mL of deionized water, 10 mL of FC (1:10), and 8 mL of 7.5% sodium carbonate. The development of the blue color was monitored at 765 nm after 120 min using a UV-ViS spectrophotometer (Jenway 6300, Bibby Scientific, UK). The calibration curve of gallic acid was made and TPC was calculated and expressed as g gallic acid equivalent (GAE) per kg of sample equivalents of the sample.

Monomeric anthocyanins were determined by the spectrophotometric method according to the method described by Giusti and Wrolstad (Giusti and Wrolstad, 2001). Total monomeric anthocyanins were expressed as cyanidin-3-glucoside and the obtained values were expressed as μg/mg and the results were presented as the ratio of anthocyanins and β-carotene.

Determination of soluble solids, reducing and total sugars

The soluble solids content of SPP was measured using an Abbe tabletop refractometer and expressed in Brix (°Brix). The Luff Schoorl method was used to determine reducing and total sugars. The total starch was determined according to the AOAC (Official Method 996.11) and the AACC (Method 76.13.01).

Determination of individual sugars by ultra-high performance liquid chromatography (UHPLC)

For the determination of the individual sugars, 1 g of the purees were extracted in an ultrasound bath with 50 mL of water at 25 °C for 15 min. The samples were then centrifuged (6596.2 x g) for 15 min (Microspin, Grant-bio, England) and filtrated through (0.45 mm PTFE) syringe filters (Labex Ltd., Hungary). UHPLC analysis was performed on a Shimadzu Nexera XR system equipped with an LC-20AD parallel double-plunger pump, SIL-20AC autosampler, CTO-20AC column oven, RID-20A refractive index detector and CBM-20A communication bus module. The separation was performed on an InertSustain NH2 column (250 × 4.60 mm inner diameter, 5 μm) (GL Sciences Inc., Tokyo, Japan). The mobile phase consisted of acetonitrile: water (75:25, v/v) and was degassed in an ultrasonic bath before use. Each run was completed within 20 min. The flow rate was 1 mL/min, the column oven temperature was 40 °C, and the injection volume of the sample was 10 μL. All samples and standards were filtered through a 0.45 μm Millipore membrane before use. Identification of individual sugars was done by comparing their retention time with authentic standards. Calibration curves were prepared for each sugar at a concentration of 1 – 10 mg/mL and expressed as mg/mL. The data was recorded and analyzed using the LabSolutions program (version 5.71 SP2).

Analysis of β-carotene

Extraction of β-carotene was performed according to the method described by Wu et al. (2008). HPLC analyses of β-carotene were performed on a Shimadzu system (Shimadzu Corporation, Kyoto, Japan) equipped with an LC-20AD Prominence solvent delivery module, an SPD-M20A Prominence UV/VIS photodiode array detector, and a SIL-10AF automatic sample injector. Chromatographic separation was performed on a LiChrospher RP18-5 column (Hichrom, United Kingdom) with a length of 250 mm and an internal diameter of 4.6 mm. β-carotene was separated using an isocratic method, with acetonitrile–methanol–ethyl acetate (80:10:10) as the mobile phase. The flow rate was 1.0 mL/min, the injection volume was 10 μL, the detection wavelength was 450 nm and chromatography was performed at 25 °C. The β-carotene was quantified using a β-carotene calibration curve generated from a series of concentrations of a β-carotene standard (Sigma, St Louis, MO, USA, C4582). All samples were determined in triplicate and expressed as μg/mg, the results were presented as the ratio of anthocyanins and β-carotene. Chromatograms were processed on a computer equipped with Lab Solution Lite software version 5.52.

Color Measurement

The color values of sweet potato flesh and flour samples were determined using a Minolta CR-300, (Japan) colorimeter. The L*, a*, and b* values are measured as lightness, components on the red-green axis, and components on the yellow-blue xis, respectively.

The color change was calculated according to equation (1), and color intensity according to equation (2).$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}$ (Eq.)$C = \sqrt{a^2 + b^2}$

(Eq. 2)

Where ΔE is color change, L* is a parameter of lightness, a* parameter measures redness/greenness, and b* measures yellowness/blueness.

Statistical analyses

MS Excel (StatPlus, Analyst Soft Inc.) was used for the statistical processing of the results. A one-way ANOVA was used. Normal distribution and homogeneity of cultivars for the experimental data were determined using the Shapiro-Wilkovim and Levenovim tests. Mean comparisons between cultivars were performed using the Fisher LSD (Least Significant Difference) test.

Results and discussion

Effect of processing on physicochemical parameters

The physicochemical parameters of the fresh processed (raw, baked, and steamed) SPPs of all three sweet potato cultivars tested are shown in table 1. The AA showed significant ($p \leq 0.05$) differences between the cultivars and the treatments. The AA of the SPPs ranged between 18.66 and 25.00 mol TE/g. Baking and steaming increased AA by 15.59% and 25.4% respectively, except for steamed white SPPs where AA was reduced by 14.2%. The phenol content varied between 0.22 – 5.44 µg GAE/mg, as in the case of AA, baking and steaming increased TPC by 102.4% and 111.8%, respectively. The increase in TPC during sweet potato processing was also found in other studies (Truong et al. 2007; Dincer et al. 2011). The total sugar content of the samples was between 36.5 – 114.8 g/kg and reducing sugar content ranged from 12.6 – 86.4 g/kg. The orange flesh sweet potato cultivar with orange flesh had a β-carotene content of 284.65 µg/mg, which was reduced by baking and steaming (105.84 and 127.72 µg/mg, respectively). White and purple cultivars did not contain β-carotene. However, the purple flesh color of the purple sweet potato cultivar was attributed to the anthocyanins content (0.89, 0.69, 0.57 µg/mg in raw, baked, and steamed SPP, respectively). The major compound in all tested cultivars was starch, with values ranging from 432.9 – 596.9 g/kg DW. The results of starch content were in agreement with those reported by Dincer et al. (2011) and slightly higher than those reported by Ellong, Billard, & Adenet (2014) for eight sweet potato cultivars.

Regarding processing, baking and steaming led to significant ($p \leq 0.05$) starch degradation, with the highest degradation observed in the white sweet potato cultivar. Thermal treatment in water could cause reductions of starch through the gelatinization and hydrolization effect (Gunaratne & Hoover, 2002; Lai, Huang, Chan, Lien, & Liao, 2013). The result of starch hydrolysis was an increase in free sugar content. In fresh sweet potatoes, sucrose, fructose, and glucose were the major sugars. However, after processing, a considerable amount of maltose (2.46 – 10.37 mg/mL) was measured in all samples.

This suggests that the thermal hydrolysis of starch is closely related to the release of maltose during processing (Wu et al., 2008). As for glucose and fructose, processing reduced the content of glucose and fructose. The changes in free sugars affected the content of soluble solids. The soluble solid content ranged from 10.8 – 14.5% for raw SPP and 16.4 – 28.6% for processed SPP. Later in the experiment, the soluble solid content was used as a marker for the change in sugar content.

Table 1. *Physicochemical parameters of raw and processed sweet potato purees made from different cultivars (orange, white, and purple).*

	Orange			White			Purple		
Fresh	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**
DPPH [mol TE/g]	$19.79 \pm 0.45^{f*}$	22.90 ± 0.21^{cd}	25.00 ± 0.38^{a}	21.76 ± 0.01^{e}	22.71 ± 0.55^{d}	18.66 ± 0.30^{g}	18.83 ± 0.27^{g}	23.85 ± 0.86^{b}	23.45 ± 0.11^{bc}
TPC[g GAE/mg]	0.23 ± 0.01^{f}	0.53 ± 0.03^{de}	0.44 ± 0.03^{de}	0.22 ± 0.01^{f}	0.36 ± 0.00^{ef}	0.60 ± 0.01^{d}	2.55 ± 0.10^{c}	5.44 ± 0.01^{a}	4.37 ± 0.29^{b}
Starch [g/kg] DW	505.2 ± 1.72^{c}	432.9 ± 3.90^{h}	458.2 ± 1.01^{g}	580.3 ± 0.62^{b}	514.5 ± 0.87^{d}	483.2 ± 0.03^{f}	596.9 ± 0.12^{a}	555.1 ± 0.16^{c}	581.3 ± 0.02^{b}
Total sugars [g/kg]	40.9	95.9	72.2	50.7	97.4	78.3	36.5	114.8	79.4
Reducing sugars [g/kg]	23.3	70.5	48.7	30.9	77.8	49.8	12.6	86.4	55.5
Glucose [mg/mL]	0.97 ± 0.01^{b}	1.02 ± 0.01^{a}	0.86 ± 0.02^{d}	0.86 ± 0.04^{d}	0.93 ± 0.01^{c}	0.57 ± 0.01^{d}	0.26 ± 0.01^{f}	0.26 ± 0.04^{f}	0.14 ± 0.01^{g}
Fructose [mg/mL]	0.31 ± 0.00^{b}	0.30 ± 0.01^{b}	0.19 ± 0.01^{c}	0.35 ± 0.02^{a}	0.31 ± 0.01^{b}	0.12 ± 0.02^{d}	0.17 ± 0.02^{c}	0.11 ± 0.01^{de}	0.09 ± 0.00^{e}
Maltose [mg/mL]	0.10 ± 0.01^{g}	6.73 ± 0.007^{b}	3.64 ± 0.04^{e}	0.00 ± 0.00^{g}	6.54 ± 0.04^{c}	2.46 ± 0.16^{f}	0.00 ± 0.00^{g}	10.37 ± 0.15^{a}	6.09 ± 0.16^{d}
Sucrose [mg/mL]	1.40 ± 0.01^{a}	1.10 ± 0.01^{b}	0.92 ± 0.07^{c}	1.40 ± 0.01^{a}	0.56 ± 0.00^{d}	0.89 ± 0.06^{c}	1.41 ± 0.01^{a}	0.33 ± 0.01^{f}	0.42 ± 0.06^{e}
Soluble solids [%]	11.1	20.7	18.1	10.8	20.0	16.4	14.5	28.6	19.8
β-carotene/Anthocyanins [μg/mg]	$284.65 \pm 0.15^{A**}$	105.84 ± 0.41^{C}	127.72 ± 0.31^{B}	-	-	-	0.89 ± 0.01^{A}	0.69 ± 0.01^{B}	0.57 ± 0.00^{C}
Color									
L	46.90 ± 0.31	41.20 ± 0.30	40.72 ± 0.22	50.06 ± 1.40	45.97 ± 0.10	37.46 ± 0.22	21.39 ± 0.19	19.35 ± 0.24	22.25 ± 0.21
a	18.26 ± 0.36	10.78 ± 0.19	8.47 ± 0.11	1.15 ± 0.55	-3.87 ± 0.11	-2.88 ± 0.16	20.09 ± 0.83	10.93 ± 0.44	12.75 ± 0.15
b	24.80 ± 0.86	23.25 ± 0.69	22.31 ± 0.54	12.45 ± 0.51	9.12 ± 0.37	7.68 ± 0.52	-2.98 ± 0.19	-3.18 ± 0.25	-5.56 ± 0.07
ΔE		9.53	11.84		7.28	12.42		9.39	7.83
C	30.80	25.63	23.86	12.50	9.91	8.20	20.31	11.38	13.91

[a]Each value is expressed as mean ± SD ($n = 3$). DW – dry weight. $*p < 0.001$. Different lower-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test < 0.001. Different upper-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test between the same cultivar.

Processing resulted in a change in the color of the SPP (ΔE = 7.28 – 12.42), which was also reflected in a reduction (16.5 – 43.9%) in the color intensity of the processed SPP. These changes occurred as a result of enzymatic browning, degradation of β-carotene and anthocyanin, and elimination by dilution in water, considering only steamed samples.

Effect of freeze-drying on physicochemical parameters

The results of the physicochemical parameters of powders from freeze-dried SPPs stored for three and six months are shown in table 2. During the first three months of storage, the AA of the powders ranged between 11.31 – 25.48 mol TE/g, the TPC between 0.22 – 4.85 μg GAE/mg, the starch content between 440.9 – 579.9 g/kg DW and the soluble solids content between 10.1 – 13.7% for powders from raw SPs, and 15.4 – 27.1% for powders from processed SPs. The highest reduction in the above-mentioned parameters was observed in powders from steamed white and raw purple sweet potato cultivars. After six months of storage, a significant reduction in all measured parameters was observed ($p \leq 0.05$). The AA content of the samples ranged between 11.05 – 13.80 mol TE/g, the TPC between 0.07 – 4.79 μg GAE/mg, the starch content between 350.9 – 537.4 g/kg DW, and the soluble solids content between 9.9 – 12.5% for powders from raw SPs and 13.0 – 27.6% for powders from processed SPs.

Table 2. *Physicochemical parameters of raw and processed potato purees made from different cultivars (orange, white, and purple) preserved by freeze-drying and stored for 3 and 6 months.*

	Orange			White			Purple		
3 month	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**
DPPH [mol TE/g]	22.07 ± 0.06^{e}	24.97 ± 0.40^{ab}	25.48 ± 0.24^{a}	24.37 ± 0.10^{b}	24.38 ± 0.77^{b}	12.44 ± 0.53^{f}	11.31 ± 0.39^{g}	19.57 ± 0.57^{d}	17.21 ± 0.01^{e}
TPC [g GAE/mg]	0.22 ± 0.01^{i}	0.50 ± 0.01^{d}	0.45 ± 0.00^{e}	0.26 ± 0.02^{h}	0.33 ± 0.01^{g}	0.41 ± 0.02^{f}	0.57 ± 0.01^{c}	4.85 ± 0.01^{a}	4.14 ± 0.02^{b}
Starch [g/kg] DW	498.2 ± 9.60^{c}	440.9 ± 7.60^{f}	453.1 ± 2.21^{e}	560.7 ± 1.11^{b}	502.2 ± 4.07^{c}	490.3 ± 1.09^{d}	579.9 ± 1.16^{a}	561.6 ± 0.02^{b}	566.3 ± 1.18^{b}
Soluble solids [%]	11.0	20.5	17.8	10.1	20.1	15.4	13.7	27.1	19.3
β-carotene/Anthocyanins [μg/mg]	63.3 ± 0.76^{C}	90.5 ± 1.31^{B}	98.8 ± 1.61^{A}	-	-	-	0.23 ± 0.01^{C}	0.65 ± 0.01^{A}	0.54 ± 0.01^{B}
Color									
L	43.90 ± 1.10	39.01 ± 0.11	40.54 ± 0.21	42.23 ± 0.70	39.30 ± 0.10	40.08 ± 0.11	26.75 ± 0.43	25 ± 0.36	27.59 ± 0.16
A	3.96 ± 0.06	12.49 ± 0.02	8.09 ± 0.03	0.55 ± 0.10	-2.84 ± 0.01	-2.00 ± 0.04	6.50 ± 0.32	6.75 ± 0.11	8.78 ± 0.09
B	14.19 ± 0.13	30.60 ± 0.17	28.80 ± 0.22	12.25 ± 0.17	8.84 ± 0.06	5.62 ± 0.08	1.11 ± 0.15	-3.14 ± 0.06	-5.05 ± 0.01
ΔE	18.06	11.37	12.64	7.86	12.03	11.12	15.17	13.82	13.06
C	14.73	33.05	29.91	12.26	9.28	5.97	6.59	7.44	10.13
6 month									
DPPH [mol TE/g]	11.05 ± 0.30^{ef}	12.47 ± 0.77^{c}	11.77 ± 0.18^{d}	10.50 ± 0.10^{f}	11.49 ± 0.29^{de}	13.16 ± 0.72^{ab}	11.58 ± 0.24^{de}	13.80 ± 0.01^{a}	12.85 ± 0.09^{bc}
TPC [g GAE/mg]	0.23 ± 0.01^{ef}	0.41 ± 0.01^{d}	$0.25 \pm 0.04d^{e}$	0.07 ± 0.02^{f}	0.33 ± 0.05^{de}	0.24 ± 0.01^{e}	0.93 ± 0.02^{c}	4.79 ± 0.09^{a}	2.53 ± 0.27^{b}
Starch [g/kg] DW	443.6 ± 0.32^{e}	381.1 ± 0.51^{h}	396.7 ± 0.16^{g}	504.9 ± 0.18^{b}	425.5 ± 0.41^{f}	350.9 ± 0.15^{i}	537.4 ± 0.19^{a}	501.8 ± 0.54^{c}	480.3 ± 0.16^{d}
Soluble solids [%]	10.6	19.6	16.1	9.9	19.0	13.0	12.5	27.6	19.0
β-carotene/Anthocyanins [μg/mg]	60.12 ± 0.05^{C}	82.45 ± 0.16^{B}	89.34 ± 0.17^{A}	-	-	-	0.12 ± 0.02^{C}	0.52 ± 0.02^{A}	0.47 ± 0.01^{B}
Color									
L	45.99 ± 0.80	43.60 ± 0.09	45.11 ± 0.30	47.47 ± 0.89	42.16 ± 0.29	39.44 ± 0.11	28.18 ± 0.79	26.54 ± 0.40	28.42 ± 0.37
A	2.64 ± 0.06	2.61 ± 0.12	0.085 ± 0.07	0.27 ± 0.08	-2.29 ± 0.04	-1.71 ± 0.05	6.51 ± 0.11	6.33 ± 0.10	8.35 ± 0.11
B	10.74 ± 0.29	20.16 ± 0.61	18.50 ± 0.53	8.73 ± 0.18	4.40 ± 0.15	3.93 ± 0.19	1.54 ± 0.11	-3.29 ± 0.04	-5.30 ± 0.10
ΔE	21.04	16.65	19.32	4.62	11.79	12.54	15.84	14.70	13.88
C	11.06	20.33	18.50	8.73	4.96	4.29	6.69	7.13	9.89

[a]Each value is expressed as mean ± SD ($n = 3$). DW – dry weight. [a]Each value is expressed as mean ± SD ($n = 3$). DW – dry weight. *$p < 0.001$. Different lower-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test < 0.001. Different upper-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test between the different treatments of the same cultivar.

Interestingly, the results of the β-carotene content of the powders indicate a higher content of β-carotene in powders from processed (baked and steamed) SPs compared to powders from raw orange fleshed SPs (table 2). It is well known that β-carotene is an unstable compound susceptible to both enzymatic and non-enzymatic oxidation. However, starch hydrolysis and the formation of free sugars affect the water content in dehydrated samples. Free sugars are highly hygroscopic and retain moisture in the food. A study conducted by Arya & Natesan (1983) showed that carotenoids in freeze-dried papaya were most stable at a_w 0.33 and their destruction rate was higher both below and above this value, suggesting that water protects carotenoids from oxidation (Sian & Ishak, 1991; Abbas, Lasekan, & Khalil, 2010).

The results of this study also showed minimal loss (5%, 9%, and 10%, respectively) of β-carotene in powders from raw, baked, and steamed SPs during storage over six months. The results of TA measurement in powders from purple SPs cultivar showed higher TA in powder from processed SPs compared to powder from raw SPs. The TA content also decreased during storage over six months (48, 20, and 13 % in powders from raw, baked, and steamed SPs, respectively).

When looking at the color of the powders, it was found that powders made from raw sweet potatoes with colored fleshed (orange and purple) showed a higher color change (ΔE) than powders from processed sweet potatoes with colored fleshed. The color change (ΔE) of powders (baked, steamed, and raw) from white-fleshed SPs were significantly different in descending order of 12, 11, and 8, respectively. The color intensity of powders was higher in powders from processed SPs than in powders from raw-colored (orange and purple) SPs. The highest change in color during storage over six months was observed in powders from orange SPs (Table 2).

Effect of freezing on physicochemical parameters

The results of the physicochemical parameters of the frozen SPPs are shown in table 3. The AA of SPPs from orange and white-fleshed sweet potatoes was not significantly different from the AA of powders from orange and white-fleshed sweet potatoes. Significantly higher AA was measured in raw, baked, and steamed SPPs compared to powders from raw, baked, and steamed purple-fleshed SPs (55%, 15%, and 26%, respectively).

Table 3. *Physicochemical parameters of raw and processed sweet potato purees made from different cultivars (orange, white, and purple) preserved by freezing and stored for 3 and 6 months.*

	Orange			White			Purple		
3 month	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**	**Raw**	**Baked**	**Steamed**
DPPH [mol TE/g]	22.06 ± 1.46^{d}	24.29 ± 0.09^{a}	23.92 ± 0.24^{ab}	22.94 ± 0.21^{bcd}	23.47 ± 0.08^{abc}	18.63 ± 0.02^{e}	17.58 ± 0.01^{e}	22.58 ± 0.53^{cd}	21.85 ± 1.52^{d}
TPC [g GAE/mg]	0.23 ± 0.07^{e}	0.42 ± 0.03^{d}	0.42 ± 0.03^{d}	0.27 ± 0.02^{de}	0.30 ± 0.01^{de}	0.25 ± 0.01^{e}	0.72 ± 0.07^{c}	4.45 ± 0.07^{a}	4.00 ± 0.23^{b}
Starch [g/kg] DW	411.1 ± 1.30^{f}	398.9 ± 1.20^{g}	409.1 ± 4.30^{f}	481.4 ± 2.56^{b}	424.8 ± 0.31^{e}	358.9 ± 1.48^{h}	486.6 ± 2.00^{a}	448.2 ± 0.96^{d}	469.3 ± 1.54^{c}
Soluble solids [%]	11.1	21.0	18.0	11.0	19.9	16.5	14.5	28.1	19.2
β-carotene/Anthocyanins [µg/mg]	24.3 ± 0.66^{A}	18.5 ± 1.05^{B}	18.8 ± 1.11^{B}	-	-	-	0.21 ± 0.01^{C}	0.66 ± 0.01^{A}	0.50 ± 0.01^{B}
Color									
L	44.46 ± 0.13	41.83 ± 0.12	43.06 ± 0.43	50.21 ± 0.10	42.41 ± 0.09	39.99 ± 0.40	29.54 ± 0.36	26.63 ± 0.21	27.44 ± 0.14
A	14.64 ± 0.05	11.56 ± 0.09	9.51 ± 0.26	0.64 ± 0.06	-3.46 ± 0.03	2.76 ± 0.07	5.58 ± 0.20	6.84 ± 0.26	8.20 ± 0.15
B	20.22 ± 0.06	22.46 ± 0.45	22.06 ± 0.68	12.07 ± 0.25	9.43 ± 0.31	7.22 ± 0.18	2.69 ± 0.17	-3.14 ± 0.09	-4.32 ± 0.04
ΔE	6.33	8.72	9.94	0.65	9.43	9.17	17.58	14.58	13.41
C	24.96	25.26	24.02	12.09	10.04	7.73	6.19	7.20	9.27
6 month									
DPPH [mol TE/g]	10.79 ± 0.393^{d}	12.35 ± 3.17^{bcd}	13.39 ± 0.713^{b}	10.99 ± 0.16^{d}	11.26 ± 0.93^{cd}	13.69 ± 0.14^{b}	13.05 ± 0.60^{bc}	17.88 ± 0.06^{a}	17.62 ± 0.35^{a}
TPC [g GAE/mg]	0.23 ± 0.00^{d}	0.40 ± 0.01^{d}	0.41 ± 0.00^{cd}	0.25 ± 0.05^{d}	0.27 ± 0.00^{d}	0.63 ± 0.08^{c}	1.02 ± 0.02^{b}	4.31 ± 0.16^{a}	4.12 ± 0.38^{a}
Starch [g/kg] DW	38.64 ± 0.12^{d}	33.18 ± 0.51^{g}	35.57 ± 0.13^{f}	46.43 ± 0.31^{b}	37.68 ± 0.22^{e}	30.79 ± 0.15^{h}	49.62 ± 0.41^{a}	46.02 ± 0.27^{b}	43.83 ± 0.26^{c}
Soluble solids [%]	11.2	20.3	17.3	11.0	19.8	18.4	13.7	27.3	18.2
β-carotene/Anthocyanins [µg/mg]	12.87 ± 0.09^{A}	10.42 ± 0.11^{B}	11.01 ± 0.01^{C}	-	-	-	0.12 ± 0.01^{C}	0.49 ± 0.01^{A}	0.36 ± 0.01^{B}
Color									
L	44.86 ± 0.21	41.28 ± 0.20	42.99 ± 0.13	50.50 ± 0.19	42.93 ± 0.09	40.75 ± 0.14	29.03 ± 0.09	26.37 ± 0.35	29.83 ± 0.36
A	15.50 ± 0.10	10.71 ± 0.19	9.93 ± 0.07	0.63 ± 0.02	-3.48 ± 0.07	-2.62 ± 0.09	5.89 ± 0.13	5.78 ± 0.21	8.17 ± 0.16
B	20.95 ± 0.17	20.49 ± 0.56	23.32 ± 0.18	12.05 ± 0.16	8.90 ± 0.31	7.69 ± 0.14	3.06 ± 0.09	-2.56 ± 0.07	-4.24 ± 0.09
ΔE	5.16	10.35	9.32	0.79	9.21	9.81	17.22	15.16	14.66
C	26.06	23.12	25.35	12.07	9.56	8.12	6.64	6.32	9.20

[a]Each value is expressed as mean ± SD (n = 3). DW – dry weight. [a]Each value is expressed as mean ± SD (n = 3). DW – dry weight. *p < 0.001. Different lower-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test < 0.001. Different upper-case letters in each row indicate significant differences at a 95% confidence level as obtained by the LSD test between the different treatments of the same cultivar.

The TPC levels of frozen SPPs ranged from 0.23 to 4.45 µg GAE/mg. The starch content in frozen SPPs was slightly lower than the starch content in powders. The fact that the starch content was lower and the soluble solid content was higher indicates that starch hydrolysis continues to unfold in frozen SPPs, making the SPPs even sweeter. During storage of the frozen SPPs, the AA value of the SPPs decreased significantly, while TPC, starch content, and soluble solids were stable over six months. The anthocyanin content was 0.21, 0.66, and 0.50 µg/mg for raw, baked, and steamed SPPs, respectively, which was similar to the anthocyanin content of powders. Unlike anthocyanins, which were found to be more stable, the β-carotene content was lower at 62%, 80%, and 81% for raw, baked, and steamed SPPs, respectively, than for powders from raw, baked, and steamed SPs. After six months of storage, this decrease was even more pronounced at 79%, 87%, and 88% for raw, baked, and steamed SPPs compared to powders from raw, baked, and steamed SPs.

Measurements of the color of SPPs showed that the ΔE of frozen SPPs from orange and white sweet potatoes were lower than the ΔE of powders from orange and white SPs. It was also shown that this change was lower for frozen raw SPPs than for processed ones. For SPPs from purple sweet potatoes, freezing caused a higher ΔE compared to the powders from purple SPs. However, the result indicated that the processing of purple sweet potatoes somehow preserved the color, as the ΔE of frozen processed SPPs was lower compared to the frozen raw SPPs. Frozen raw SPPs had higher color intensity compared to the powders prepared from the raw SPs. Furthermore, frozen processed SPPs had higher color intensity than frozen raw SPPs. During the six months of the storage period, there were no significant changes in terms of color change and color intensity of all samples.

Conclusion

This study showed that processing does not necessarily lead to a reduction in the quality of the product. The results of the study show that the sweet potato cultivars investigated have a high AA and TPC, which can be increased by baking or steaming. Moreover, processing led to an increase in starch hydrolysis, free sugars, and soluble solids, all of which contribute to the stabilization of β-carotene, anthocyanins, and finally color stabilization of the freeze-dried samples. The results obtained after storage indicate higher stability of the processed SPPs, especially the SP powders, which could be used for the research and development of a wide range of new value-added products.

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