The Journal of Supercritical Fluids 138 (2018) 215–220

Contents lists available at ScienceDirect

The Journal of Supercritical Fluids

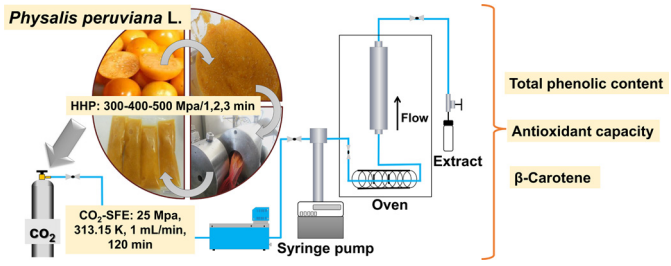
journal homepage: www.elsevier.com/locate/supflu

Effects of high hydrostatic pressure processing and supercritical fluid extraction on bioactive compounds and antioxidant capacity of Cape gooseberry pulp (*Physalis peruviana L.*)

Maria José Torres-Ossandón[a], Antonio Vega-Gálvez[a], Jéssica López[c,*], Karina Stucken[a,b], Julio Romero[d], Karina Di Scala[e,f]

[a] Department of Food Engineering,University of La Serena. Av. Raúl, Bitrán N° 1305, Box 599, La Serena, Chile
[b] Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, Av. Raúl Bitrán Nachary 1305, Casilla 599, La Serena, Chile
[c] Escuela de Alimentos, Pontificia Universidad Católica de Valparaíso, Waddington 716, Playa Ancha, Valparaíso 2360100, Chile
[d] Laboratory of Membrane Separation Processes (LabProSeM), Department of Chemical Engineering, University of Santiago de Chile, Santiago, Chile
[e] Food Engineering Research Group, Faculty of Engineering, Universidad Nacional del Mar del Plata, Juan B. Justo 4302, Mar del Plata 7600, Argentina
[f] CONICET (National Council of Scientific and Technical Research), Argentina

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Cape gooseberry
Antioxidant capacity
HHP
Supercritical fluids
Functional foods

ABSTRACT

The aim of this study was to combine high hydrostatic pressure (HHP) and SFE-CO_2 to extract bioactive compounds with antioxidant capacity (phenolics and β-carotene) from Cape gooseberry (*Physalis peruviana* L.) pulp. Extracts were evaluated immediately after processing by HHP at 300–400–500 MPa/1-3–5 min, respectively, and after 60 days of storage at 4 °C. Treatments at 300 MPa/1 min and 400 MPa/3 min showed an increase of antioxidant capacity compared to control untreated samples at day 0. Treatments at 500 MPa presented the highest antioxidant capacity (12388.3 μmol TE/100 g d.m.) after storage. Samples treated at 400 MPa/3 min presented a high content of total phenols at day 60. The highest β-carotene content was observed at 300 MPa/3 min (5.51 mg β-carotene/100 g d.m.). Our results indicate that HHP treatments combined with SFE-CO_2 can promote active ingredient release in fruit matrices, increasing their bioactivities, as seen with antioxidant activity.

1. Introduction

There is a growing awareness of the health benefits associated to diets based on foods enriched with bioactive compounds. This has spiked the interest in functional foods [1,2]. In order to promote the consumption of healthy food, the European Commission recommended a 600 g daily intake of fruit and vegetables, a criterion met only by a limited number of consumers. A strategy to address this deficiency is to

* Corresponding author.
E-mail address: jessica.lopez@pucv.cl (J. López).

https://doi.org/10.1016/j.supflu.2018.05.005
Received 9 March 2018; Received in revised form 18 April 2018; Accepted 2 May 2018
Available online 03 May 2018
0896-8446/

produce a large diversity of new and improved fruit- and vegetable-based products that preserve health-promoting components, structural and sensory quality attributes, fulfilling thus, consumer preferences and needs (WHO-Europe, 2003). The high variability of bioactive compounds found in fruits and vegetables requires custom development of suitable extraction approaches. Importantly, the steps that follow extraction, such as separation, identification and characterization of bioactive compounds, are highly dependent on the suitability of the extraction process [2]. Some of the most applied methods include Soxhlet extraction, ultrasound-assisted extraction and novel technologies as supercritical fluid extraction (SFE) [3]. SFE is an extraction/fractionation method that exploits the unique properties of fluids above their critical temperature and pressure [4]. In this state, fluids present the characteristics of gas and liquid resulting in a high solvation power that is used to extract soluble components from a raw material [5–7]. The most commonly used solvent for SFE is carbon dioxide since is a low cost, non-toxic and non-explosive gas, easy to obtain and easy to remove from extracted products. Thus, SFE is considered a clean or green alternative to conventional extraction methods that use hazardous organic solvents at high temperatures [5]. Furthermore, supercritical fluid extracts have a higher quality than those obtained with extraction solvents or by water or steam distillation, since extracts obtained by these methods can carry over residual solvent or may undergo thermal degradation [4,8]. In recent years, SFE has proved to be an excellent choice for the extraction of high quality berry, coffee and essential oils, among others [9–12], bioactive compounds from by-products of the agroindustry [13] and from a wide range of bioactive compounds with antiviral, antitumor, anti-inflammatory, antibacterial and antioxidant activity [6]. For example, supercritical CO_2 was able to reduce the amount of bergapten, a toxic secondary metabolite, from citrus by-products resulting in “clean” citrus oils with low toxicity and high antimicrobial activity [14]. High hydrostatic pressure (HHP) is a non-thermal processing technology characterized by maintaining the quality and organoleptic characteristics of foods, as well as extending the shelf life of treated products [15]. The application of HHP increases cell permeability and enables the diffusion of metabolites from the inside to outside of the cells. [16]. This technology has been applied to the extraction of bioactive compounds from several fruits and fruit products [17]. Thus, applying HHP as a pretreatment before supercritical extraction may increase extraction efficiency. The use of HPP and SFE technologies combined, has shown to recover sulphur bioactive compounds from Allium species with superior quality than thermal extraction methods [10].

Cape gooseberry (*Physalis peruviana* L.) is an edible fruit that belongs to the family Solanaceae, has a high nutritional value [18] and it is one of the herbal plants used for treating various diseases [19]. According to its antioxidant properties, Cape gooseberry can be considered a functional food [20,21], representing an emerging market of growing economic importance. This work aims to assess the effect of high hydrostatic pressure processing on the antioxidant capacity of supercritical CO_2 extracts of Cape gooseberry pulp, as well as total phenolic content and β-carotene immediately after processing and after 60 days of storage at 4 °C.

2. Materials and methods

2.1. Cape gooseberry sample preparation, HHP treatment and storage conditions

Cape gooseberries were purchased in La Serena, Region of Coquimbo, Chile. The samples were selected to provide a homogenous group, based on date of harvest, color, size, and freshness according to visual analysis. Before pressurization, the fruits were pressed with peel and seeds and homogenized in a blender (Philips, HR1720, Amsterdam). The fresh pulp had a moisture of 78.61 ± 0.24% whereas the moisture of pressurized samples was in the range of 76.92 ± 3.14 to 88.23 ± 3.34 [22]. The gooseberry pulp was packed in polyethylene flexible pouches. HHP experiments were performed in a factorial design that included three pressure levels: 300, 400 and 500 MPa and three holding times: 1, 3 and 5 min respectively, at room temperature. Quality analyses were performed immediately after processing (day 0) and after 60 days of storage at 4 °C (day 60). All experiments were performed in triplicate. Samples were stored in a refrigerator (GM-341SC, LG, Korea) at 4 ± 0.1 °C until quality analyses.

2.2. Supercritical fluid extraction (SFE)

Each extraction was performed from control and pressurized samples using 10 g of lyophilized Cape gooseberry pulp. Samples were loaded into a 100 mL steel cylindrical extractor vessel. A modifier for the extraction (50 mL of 50% ethanol in water) was added directly to the bottom end of the vessel containing the sample (CO_2 flows from the bottom of the vessel to the top). After the loaded extractor vessel was assembled, CO_2 was pumped into the extractor vessel with a syringe pump ISCO 500D. Static extraction assays were performed at 25 MPa and 313.15 K with a CO flow rate of 1 mL/min at constant pressure and an extraction time of 120 min. The temperature of the extractor vessel was controlled using a thermostatic electric resistance around the vessel. When the scheduled time was achieved, the extractor vessel was depressurized, the extract separated from the carbon dioxide and collected in a glass tube. After each extraction, the vessel was thoroughly washed with ethanol. Each extract was reconstituted in 10 mL methanol 80% and stored in a freezer (WVE29, Whirlpool, USA) at −20 ± 0.1 °C, until analysis. All extractions were carried out in triplicate.

2.3. Antioxidant capacity

Antioxidant capacity was estimated based on the Oxygen Radical Absorbance Capacity (ORAC) assay, which measures the peroxyl radical scavenging activity of each sample. Trolox, a water soluble vitamin E analog, was used as standard [23]. The ORAC assay was performed as described in Torres-Ossandón et al. [24] using 40 µL extract obtained by SFE-CO_2 or standard for the measurements. ORAC values were expressed in micromoles of Trolox equivalents (TE)/100 g dry matter (d.m.). All measurements were carried out in triplicate.

2.4. Total phenolic content (TPC)

Total phenolic content was determined by the Folin Ciocalteau method. The TPC was assayed colorimetrically by the procedure of Chuah et al. [25] with the modifications described in Vega-Galvez et al. [22]. Total phenolic content was measured from 0.5 mL aliquots of Cape gooseberry pulp extracts and was calculated from a gallic acid (GA) calibration curve at concentrations between 25 and 500 µg/mL. Results were expressed as mg gallic acid equivalents (GAE/100 g d.m.). All reagents were purchased from Merck (Merck KGaA, Darmstadt, Germany). All measurements were done in triplicate.

2.5. β-Carotene content

β-carotene was measured chromatographically as previously described by Laur and Tian [26] in an Agilent 1200 series HPLC system (Agilent, Singapore City, Singapore) under the conditions described in Torres-Ossandón et al. [23]. The identification of β-carotene was based on retention time and peak areas compared to a β-carotene standard. The standard curve was prepared using β-carotene at a concentration range of 50–500 µg of β-carotene/mL. Results were expressed as mg β-carotene/100 g d.m. All measurements were carried out in triplicate.

Table 1
Antioxidant capacity of HHP-treated Cape gooseberry pulp, extracted by SFE-CO_2 and stored for 60 days at 4 °C.

HHP treatments	Antioxidant capacity (μmol TE/100 g d.m.)	
	Day 0	Day 60
Control	6914.10 ± 417.27^{a}	7621.00 ± 628.31^{AD}
300 MPa/1 min	12581.00 ± 49.29^{be1}	6993.37 ± 328.57^{A2}
300 MPa/3 min	9627.71 ± 988.30^{cd1}	6944.31 ± 4076.81^{B2}
300 MPa/5 min	9475.79 ± 273.80^{cd1}	5103.43 ± 142.89^{B2}
400 MPa/1 min	10921.82 ± 913.28^{bd}	9404.16 ± 598.05^{C}
400 MPa/3 min	12786.21 ± 5542.30^{e1}	7824.87 ± 477.88^{AD2}
400 MPa/5 min	10361.80 ± 703.60^{d}	8379.65 ± 967.71^{CD}
500 MPa/1 min	9647.15 ± 1157.49^{cd1}	12161.29 ± 210.54^{EF2}
500 MPa/3 min	10916.53 ± 1078.36^{d}	13275.40 ± 194.26^{F}
500 MPa/5 min	8429.48 ± 158.83^{ac1}	11728.14 ± 351.94^{E2}

The presented values are the mean ± s.d. of three (n = 3) replicates. Different letters a-e indicate significant differences ($P < 0.05$) for day 0 and A-F for day 60, compared to the control sample; 1, 2 indicate significant differences ($P < 0.05$), between storage conditions (no numbers are indicated when $P > 0.05$).

2.6. Statistical analysis

Significant differences among samples were tested by one-way analysis of variance (ANOVA) using the Statgraphics Plus® 5.1 software (Statistical Graphics Corp., Herndon, USA). Testing included a multiple range test (MRT) (Fisher's least significant difference) to prove the existence of homogeneous groups within each of the parameters analyzed. Differences were taken as statistically significant when $P < 0.05$.

3. Results and discussion

3.1. Antioxidant capacity

Table 1 shows the antioxidant capacity of control and pressurized samples at day 0 and after 60 days' storage at 4 °C, determined by the ORAC assay. On day 0, the antioxidant capacity of the control sample was 6914.10 ± 417.27 μmol TE/100 g d.m., whereas the corresponding values for pressurized samples were in the range of 8429.48 ± 158.83 μmol TE/100 g d.m. at 500 MPa/5 min to 12786.2 ± 5542.30 μmol TE/100 g d.m. at 400 MPa/3 min. Thus, all pressurized samples showed higher antioxidant capacity than the control samples ($P < 0.05$). The highest values were observed at 300 MPa/1 min and 400 MPa/3 min. The higher extractability of Cape gooseberry antioxidants cannot be attributed to HHP since in a previous report, we showed that HHP treatment did not influence the antioxidant capacity of Cape gooseberry pulp [22]. Furthermore, there is a discrepancy in the literature over the effects of HHP on the antioxidant capacity of fruits. While some studies report increased antioxidant capacity of fruit and plant matrices treated by HHP compared to unpressurized samples [27], there have also been reports showing no differences in antioxidant capacity between pressurized and unpressurized samples [28,29]. Di Scala et al. [30] reported that HHP processing either increased or maintained the antioxidant activity of aloe vera depending on the applied pressure and holding times. Our results thus, demonstrate that the combined effect of HHP and SFE-CO_2 is an efficient system for the extraction of antioxidants from Cape gooseberry. Extraction by SFE-CO_2 is known for its effectiveness on plant matrices [31,32] and many reports agree that the use of carbon dioxide (CO_2) as solvent in SFE, in addition to ethanol as co-solvent, improve extraction efficiency [32,33]. This is because ethanol changes the fluid polarity, increasing its solvation power [4]. Thus, antioxidant capacity can also be enhanced by choosing different solvents based on polarity. In the present investigation, ethanol was used as co-solvent, showing a significant improvement of antioxidant activity compared to traditional extraction methods.

After 60 days' storage, samples treated with 500 MPa for 1, 3 and 5 min, showed significantly higher ($P < 0.05$) antioxidant capacity than unpressurized control samples and samples treated at lower pressures. Moreover, the antioxidant capacity of samples stored for 60 days was higher compared to that reported in *Lonicera caerulea* berry extracts [34], and blueberry juices [35]. Our results indicated that even after 60 days of storage at 4 °C, the antioxidant capacity of Cape gooseberry remained high (12388 μmol TE/100 g d.m., average at 500 MPa). Taken together, appropriate HHP treatment along with conditions of SFE can promote active ingredient release in fruit matrices, thus increasing antioxidant capacity. The present findings also provide an important pharmacological background of supercritical fluid extracts of *Physalis peruviana*, which can potentially develop into

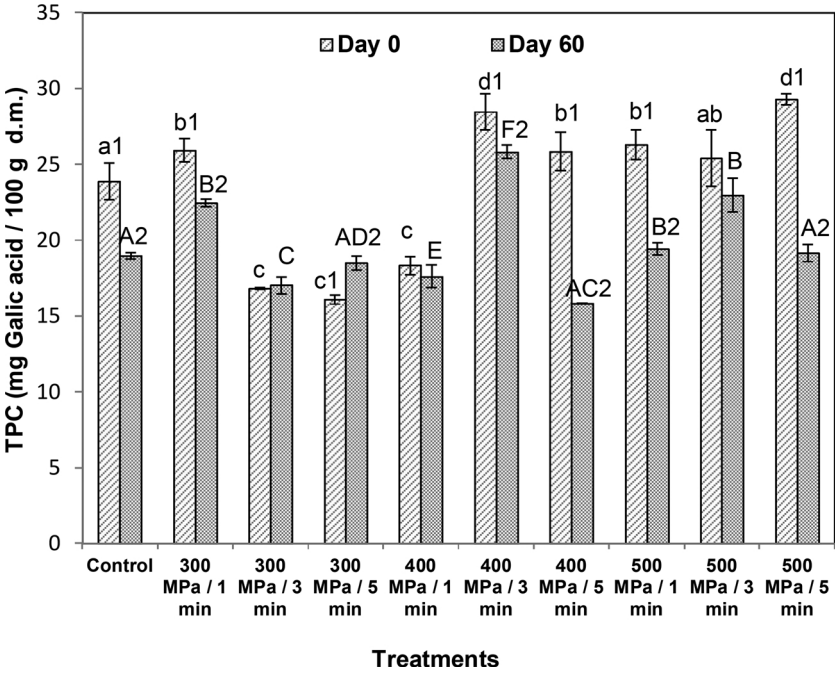


Fig. 1. Effects of pressure and holding time on total phenolic content of Cape gooseberry pulp extracted by SFE-CO_2.
Bars represent mean ± standard deviation of triplicates. Different letters a-d indicate significant differences ($P < 0.05$) between samples for day 0 and A-E for day 60, compared to the control sample; 1, 2 indicate significant differences ($P < 0.05$) between storage conditions (no numbers are indicated when $P > 0.05$).

products for the prevention of aging and other related diseases [36].

3.2. Total phenolic content (TPC)

Fig. 1 shows the phenolic content of Cape gooseberry supercritical extracts. At day 0, the initial TPC was 23.86 ± 1.22 mg GAE/100 g d.m. whereas pressurized samples changed in the range from 16.09 ± 0.29 to 29.28 ± 0.35 mg GAE/100 g d.m. at 300 and 500 MPa/5 min, respectively. Comparable values to control samples were reported in supercritical pistachio extracts (*Pistachia vera*) at processing conditions of 35–55 °C and 10–35 MPa and in Siitake extracts (*Lentinula edodes*) at 35–50 °C and 15–30 MPa [37,38]. Phenolic concentration in food extracts is dependent on the solvent and extraction method [36]. High TPC values were reported in acetone extracts of Cape gooseberry pulp treated with HHP [21]. Moreover, other supercritical extracts of myrtle leaves and berries exhibited a much higher content of polyphenols when compared to conventional extraction [39]. This can be explained since operating at low temperatures and in the absence of light and oxygen avoids degradation and decomposition of the active compounds [40]. Further experiments modifying the solvent/co solvent ratio during SFE extraction are necessary to optimize the TPC content from HHP treated Cape gooseberry pulp. Previous studies showed that total flavonoid and phenolic compounds were enriched after supercritical extraction, and suggested that the use of organic solvents with SFE-CO_2 extraction can increase the efficiency in isolating phenolic compounds from grape seeds [9]. When comparing control with pressurized samples, TPC increased in most samples except for those treated at 300 MPa/3 and 5 min and 400 MPa/1 min ($P < 0.05$). A similar behavior was reported in fresh mango pulp [15]. This increase could be the result of plant cell disruption caused by the treatment conditions, leading to a higher extractability of these compounds, especially at high pressures (400 and 500 MPa) [41]. The effect of 60 days storage on TPC was variable, the only conditions that increased TPC were 300 MPa/3–5 min and 400 MPa/3 min where the maximum content was observed at 400 MPa/3 min ($P < 0.05$). Similar results were reported for pressurized orange juice after 4 months of storage [42] and pressurized pulp of Cape gooseberry (*Physalis peruviana* L.) after 30 days of storage [43]. The high variability observed may be due to a higher residual activity of enzymes such as polyphenoloxidase and peroxidase in HHP-treated fruit pulp, since these enzyme's substrates are the endogenous phenols in pulp [22,41]. Nevertheless, results are diverse due to two factors, the enzyme or the substrate, that play a decisive role in the overall phenomenon of enzymatic browning. In addition, previous reports informed that HHP treatment can increase the rate of mass transfer resulting in an enhancement of solvent penetration into the cells by disrupting the cellular walls and hydrophobic bonds in the cell membrane, which may lead to a high permeability [44]. Regarding to extraction methodology, other authors informed that extracts obtained by SFE maintain or exceed the bioactivity of extracts obtained by conventional extraction techniques [4].

3.3. β-carotene content

Table 2 presents β-carotene content of supercritical fluid extracts (313 K and 25 MPa) after different high pressure treatments. At day 0, the control presented a value of 7.70 ± 0.12 (mg β-carotene/100 g d.m.). samples at 300 MPa/3 min showed the highest β-carotene content, whereas the remaining samples either maintained or decreased respect to the control values. Although conventionally, carotenoids are extracted using organic solvents, a number of studies have discussed the use of SFE for carotenoids recovery, mostly of β-carotene and lycopene [39]. Similar values of β-carotene content extracted by SFE were reported in Carrot (*Apache*) (17.17–89.9 mg β-carotene/100 g feed) [45] and in Roseship (*Rosa canica*) (15.4–101.7 mg β-carotene/100 g) [46]. Extraction conditions reported by these authors were 15–45 MPa, temperatures of 40–80 °C and CO_2 flow rates of 2–4 mL/min. It has been demonstrated that in SFE, temperature was the relevant variable affecting the carotenoids yield since increasing the temperature increases carotenoids solubility resulting in higher yields [4]. However, higher carotenoid yields (722 mg β-carotene/100 g) have also been reported in fresh Cape gooseberry extracted with a mixture of organic and polar solvents [47]. Our results show that the tested conditions were not able to recover the high β-carotene expected from Cape gooseberry pulp, as it was seen for supercritical extraction of other lipidic bioactive compounds from Allus species [10], berry seeds oils [12,48] and green coffee oil [11]. It has been reported that HHP increases carotenoids extractability since it can affect membranes in vegetable cells, disrupt chromoplasts where carotenoids are located, in addition to the pressure-induced denaturation of the carotenoid-binding protein, thus inducing a better release of these compounds [49]. With the exception of the high β-carotene content measured in the 300 MPa/3 min sample, our results do not agree with these findings. The great variability observed on β-carotene content may lie in external factors affecting either SFE or HHP. Since β-carotene content remained variable despite the diverse range in HHP parameters tested here (pressure and holding times), modifying SFE parameters such as temperature, pressure, extraction times and type of solvent and modifier would be a better approach to improve the extractability of β-carotene.

Table 2
Effects of pressure intensity and holding times on β-carotene content of Cape gooseberry pulp extracted by SFE-CO_2 at day 0 and after 60 days of storage at 4 °C.

HHP treatments	β-carotene content (mg β-carotene/100 g d.m.)	
	Day 0	Day 60
Control	7.70 ± 0.12^{a1}	5.93 ± 0.13^{A2}
300 MPa/1 min	7.55 ± 0.22^{ae1}	4.58 ± 0.16^{BD2}
300 MPa/3 min	9.61 ± 0.04^{b1}	5.51 ± 0.01^{C2}
300 MPa/5 min	7.80 ± 0.14^{ac1}	5.37 ± 0.19^{C2}
400 MPa/1 min	6.38 ± 0.09^{d1}	4.40 ± 0.27^{B2}
400 MPa/3 min	7.69 ± 0.26^{a1}	4.81 ± 0.13^{D2}
400 MPa/5 min	7.25 ± 0.32^{e1}	4.71 ± 0.12^{D2}
500 MPa/1 min	7.48 ± 0.09^{ae1}	3.84 ± 0.16^{EF2}
500 MPa/3 min	5.40 ± 0.35^{f1}	4.01 ± 0.14^{F2}
500 MPa/5 min	8.08 ± 0.07^{c1}	3.70 ± 0.05^{E2}

The presented values are the mean ± s.d. of three (n = 3) replicates. Different letters a-f indicate significant differences ($P < 0.05$) for day 0 and A, B, C for day 60, compared to the control sample; 1, 2 indicate significant differences ($P < 0.05$) between storage conditions.

The β-carotene content from samples stored 60 days decreased ($P < 0.05$) in the control sample compared to day 0 as well as in the pressurized samples. A similar behavior was seen on smoothies from different fruits treated by HHP at 450–600 MPa/3 min/20 °C [50]. These authors reported 4.3% decrease in total carotenoids in the untreated smoothie after 30 days. The reason explaining this loss was storage, which leads to instability of the polyene chain of carotenoids. As a consequence, these compounds may undergo geometric isomerization (promoted by heat, light and acids) and oxidation (stimulated by light, heat, metals, enzymes and peroxides, and inhibited by antioxidants) which are the main causes of carotenoid degradation [51].

4. Conclusions

In this work, we combine HHP processing with SFE-CO_2 extraction of bioactive compounds from Cape gooseberry pulps. We show here that both methods combined enhance antioxidant capacity in fresh samples and that storage for 60 days had a significant effect in the antioxidant capacity of unpressurized and 500 MPa pressurized samples. At the tested conditions, HHP and SFE-CO_2 were not effective in

recovering the high levels of TPC and β-carotene previously reported for Cape gooseberry. Considering the number of reports on successful supercritical extraction for recovery of essential oils from fruits and fruits byproducts, SFE conditions for Cape gooseberry must be optimized. Taken together, the present findings provide an important knowledge of supercritical fluid extraction of *Physalis peruviana*, which can potentially develop into new functional food products.

Funding sources

This work was supported by project FONDECYT 1120102.

References

[1] K. Gul, A.K. Singh, R. Jabeen, Nutraceuticals and functional foods: the foods for the future world, Crit. Rev. Food Sci. Nutr. 56 (2016) 2617–2627.
[2] B. Vieira da Silva, J.C.M. Barreira, M.B.P.P. Oliveira, Natural phytochemicals and probiotics as bioactive ingredients for functional foods: extraction, biochemistry and protected-delivery technologies, Trends Food. Sci. Technol. 50 (2016) 144–158.
[3] E. Uribe, A. Delgadillo, C. Giovagnoli-Vicuña, I. Quispe-Fuentes, L. Zura-Bravo, Extraction techniques for bioactive compounds and antioxidant capacity determination of Chilean papaya (*Vasconcellea pubescens*) fruit, J. Chem. 2015 (2015) 1–8.
[4] C.G. Pereira, M.A.A. Meireles, Supercritical fluid extraction of bioactive compounds: fundamentals, applications and economic perspectives, Food Bioproc. Tech. 3 (2010) 340–372.
[5] B.A.S. Machado, C.G. Pereira, S.B. Nunes, F.F. Padilha, M.A. Umsza-Guez, Supercritical fluid extraction using CO2: main applications and future perspectives, Sep. Sci. Technol. 48 (2013) 2741–2760.
[6] R.P.F.F. da Silva, T.A.P. Rocha-Santos, A.C. Duarte, Supercritical fluid extraction of bioactive compounds, Trends Analyt. Chem. 76 (2016) 40–51.
[7] K. Ameer, H.M. Shahbaz, J.-H. Kwon, Green extraction methods for polyphenols from plant matrices and their byproducts: a review, Compr. Rev. Food Sci. Food Saf. 16 (2017) 295–315.
[8] E. Arranz, L. Jaime, M.C. Lopez de la Hazas, G. Vicente, G. Reglero, S. Santoyo, Supercritical sage extracts as anti-inflammatory food ingredients, Ind. Crops Prod. 54 (2014) 159–166.
[9] H.B. Mohamed, K.S. Duba, L. Fiori, H. Abdelgawed, I. Tlili, T. Tounekti, et al., Bioactive compounds and antioxidant activities of different grape (*Vitis vinifera* L.) seed oils extracted by supercritical CO2 and organic solvent, LWT − Food Sci. Technol. 74 (2016) 557–562.
[10] M.M. Poojary, P. Putnik, D.B. Kovačević, F.J. Barba, J.M. Lorenzo, D.A. Dias, et al., Stability and extraction of bioactive sulfur compounds from *Allium* genus processed by traditional and innovative technologies, J. Food Compost. Anal. 61 (2017) 28–39.
[11] R.G. Bitencourt, N.J. Ferreira, A.L. Oliveira, F.A. Cabral, A.J.A. Meirelles, High pressure phase equilibrium of the crude green coffee oil –CO2–ethanol system and the oil bioactive compounds, J. Supercrit. Fluids 133 (2018) 49–57.
[12] J. Milala, K. Grzelak-Błaszczyk, M. Sójka, M. Kosmala, A. Dobrzyńska-Inger, E. Rój, Changes of bioactive components in berry seed oils during supercritical CO2 extraction, J. Food Process. Preserv. 42 (2017) e13368–7.
[13] J. Ndayishimiye, B.S. Chun, Optimization of carotenoids and antioxidant activity of oils obtained from a co-extraction of citrus (*Yuzu ichandrin*) by-products using supercritical carbon dioxide, Biomass Bioenergy. 106 (2017) 1–7.
[14] J. Ndayishimiye, D.J. Lim, B.S. Chun, Impact of extraction conditions on bergapten content and antimicrobial activity of oils obtained by a co-extraction of citrus by-products using supercritical carbon dioxide, Biotechnol. Bioproc E. 22 (2017) 586–596.
[15] N. Kaushik, B.P. Kaur, P.S. Rao, H.N. Mishra, Effect of high pressure processing on color, biochemical and microbiological characteristics of mango pulp (*Mangifera indica* cv. Amrapali), Innov. Food Sci. Emerg. Technol. 22 (2014) 40–50.
[16] G. Préstamo, G. Arroyo, High Hydrostatic Pressure Effects on Vegetable Structure, J. Food Sci. 63 (5) (1998) 878–881.
[17] C.-Y. Wang, H.-W. Huang, C.-P. Hsu, B.B. Yang, Recent advances in food processing using high hydrostatic pressure technology, Crit. Rev. Food Sci. Nutr. 56 (2016) 527–540.
[18] S.K. Gautam, D.H. Dwivedi, P. Kumar, Preliminary studies on the bioactive phytochemicals in extract of Cape gooseberry (*Physalis Peruviana* L.) fruits and their Products, J. Pharmacogn. Phytochem. 3 (2015) 93–95.
[19] M.A. Dkhil, S. Al-Quraishy, M.M.S. Diab, M.S. Othman, A.M. Aref, A.E. Abdel Moneim, The potential protective role of *Physalis peruviana* L. fruit in cadmium-induced hepatotoxicity and nephrotoxicity, Food Chem. Toxicol. 74 (2014) 98–106.
[20] M.F. Ramadan, J.-T. Moersel, Oil extractability from enzymatically treated goldenberry (*Physalis peruviana* L.) pomace: range of operational variables, Int. J. Food Sci. Technol. 44 (2009) 435–444.
[21] K. Bravo, E. Osorio, Characterization of polyphenol oxidase from Cape gooseberry (*Physalis peruviana* L.) fruit, Food Chem. 197 (2016) 185–190.
[22] A. Vega-Gálvez, J. López, M.J. Torres-Ossandón, M.J. Galotto, L. Puente-Díaz, I. QuispeFuentes, et al., High hydrostatic pressure effect on chemical composition color, phenolic acids and antioxidant capacity of Cape gooseberry pulp (*Physalis peruviana* L.), LWT − Food Sci. Technol. 58 (2014) 519–526.
[23] L. Zhang, J. Li, S. Hogan, H. Chung, G.E. Welbaum, K. Zhou, Inhibitory effect of raspberries on starch digestive enzyme and their antioxidant properties and phenolic composition, Food Chem. 119 (2010) 592–599.
[24] M.J. Torres-Ossandón, J. López, A. Vega-Gálvez, M.J. Galotto, M. Perez-Won, K. Di Scala, Impact of high hydrostatic pressure on physicochemical characteristics, nutritional content and functional properties of Cape gooseberry pulp (*Physalis peruviana* L.), J. Food Process. Preserv. 39 (2015) 2844–2855.
[25] A.M. Chuah, Y.-C. Lee, T. Yamaguchi, H. Takamura, L.-J. Yin, T. Matoba, Effect of cooking on the antioxidant properties of coloured peppers, Food Chem. 111 (2008) 20–28.
[26] L.M. Laur, L. Tian, Provitamin A and vitamin C contents in selected California-grown cantaloupe and honeydew melons and imported melons, J. Food Compost. Anal. 24 (2011) 194–201.
[27] R. Casquete, S.M. Castro, A. Martín, S. Ruiz-Moyano, J.A. Saraiva, M.G. Córdoba, et al., Evaluation of the effect of high pressure on total phenolic content, antioxidant and antimicrobial activity of citrus peels, Innov. Food Sci. Emerg. Technol. 31 (2015) 37–44.
[28] C. Sánchez-Moreno, L. Plaza, B. De Ancos, M.P. Cano, Impact of high-pressure and traditional thermal processing of tomato purée on carotenoids, vitamin C and antioxidant activity, J. Sci. Food Agric. 86 (2006) 171–179.
[29] F.J. Barba, M.J. Esteve, A. Frigola, Physicochemical and nutritional characteristics of blueberry juice after high pressure processing, Food Res. Int. 50 (2013) 545–549.
[30] K. Di Scala, A. Vega-Gálvez, K. Ah-Hen, Y. Nuñez-Mancilla, G. Tabilo-Munizaga, M. Pérez-Won, et al., Chemical and physical properties of aloe vera (*Aloe barbadensis* Miller) gel stored after high hydrostatic pressure processing, Food Sci. Technol. 33 (2013) 52–59.
[31] B. Díaz-Reinoso, A. Moure, H. Domínguez, J.C. Parajó, Supercritical CO2 extraction and purification of compounds with antioxidant activity, J. Agric. Food Chem. 54 (2006) 2441–2469.
[32] F.J. Barba, Z. Zhu, M. Koubaa, A.S. Sant'Ana, V. Orlien, Green alternative methods for the extraction of antioxidant bioactive compounds from winery wastes and by-products: a review, Trends Food Sci. Technol. 49 (2016) 96–109.
[33] M.R. García-Risco, E. Vázquez, J. Sheldon, E. Steinmann, N. Riebesehl, T. Fornari, et al., Supercritical fluid extraction of heather (*Calluna vulgaris*) and evaluation of anti-hepatitis C virus activity of the extracts, Virus Res. 198 (2015) 9–14.
[34] S. Liu, Q. Xu, X. Li, Y. Wang, J. Zhu, C. Ning, et al., Effects of high hydrostatic pressure on physicochemical properties enzymes activity, and antioxidant capacities of anthocyanins extracts of wild *Lonicera caerulea* berry, Innov. Food Sci. Emerg. Technol. 36 (2016) 48–58.
[35] F.J. Barba, H. Jäger, N. Meneses, M.J. Esteve, A. Frígola, D. Knorr, Evaluation of quality changes of blueberry juice during refrigerated storage after high-pressure and pulsed electric fields processing, Innov. Food Sci. Emerg. Technol. 14 (2012) 18–24.
[36] S.J. Wu, J.Y. Tsai, S.P. Chang, D.L. Lin, S.S. Wang, S.N. Huang, et al., Supercritical carbon dioxide extract exhibits enhanced antioxidant and anti-inflammatory activities of *Physalis peruviana*, J. Ethnopharmacol. 108 (2006) 407–413.
[37] A.H. Goli, M. Barzegar, M.A. Sahari, Antioxidant activity and total phenolic compounds of pistachio (*Pistachia vera*) hull extracts, Food Chem. 92 (2005) 521–525.
[38] C.S.G. Kitzberger, A. Smânia, R.C. Pedrosa, S.R.S. Ferreira, Antioxidant and antimicrobial activities of shiitake (*Lentinula edodes*) extracts obtained by organic solvents and supercritical fluids, J. Food Eng. 80 (2007) 631–638.
[39] P. Pereira, M.-J. Cebola, M.C. Oliveira, M.G. Bernardo-Gil, Supercritical fluid extraction vs conventional extraction of myrtle leaves and berries: comparison of antioxidant activity and identification of bioactive compounds, J. Supercrit. Fluids. 113 (2016) 1–9.
[40] M.A. Meneses, G. Caputo, M. Scognamiglio, E. Reverchon, R. Adami, Antioxidant phenolic compounds recovery from *Mangifera indica* L. by-products by supercritical antisolvent extraction, J. Food Eng. 163 (2015) 45–53.
[41] X. Cao, Y. Zhang, F. Zhang, Y. Wang, J. Yi, X. Liao, Effects of high hydrostatic pressure on enzymes phenolic compounds, anthocyanins, polymeric color and color of strawberry pulps, J. Sci. Food Agric. 91 (2011) 877–885.
[42] I. Klimczak, M. Małecka, M. Szlachta, A. Gliszczyńska-Świgło, Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices, J. Food Compost. Anal. 20 (2007) 313–322.
[43] A. Vega-Gálvez, R. Díaz, J. López, M.J. Galotto, J.E. Reyes, M. Pérez-Won, et al., Assessment of quality parameters and microbial characteristics of Cape gooseberry pulp (*Physalis peruviana* L.) subjected to high hydrostatic pressure treatment, Food Bioprod. Process. 97 (2016) 30–40.
[44] K.N. Prasad, E. Yang, C. Yi, M. Zhao, Y. Jiang, Effects of high pressure extraction on the extraction yield, total phenolic content and antioxidant activity of longan fruit pericarp, Innov. Food Sci. Emerg. Technol. 10 (2009) 155–159.
[45] M. Sun, F. Temelli, Supercritical carbon dioxide extraction of carotenoids from carrot using canola oil as a continuous co-solvent, J. Supercrit. Fluids. 37 (2006) 397–408.
[46] S. Machmudah, Y. Kawahito, M. Sasaki, M. Goto, Process optimization and extraction rate analysis of carotenoids extraction from rosehip fruit using supercritical CO2, J. Supercrit. Fluids. 44 (2008) 308–314.
[47] J. López, A. Vega-Gálvez, M.J. Torres, R. Lemus-Mondaca, I. Quispe-Fuentes, K. Di Scala, Effect of dehydration temperature on physico-chemical properties and antioxidant capacity of goldenberry (*Physalis peruviana* L.), Chilean J. Agric. Res. 73 (2013) 293–300.
[48] A. Wajs-Bonikowska, A. Stobiecka, R. Bonikowski, A. Krajewska, M. Sikora, J. Kula, A comparative study on composition and antioxidant activities of supercritical carbon dioxide, hexane and ethanol extracts from blackberry (*Rubus fruticosus*) growing in Poland, J. Sci. Food Agric. 97 (2017) 3576–3583.
[49] L. Plaza, C. Colina, B. de Ancos, C. Sánchez-Moreno, M. Pilar Cano, Influence of

ripening and astringency on carotenoid content of high-pressure treated persimmon fruit (*Diospyros kaki* L.), Food Chem. 130 (2012) 591–597.

[50] V. Andrés, M.J. Villanueva, M.D. Tenorio, The effect of high-pressure processing on colour, bioactive compounds, and antioxidant activity in smoothies during refrigerated storage, Food Chem. 192 (2016) 328–335.

[51] L. Plaza, C. Sánchez-Moreno, B. De Ancos, P. Elez-Martínez, O. Martín-Belloso, M.P. Cano, Carotenoid and flavanone content during refrigerated storage of orange juice processed by high-pressure, pulsed electric fields and low pasteurization, LWT − Food Sci. Technol. 44 (2011) 834–839.