International Journal of Gastronomy and Food Science 25 (2021) 100389

Contents lists available at ScienceDirect

International Journal of Gastronomy and Food Science

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

Influence of culinary process on free and bound (poly)phenolic compounds and antioxidant capacity of artichokes

Maite Domínguez-Fernández [a], Ángel Irigoyen [b], Maria de los Angeles Vargas-Alvarez [a], Iziar A. Ludwig [c,*], María-Paz De Peña [a,d,1], Concepción Cid [a,d,1]

[a] Universidad de Navarra, Facultad de Farmacia y Nutrición, Departamento de Ciencias de la Alimentación y Fisiología, C/Irunlarrea 1, E-31008, Pamplona, Spain
[b] Universidad de Navarra, Facultad de Farmacia y Nutrición, Departamento de Tecnología y Química Farmacéuticas, C/Irunlarrea 1, E-31008, Pamplona, Spain
[c] Universidad de Navarra, Centro de Investigación Médica Aplicada (CIMA), Terapias Moleculares/Química Médica, Avda. Pío XII, 55, E-31008, Pamplona, Spain
[d] IdiSNA, Navarra Institute for Health Research, Pamplona, Spain

ARTICLE INFO

Keywords:
Artichokes
Cynara
Polyphenols
Culinary techniques
Antioxidant
Phenolic acids
LC-MS/MS

ABSTRACT

Artichokes are an important source of (poly)phenolic compounds, mainly caffeoylquinic acids, which consumption has been associated with health benefits. However, heat treatments have shown to affect the amounts of these bioactive food compounds.

In the present study the influence of culinary techniques (boiling, griddling, and frying) on the total (poly) phenolic content of artichokes **(*Cynara Scolymus* cv. Blanca de Tudela)** was evaluated by LC-MS/MS. Additionally, the antioxidant capacity of cooked artichokes was evaluated by spectrophotometric methods.

A total of 31 (poly)phenols were identified and quantified, being caffeoylquinic acids the most abundant compounds in raw artichokes accounting for more than 95% of total (poly)phenolic compounds. With the different culinary techniques, these compounds suffered degradation but also redistribution, probably due to isomerization and hydrolysis reactions. Frying and griddling showed the lowest content of (poly)phenolic compounds and antioxidant capacity suggesting thermal degradation. Boiling also provoked losses, which were mainly due to leaching of phenolic compounds into the water. However, it was the heat treatment that best preserved (poly)phenolic compounds in artichokes.

Introduction

Globe artichoke (*Cynara Scolymus* L.) is a highly cultivated and consumed Mediterranean plant (Fratianni et al., 2007). According to FAO, Spain was the second artichoke producer in the world in 2018, only behind Italy (Eurostat, 2019). Cultivation of artichoke in Spain comes almost exclusively from clones of the variety "Blanca de Tudela", and those cultivated in 33 municipalities of Navarre are commercially available as "Alcachofa de Tudela", and protected by the seal of quality "Geographic Indication" (GI) (MAPAMA, 2010).

Artichokes are an important source of bioactive compounds, mainly (poly)phenols. (Poly)phenols are secondary metabolites of plants and are subject of increasing scientific interest for their great abundance in diet, antioxidant capacity, and possible role in the prevention of various chronic human diseases, such as cancer, cardiovascular and neurodegenerative disease (Galanakis, 2018; Del Rio et al., 2013; Rodriguez-Mateos et al., 2014; Scalbert et al., 2005).

Artichoke's major (poly)phenols are caffeoylquinic acids (CQAs); esters between quinic acid and the hydroxycinnamate caffeic acid. Many positional isomers of both monocaffeoylquinic acids (monoCQAs) and dicaffeoylquinic acids (diCQAs) have been identified in raw artichokes (Abu-Reidah et al., 2013; Alarcón-Flores et al., 2014; Lombardo et al., 2010; Palermo et al., 2013; Pandino et al., 2013). Besides, some flavonoids have been found in lower amounts, mainly apigenin and luteolin derivatives (Lattanzio et al., 2009; Lombardo et al., 2010; Palermo et al., 2013; Pandino et al., 2013).

Nevertheless, as many other vegetables, artichokes are commonly consumed after being cooked, so it is necessary to understand how culinary processing affects artichoke (poly)phenols (Tomás-Barberán and Espín, 2001). Culinary processes have shown to impact on the amounts of these bioactive compounds in foods such as green pepper, cardoon stalks, onion and cactus cladodes depending on the cooking

* Corresponding author.
E-mail address: iludwig@unav.es (I.A. Ludwig).
[1] Equal contribution.

https://doi.org/10.1016/j.ijgfs.2021.100389
Received 18 December 2020; Received in revised form 28 June 2021; Accepted 6 July 2021
Available online 8 July 2021

technique used (De Santiago et al., 2018; Juániz et al, 2016a, 2016b). Boiling is the most common cooking process used as hydrothermal treatment for vegetables (Shahidi and Yeo, 2016). Other heat treatments which apply high temperatures, such as frying and griddling, are also traditionally applied to vegetables.

Information on the effects of the most common cooking treatments on artichoke (poly)phenolic profile is scarce, with only two studies reporting values for boiling and frying (Ferracane et al., 2008; Lutz et al., 2011), and no study was found on the effects of griddling. Additionally, these studies quantified only 10 and 3 (poly)phenols in edible parts of cooked artichokes, using HPLC-UV techniques. Although HPLC coupled to UV-visible detectors has been widely used for the identification and quantification of (poly)phenolic compounds, the use of LC-MS techniques has some advantages such as higher sensibility as it allows to quantify lower concentrations, and better specificity as it is able to distinguish coeluting peaks (Grebe and Singh, 2011), enabling the quantification of a larger number of compounds. Only one recent study has been found on the effect of heat treatments, including *sous-vide* and microwaving, on (poly)phenols by LC-MS/MS (Domínguez-Fernández et al., 2021).

(Poly)phenolic compounds in fruits and vegetables can be found in their free or bound form (Pérez-Jiménez and Torres, 2011; White et al., 2010), associated with some food matrix structures such as proteins or polysaccharides by covalent or other interactions (Monente et al., 2015). The content of bound compounds vary considerably among vegetables (Gao et al., 2017; Juániz et al, 2016a, 2017). However, they might play an important role in antioxidant activity of vegetables because after reaching the small intestine or the colon they can be hydrolyzed by pH changes, intestinal enzymes or colonic microbiota, respectively, being bioaccessible afterwards. Colantuono et al. (2017) identified and quantified bound compounds in raw artichokes, however, to our knowledge, this is the first study were free and bound compounds were identified and quantified in both raw and cooked artichokes.

Thus, the aim of this work was to study the influence of boiling, griddling and frying on the (poly)phenolic profile (free and bound) and antioxidant capacity of artichokes. Additionally, this study pretends to give a more extensive identification and quantification of (poly)phenolic compounds present in artichokes by the use of LC-MS/MS.

Material and methods

Chemical and reagents

Fresh Tudela artichokes (*Cynara Scolymus* cv. Blanca de Tudela) were obtained from a local farmer's market in Tudela (Spain) and kept refrigerated (4 °C) until cooking. Refined olive oil was obtained from local stores. Methanol (LC-MS grade) was from Panreac (Barcelona, Spain). Acetonitrile and formic acid (LC-MS grade) were purchased from Scharlau (Barcelona, Spain). Sodium hydroxide, citric acid, Folin–Ciocalteu reagent, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox), 2,2′-azinobis (3-ethylbenzothiazonile-6-sulfonic acid) diammonium salt (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH$^{\bullet}$) and pure standards for LC-MS identification and quantification (5-O-caffeoylquinic acid (5-CQA), caffeic acid, 4-O-caffeoylquinic acid (4-CQA), luteolin glucoside, 3,4-O-dicaffeoylquinic acid (3,4-diCQA), apigenin rutinoside, 1,5-O-dicaffeoylquinic acid (1,5-diCQA), 3,5-O-dicaffeoylquinic acid (3,5-diCQA), apigenin glucoside, apigenin glucuronide, luteolin glucuronide, luteolin and apigenin) were purchased from Sigma-Aldrich (Steinheim, Germany). 1,3-O-dicaffeoylquinic acid (1,3-diCQA or cynarin) and 4,5-O-dicaffeoylquinic acid (4,5-diCQA) were obtained from Merck (Darmstadt, Germany).

Samples preparation

Three different culinary techniques (boiling, griddling and frying) were selected for the analysis of (poly)phenolic compounds in Tudela artichokes. Each heat treatment cooks through different mechanism of heating, via transference of the heat from the boiling water (boiling), hot surface (griddling) or frying oil (frying), respectively. Thus, with the aim of softening the matrix to improve the palatability, the three heat treatments were applied to artichokes for different times and reaching different temperatures.

After removing the external leaves of the artichoke heads, edible parts were divided into four portions. One portion (raw sample) was not cooked, stored at -80 °C until lyophilization and used as control. The other three samples were cooked in duplicate as described below:

Boiling: 225 g artichokes were added to 2 L of boiling water (100 °C) in a stainless-steel pot and were cooked for 15 min. Then, samples were drained off. Immediately afterwards, samples were cooled in an ice-bath for 10 min and stored at -80 °C until lyophilization.

Griddling: 225 g artichokes were firstly chopped and then cooked in an electric non-stick griddle at 180 °C for 10 min. Immediately afterwards, samples were cooled in an ice-bath for 10 min and stored at -80 °C until lyophilization.

Frying: 225 g artichokes were cut in four parts and fried in a non-stick frying pan with 20 mL of refined olive oil at 170 °C for 7 min. Immediately afterwards, samples were cooled in an ice-bath for 10 min and stored at -80 °C until lyophilization.

Raw and cooked artichokes (boiled, griddled and fried) were lyophilized in a freeze dryer Cryodos-80 (Telstar, Terrasa, Spain) and stored at -18 °C until analysis.

(Poly)phenolic compounds extraction

Extraction of free (poly)phenolic compounds from raw and cooked artichokes was performed according to Sánchez-Salcedo et al. (2015) with some modifications. Briefly, each lyophilized artichoke sample was powdered, and 25 mg were extracted in triplicate with 0.5 mL of methanol/acidified water (0.1% formic acid) (80:20 v/v), sonicated for 90 min, and centrifuged for 10 min at 18620 g (Mikro 200, Hettich, Tuttlingen, Germany). The supernatant was collected and the residue was re-extracted using 0.25 mL of methanol/acidified water (0.1% formic acid) (80:20 v/v), sonicated for 25 min, and centrifuged for 10 min at 18620 g. Both supernatants were combined and stored at -18 °C until LC-MS/MS analysis.

Extraction of bound (poly)phenolic compounds was performed following the method reported by Zaupa et al. (2014) with some modifications. The final residue obtained (pellet) after the previously described extraction was hydrolyzed for 1 h with 0.75 mL of 2 M NaOH at room temperature. After alkaline hydrolysis, the pH of the mixture was adjusted to pH 3 by adding 675 μL of 3 M citric acid. After hydrolysis, samples were lyophilized in a freeze dryer Cryodos-80 (Telstar, Terrasa, Spain). The bound phenolic compounds were then extracted by adding 0.5 mL of methanol/acidified water (0.1% formic acid) (80:20 v/v) to the lyophilized residue and following from here the same procedure as for the free compounds.

For both free and bound compounds extraction, three independent assays were performed for each sample.

LC-MS/MS identification and quantification of (poly)phenolic compounds

Qualitative and quantitative analyses of (poly)phenolic compounds were carried out using an HPLC unit model 1200 (Agilent Technologies, CA, USA) equipped with a triple quadrupole linear ion trap mass spectrometer (3200 Q-TRAP, AB SCIEX). The column used was a CORTECS® C18 (3 × 75 mm, 2.7 μm) from Waters.

For HPLC separation, mobile phase A was 0.1% (v/v) formic acid in water and mobile phase B was acetonitrile. Gradient elution was as follows: 5% B (0–1.20 min); 5–11.4% B (1.20–8.80 min); 11.4–11% B (8.80–10 min); 11–28% B (10–30 min); 28–100% B (30–32 min), and then return to 5% B in 2 min and maintained isocratic until the end of the analysis (38 min). Injection volume was 4 μl, column oven

temperature 30 °C and elution flow rate 0.35 mL/min.

To identify (poly)phenolic compounds, a preliminary analysis was carried out in a full scan mode, scanning from m/z of 100–1000, and a consecutively selective product ion mode analysis MS2 with specific mass to charge (m/z). For the final identification and quantification of the (poly)phenolic compounds, ion multiple reaction monitoring (MRM) mode was used.

The mass spectrometer (MS) run in negative ionization mode, with the turbo heater maintained at 500 °C and IonSpray voltage set at -3500 V. Nitrogen was used as nebulizing, turbo heater and curtain gas, and it was set at the pressure of -40, -50 and -35 psi, respectively. Declustering potential (DP) and entrance potential (EP) were optimized using 5-CQA and apigenin standards and they were set at -60 V and -11 V, respectively. Collision energy (CE) was optimized for each compound using the same standards as for (poly)phenolic compounds identification (Supplementary Information Table S1). For DP, EP and CE optimization, standards were infused directly into the mass spectrometer at a constant flow rate of 10 μL/min using a syringe pump (1001 TLL SYR, Hamilton, Giarmata, Romania).

For identification, 5-CQA, caffeic acid, 4-CQA, luteolin glucoside, 3,4-diCQA, apigenin rutinoside, 1,5-diCQA, 3,5-diCQA, apigenin glucoside, apigenin glucuronide, luteolin glucuronide, 1,3-diCQA and 4,5-diCQA pure standards were used as reference compounds for comparison of the obtained MS/MS fragmentation. When no standard was available, MS/MS fragmentation was compared with the literature fragmentation pathway. Quantification was performed with calibration curves. Phenolic acids were quantified as 5-CQA equivalents, while flavonoids and pinoresinol derivatives were quantified using rutin.

Chromatograms and spectral data were acquired using Analyst software 1.6.3 (AB SCIEX). Results were expressed as milligrams of each compound per gram of dry matter sample (mg/g dm).

Total phenolic content (TPC)

Total phenolic content (TPC) was measured by the Folin–Ciocalteu method according to Singleton and Rossi (Singleton and Rossi, 1965). A volume of 500 μL of Folin-Ciocalteu reagent was mixed with 100 μL of the extract, properly diluted, and 7.9 mL of demineralized water. After 2 min, 1.5 mL of a 75% sodium carbonate solution was added. Later, the mixture was incubated in darkness at room temperature for 90 min. Absorbance of the samples was measured at 765 nm in a Lambda 25 UV/VIS spectrophotometer (PerkinElmer Instruments, Madrid, Spain) at 25 °C. Gallic Acid (GA) was used as reference, and results were expressed as milligrams of GA equivalent per gram of dry matter (mg GA/g dm).

Antioxidant capacity by DPPH assay

DPPH antioxidant capacity was measured using 2,2-diphenyl-1-picrylhydrazyl (DPPH$^{\bullet}$) assay according to Brand-Williams et al. (1995) with modifications. A 6.1 × 10^{-5} M DPPH$^{\bullet}$ methanolic solution was prepared immediately before use. Methanol was used to adjust DPPH$^{\bullet}$ solution to an absorbance of 0.700 (±0.020) at 515 nm in a Lambda 25 UV/VIS spectrophotometer (PerkinElmer Instruments, Madrid, Spain) at 25 °C. Fifty microliters of each properly diluted extract were mixed with 1.95 mL of DPPH$^{\bullet}$ solution. After exactly 18 min, absorbance was measured at 515 nm. Calibration curve for quantification was made with Trolox solution (a water-soluble vitamin E analog). Antioxidant capacity was expressed as micromoles of Trolox equivalent per gram of dry matter (μmol Trolox/g dm).

Antioxidant capacity by ABTS assay

ABTS antioxidant capacity was measured according to Re et al. (1999). ABTS$^{\bullet+}$ radicals were generated by the addition of 0.36 mM potassium persulfate to a 0.9 mM ABTS solution prepared in phosphate

Table 1
Content of (poly)phenolic compounds (mg (poly)phenolic compound/g dry matter) in artichokes before and after different heat treatments. Results are expressed as mean ± standard deviation (n = 3).

COMPOUND	RAW	HEAT TREATED		
		Boiled	Griddled	Fried
1-CQA				
Free compounds	0.652 ± 0.020 a	0.603 ± 0.019 a	0.339 ± 0.020 a	0.302 ± 0.011 a
Bound compounds	nd	nd	nd	nd
3-CQA				
Free compounds	0.186 ± 0.007 a	1.863 ± 0.047 b	0.284 ± 0.012 a	0.254 ± 0.004 a
Bound compounds	nd	nd	nd	nd
4-CQA				
Free compounds	0.053 ± 0.004 a	2.821 ± 0.062 b	0.817 ± 0.022 a	0.747 ± 0.407 a
Bound compounds	0.061 ± 0.008 a	0.018 ± 0.000 a	0.014 ± 0.008 a	0.016 ± 0.006 a
5-CQA				
Free compounds	38.653 ± 1.823 c	23.083 ± 1.201 b	15.419 ± 0.588 a	15.127 ± 1.771 a
Bound compounds	0.123 ± 0.018 a	0.055 ± 0.008 a	0.046 ± 0.020 a	0.033 ± 0.016 a
5-CQAcis				
Free compounds	0.154 ± 0.018 a	0.113 ± 0.010 a	0.097 ± 0.007 a	0.088 ± 0.052 a
Bound compounds	nd	nd	nd	nd
1.3-diCQA				
Free compounds	0.104 ± 0.001 a	1.628 ± 0.026 b	0.262 ± 0.013 a	0.208 ± 0.002 a
Bound compounds	0.221 ± 0.018 b	0.178 ± 0.020 ab	0.130 ± 0.003 ab	0.089 ± 0.016 a
1.4-diCQA				
Free compounds	0.093 ± 0.003 a	0.729 ± 0.008 a	0.362 ± 0.008 a	0.317 ± 0.001 a
Bound compounds	0.011 ± 0.002 a	0.008 ± 0.000 a	0.002 ± 0.000 a	<LOQ
3.4-diCQA				
Free compounds	0.141 ± 0.008 a	1.308 ± 0.014 b	0.555 ± 0.010 ab	0.556 ± 0.010 ab
Bound compounds	0.066 ± 0.00 a	0.015 ± 0.003 a	0.005 ± 0.004 a	0.008 ± 0.005 a
1.5-diCQA				
Free compounds	12.583 ± 0.787 b	11.450 ± 0.725 b	9.111 ± 0.263 a	8.401 ± 0.717 a
Bound compounds	0.073 ± 0.016 a	0.034 ± 0.005 a	0.022 ± 0.007 a	0.011 ± 0.010 a
3.5-diCQA				
Free compounds	14.745 ± 0.949 c	4.892 ± 0.276 a	4.981 ± 0.333 a	6.399 ± 0.197 b
Bound compounds	0.074 ± 0.012 a	0.017 ± 0.006 a	0.012 ± 0.004 a	0.010 ± 0.008 a
4.5-diCQA				
Free compounds	0.149 ± 0.009 a	2.572 ± 0.004 c	1.280 ± 0.024 b	1.327 ± 0.022 b
Bound compounds	0.077 ± 0.003 a	0.022 ± 0.005 a	0.009 ± 0.005 a	0.013 ± 0.007 a
diCQA glucoside I				
Free compounds	0.038 ± 0.002 a	0.028 ± 0.001 a	0.023 ± 0.001 a	0.023 ± 0.000 a
Bound compounds	nd	nd	nd	nd
diCQA glucoside II				
Free compounds	0.132 ± 0.007 a	0.089 ± 0.002 a	0.088 ± 0.002 a	0.074 ± 0.000 a
Bound compounds	nd	nd	nd	nd
Caffeoyl-hexoside				
Free compounds	0.151 ± 0.007 a	0.103 ± 0.006 a	0.084 ± 0.002 a	0.077 ± 0.003 a
Bound compounds	0.055 ± 0.001 a	0.029 ± 0.003 a	0.071 ± 0.001 a	0.029 ± 0.003 a
Caffeic acid				

(continued on next page)

Table 1 (*continued*)

COMPOUND	RAW	HEAT TREATED		
		Boiled	Griddled	Fried
Free compounds	nd	nd	nd	nd
Bound compounds	0.424 ± 0.028 ab	0.589 ± 0.032 bc	0.656 ± 0.065 c	0.355 ± 0.016 a
Caffeic acid derivative				
Free compounds	0.022 ± 0.001 a	<LOQ	0.025 ± 0.001 a	0.070 ± 0.000 a
Bound compounds	nd	nd	nd	nd
p-coumaroylquinic acid I				
Free compounds	0.276 ± 0.011 a	0.161 ± 0.002 a	0.267 ± 0.002 a	0.197 ± 0.010 a
Bound compounds	nd	nd	nd	nd
p-coumaroylquinic acid II				
Free compounds	0.091 ± 0.003 a	0.062 ± 0.001 a	0.064 ± 0.005 a	0.045 ± 0.001 a
Bound compounds	nd	nd	nd	nd
Ferulic acid isomer				
Free compounds	nd	nd	nd	nd
Bound compounds	0.361 ± 0.021 b	0.037 ± 0.007 a	0.041 ± 0.027 a	0.045 ± 0.022 a
Apigenin 7-O-rutinoside				
Free compounds	0.073 ± 0.004 a	0.049 ± 0.001 a	0.100 ± 0.003 a	0.101 ± 0.004 a
Bound compounds	nd	nd	nd	nd
Apigenin 7-O-glucoside				
Free compounds	0.037 ± 0.001 a	0.030 ± 0.001 a	0.038 ± 0.002 a	0.029 ± 0.001 a
Bound compounds	0.003 ± 0.000 ab	0.002 ± 0.000 ab	0.003 ± 0.001 b	0.001 ± 0.000 a
Apigenin 7-O-glucuronide				
Free compounds	0.488 ± 0.024 a	0.418 ± 0.008 a	0.432 ± 0.027 a	0.336 ± 0.008 a
Bound compounds	0.031 ± 0.002 a	0.025 ± 0.002 a	0.028 ± 0.009 a	0.016 ± 0.002 a
Apigenin				
Free compounds	0.004 ± 0.000 a	0.004 ± 0.000 a	0.007 ± 0.000 a	0.014 ± 0.001 a
Bound compounds	nd	nd	nd	nd
Apigenin acetylglucoside				
Free compounds	0.007 ± 0.000 a	0.006 ± 0.000 a	0.007 ± 0.001 a	0.004 ± 0.000 a
Bound compounds	nd	nd	nd	nd
Luteolin 7-O-rutinoside				
Free compounds	0.283 ± 0.013 a	0.135 ± 0.004 a	0.214 ± 0.010 a	0.281 ± 0.009 a
Bound compounds	nd	nd	nd	nd
Luteolin 7-O-glucoside				
Free compounds	0.305 ± 0.010 a	0.167 ± 0.003 a	0.274 ± 0.011 a	0.267 ± 0.010 a
Bound compounds	nd	nd	nd	nd
Luteolin 7-O-glucuronide				
Free compounds	0.132 ± 0.004 a	0.084 ± 0.003 a	0.109 ± 0.002 a	0.094 ± 0.003 a
Bound compounds	0.010 ± 0.000 a	0.008 ± 0.001 a	0.011 ± 0.005 a	0.008 ± 0.001 a
Luteolin acetylglucoside				
Free compounds	0.131 ± 0.006 a	0.046 ± 0.000 a	0.110 ± 0.015 a	0.092 ± 0.001 a
Bound compounds	nd	nd	nd	nd
Luteolin				
Free compounds	<LOQ	0.010 ± 0.000 a	0.018 ± 0.001 a	0.043 ± 0.004 a
Bound compounds	nd	nd	nd	nd
Pinoresinol 4-O-β-D-glucoside				
Free compounds	0.259 ± 0.010 a	0.105 ± 0.002 a	0.264 ± 0.006 a	0.270 ± 0.000 a
Bound compounds	0.012 ± 0.001 a	0.006 ± 0.000 a	0.013 ± 0.006 a	0.006 ± 0.001 a
Pinoresinol-acetylhexoside				
Free compounds	0.037 ± 0.000 a	0.023 ± 0.001 a	0.040 ± 0.002 a	0.029 ± 0.001 a
Bound compounds	nd	nd	nd	nd

Different letters for each row indicate significant differences ($p \leq 0.05$) among samples; nd = not detected; <LOQ = below the limit of quantification.

Table 2
Content of total (poly)phenolic compounds (mg (poly)phenolic compound/g dry matter) in artichokes before and after different heat treatments. Results are expressed as mean ± standard deviation (n = 3).

COMPOUND	RAW	HEAT TREATED		
		Boiled	Griddled	Fried
Total monoCQAs and derivatives				
Free compounds	39.697 ± 1.827 c	28.483 ± 1.313 b	16.956 ± 0.640 a	15.821 ± 1.853 a
Bound compounds	0.184 ± 0.011 a	0.073 ± 0.012 a	0.060 ± 0.029 a	0.049 ± 0.022 a
Total diCQAs and derivatives				
Free compounds	28.507 ± 1.257 c	22.696 ± 0,891 b	16.662 ± 0.587 a	16.915 ± 0.861 a
Bound compounds	0.522 ± 0.001 b	0.274 ± 0.012 a	0.192 ± 0.015 a	0.132 ± 0.043 a
Other phenolic acids				
Free compounds	0.540 ± 0.021 a	0.326 ± 0.008 a	0.439 ± 0.005 a	0.389 ± 0.014 a
Bound compounds	0.839 ± 0.051 b	0.655 ± 0.042 b	0.782 ± 0.093 b	0.430 ± 0.041 a
Total phenolic acids				
Free compounds	68.222 ± 2.725 c	51.505 ± 2.192 b	34.058 ± 0.922 a	33.124 ± 2.728 a
Bound compounds	1.545 ± 0.041 c	1.002 ± 0.013 b	1.049 ± 0.020 b	0.610 ± 0.106 a
Total flavonoids				
Free compounds	1.461 ± 0.052 a	0.949 ± 0.013 a	1.310 ± 0.024 a	1.260 ± 0.041 a
Bound compounds	0.044 ± 0.003 a	0.035 ± 0.003 a	0.042 ± 0.015 a	0.025 ± 0.003 a
Total lignans				
Free compounds	0.296 ± 0.011 a	0.128 ± 0.001 a	0.286 ± 0.017 a	0.298 ± 0.001 a
Bound compounds	0.012 ± 0.001 a	0.006 ± 0.000 a	0.013 ± 0.006 a	0.006 ± 0.001 a
TOTAL (POLY)PHENOLIC COMPOUNDS				
Free compounds	69.979 ± 2.718 c	52.582 ± 2.203 b	35.653 ± 0.919 a	34.683 ± 2.771 a
Bound compounds	1.600 ± 0.044 c	1.044 ± 0.016 b	1.117 ± 0.024 b	0.641 ± 0.109 a

Different letters for each row indicate significant differences ($p \leq 0.05$) among samples.

buffered saline (PBS) (pH 7.4). $ABTS^{\bullet+}$ solution was stored in darkness for 12 h. Afterwards, $ABTS^{\bullet+}$ solution was adjusted with PBS to an absorbance of 0.700 (±0.020) at 734 nm in a Lambda 25 UV/VIS spectrophotometer (PerkinElmer Instruments, Madrid, Spain) at 25 °C. 100 μL of each extract dilution was added to 2 mL of $ABTS^{\bullet+}$ solution. After exactly 18 min, the final absorbance was measured spectrophotometrically at 734 nm. Calibration curve for quantification was made with Trolox solution (a water-soluble vitamin E analog). Antioxidant capacity was expressed as micromoles of Trolox equivalent per gram of dry matter (μmol Trolox/g dm).

Statistical analysis

Each extraction and analysis were performed in triplicate. Results are shown as the mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was applied for each parameter followed by a Tukey test as *a posteriori* test with a level of significance of 95%. Principal Component Analysis (PCA) standardized was applied in order to study the effect of heat treatment. Both ANOVA and PCA were performed using GraphPad Prism Software (version 9.0.0 for Windows, GraphPad Software, San Diego, California USA, www.graphpad.com).

Results and discussion

(Poly)phenolic compounds by LC-MS/MS

A total of 31 (poly)phenolic compounds were identified and quantified in the free and bound fractions of artichoke samples (Table 1). Nineteen were phenolic acids, specifically hydroxycinnamic acids derivatives, including caffeic, ferulic and p-coumaric derivatives; ten flavonoids belonging to the family of flavones (apigenin and luteolin derivatives); and two lignans (pinoresinol derivatives). Table 2 shows total (poly)phenolic content as the sum of every individual compound quantified, as well as total phenolic acids, total flavonoids and total lignans. Mass spectrometric characteristics of (poly)phenolic compounds identified by LC-MS/MS are shown in Supplementary Information Table S1.

The most representative compounds in raw and cooked samples were phenolic acids, especially caffeoylquinic acids, both monoCQAs and diCQAs, which accounted for 45–56% and 40–48% of the total (poly) phenolic compounds content, respectively (Table 2). As previously reported (Ferracane et al., 2008; Palermo et al., 2013), 5-CQA was the major compound and accounted for more than 50% and 40% of the total compounds in raw and cooked samples, respectively (Table 1). Following 5-CQA, 1,5-diCQA and 3,5-diCQA were the most abundant compounds accounting respectively for >20% and >10% of total (poly) phenolic content in all samples.

In raw artichokes, total (poly)phenolic compounds accounted for 69.98 mg/g dm. In the literature, important differences in the content of (poly)phenols in raw artichokes have been reported (4.35–45.5 mg/g dm) (Lombardo et al., 2010; Palermo et al., 2013; Pandino et al., 2013), probably due to different varieties or cultivars (Lombardo et al., 2010) and time of harvest (Palermo et al., 2013), as well as the analytical technique applied. Cooking treatments caused both changes in total and individual amounts of the native phenolics due to isomerization, hydrolysis and thermal degradation. Overall, all three cooking techniques provoked significant losses in total artichoke (poly)phenols.

Boiling significantly decreased total (poly)phenol content in artichokes by approximately 25%. In the case of monoCQAs, 5-CQA contents were 40% lower than in raw artichokes but the formation of 4- and 3-CQA isomers due to transesterification compensated to some extent the loss. For that, total monoCQAs were reduced during boiling by no more than 30%. Regarding diCQAs, 1,5-CQA contents were not decreased significantly but 3,5-diCQA suffered losses of up to 65%. However, formation of 4,5-, 3,4-, 1,3-, and 1,4-diCQA resulting from transesterification compensated the losses, and total diCQAs contents did not differ significantly from raw artichokes. Substantial redistribution of CQAs due to transesterification phenomenon after being submitted to different thermal treatments has been previously reported in artichokes samples (Ferracane et al., 2008) as well as in isolated CQAs (Li et al., 2015). Flavonoids and lignans, minor phenolic constituents of artichokes, were also reduced significantly after boiling (35% and 56%, respectively) with no increase observed in any isomers. The decrease of (poly)phenolic content observed in boiled artichoke samples are most probably the consequence of losses due to leaching into the boiling water rather than thermal degradation. Additionally, the weaker polarity and higher molecular weight of diCQAs, compared to monoCQAs, might explain that these compounds are less easily extracted into the boiling water and suffer mostly transesterification reactions. Higher extractability of monoCQAs compared to diCQA has been previously reported in coffee beverages (Ludwig et al., 2013).

On the other hand, griddling and frying, reduced (poly)phenolic amount by approximately 50%. This loss was mainly because of the high decrease of 5-CQA (60% loss in fried and griddled artichokes) and 3,5-CQA (66% loss for griddled and 57% for fried artichokes), while 1,5-CQA was less affected by frying and griddling. Transesterification also occurred during frying and griddling but to a lesser extent. Further, losses were very different among compound families. While total phenolic acids showed losses of 50% after frying and griddling, flavonoid levels decreased only by a non-significant 15% and lignans levels were maintained. Interestingly, these minor compounds were less affected by frying and griddling comparing with boiling where the reduction was significantly higher.

It seems that phenolic acids presented in artichokes are more affected as the temperature increases (losses were lower in boiling than in frying and griddling); however, flavonoids and lignans present in artichokes seem to be more affected by leaching rather than by high temperatures (losses were higher in boiling than frying and griddling).

The high temperature in frying and griddling, 170 °C and 180 °C respectively, resulted probably in a greater degradation of phenolic acids. However, incorporation of CQAs into high molecular-weight polymers, such as melanoidins, produced due to the high temperature, should also be considered. Some studies have shown the presence of covalently linked chlorogenic acids in melanoidins structure of roasted coffee (Bekedam et al., 2008; Monente et al., 2015; Moreira et al., 2015) and the incorporation of artichoke chlorogenic acids to melanoidins formed during frying and griddling might also explain the lower amounts found in these samples. Nevertheless, further investigation is needed to confirm this hypothesis.

(Poly)phenolic compounds were mainly found in the free form although some of them were also found in the bound fraction of the artichoke samples, which represented between 1.81 and 3.11% of the total amount of phenolic compounds.

While we observed losses on artichoke caffeoylquinic acids due to the three heat treatments, previous studies found significant increases (mono and diCQA) after boiling, steaming and frying of globe artichokes (Ferracane et al., 2008) and after griddling of artichoke stalks (Juániz et al., 2016b). Authors concluded that the increases observed were due to a softening of the cellular matrix and hydrolysis reactions that liberated bound phenolics, however, bound phenolics were not analyzed in these studies. Juániz et al. (2017) analyzed free and bound phenolics in artichoke stalks and detected a decrease of bound compounds with a concomitant increase of free phenolic compounds. Differences between our results and studies that report an increase in phenolic compounds are probably due to the very low amounts of bound phenolics (2.2%) in the raw artichokes analyzed in the present study. Bound phenolic fraction in artichokes may depend on various factors such as variety and maturity (Lutz et al., 2011). Therefore, it can be concluded that when bound compounds represent a high percentage of total phenolics, heat treatments may induce a better extraction of the compounds from the cell matrix, but when bound compounds are low, predominant reactions during heat treatments are thermally caused changes in the phenolic structure (transesterification and degradation). In this sense, results obtained in the present study demonstrated that boiling, griddling and frying decreased total (poly)phenolic compounds by 25%, 49% and 51%, respectively, likely due to leaching in boiled samples and thermal degradation/incorporation in high molecular weight MRP in griddled and fried samples.

Total phenolic content (TPC) and antioxidant capacity (AOC)

There is a large variety of methods to measure the antioxidant capacity of foods. In this study, TPC by the Folin-Ciocalteu method and

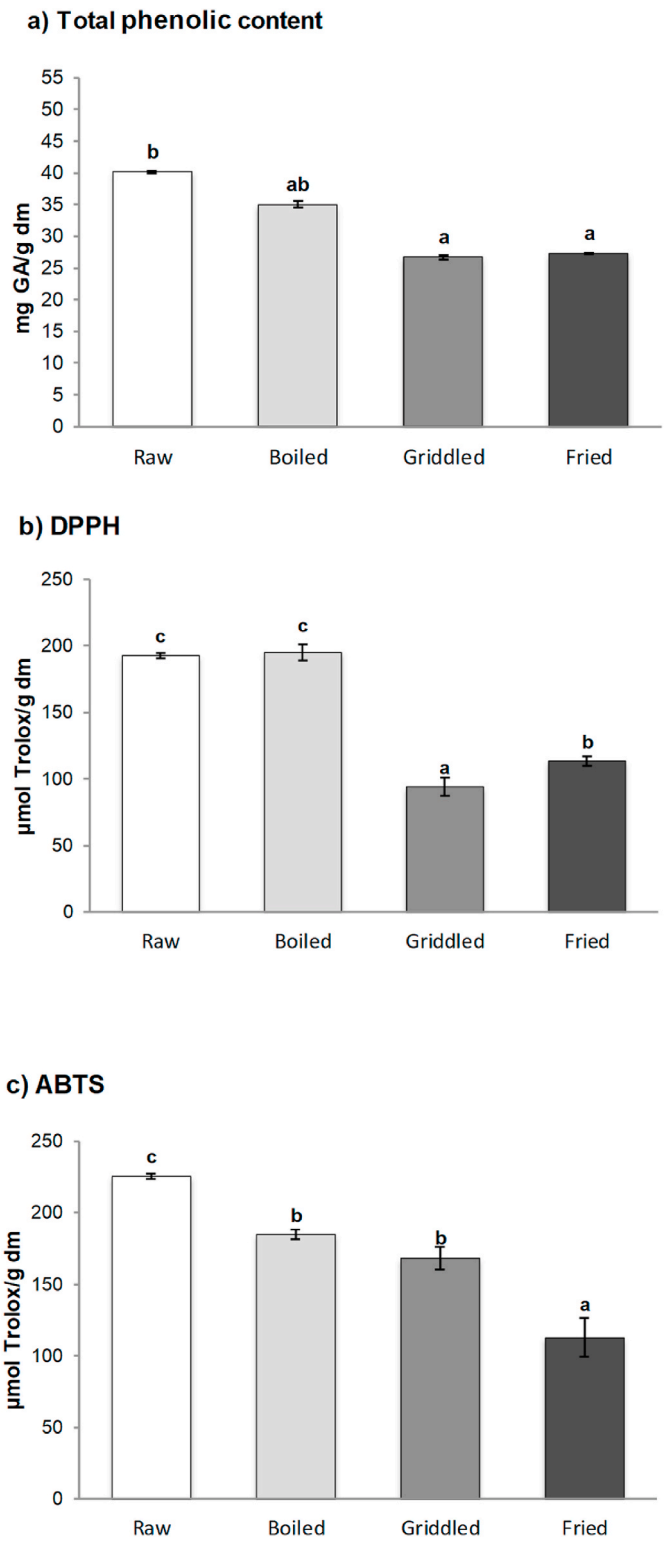

Fig. 1. Total phenolic content (a) and antioxidant capacity measured by DPPH (b) and ABTS (c) of artichokes before and after different heat treatments. Different letters indicate significant differences ($p \leq 0.05$).

DPPH and ABTS scavenging assays were performed. These assays are based on the ability of antioxidant compounds present in the samples to inhibit the oxidation of Folin-Cicalteau reagent or to reduce or scavenge $DPPH^{\bullet}$ and $ABTS^{\cdot+}$ radicals by transferring an electron. Results obtained for TPC and AOC in raw and cooked artichokes are shown in Fig. 1.

TPC measured in this study in raw artichokes was 40.15 mg GA/g dm which is higher than the TPC obtained by Gouveia and Castilho (2012), 2.34 mg GA/g dm. Antioxidant capacity by ABTS assay (225.43 µmol T/g dm) was higher than antioxidant capacity by DPPH (192.67 µmol T/g dm). Palermo et al. (2014) found similar values of antioxidant capacity measured by ABTS assay in raw artichokes from 6 different origins (100.1 µmol/g - 311.9 µmol/g). However, Guillén et al. (2017) reported higher values of antioxidant capacity analyzed with DPPH (670.7 µmol/g) and Gouveia and Castilho (2012) found lower values with both ABTS and DPPH assay (69.4 µmol/g and 37.7 µmol/g respectively). Differences in TPC and antioxidant capacity may arise from differences in origin, variety or cultivar of the artichokes, as already mentioned for individual (poly)phenolic compounds.

TPC in cooked artichokes follows a similar tendency as total (poly) phenolic compounds quantified by LC-MS/MS (Table 2). Frying and griddling induced the highest losses with a significant decrease of 30% in TPC in comparison with raw artichokes, however, although boiling showed a decrease of 12%, it was non-significant. No significant differences ($p < 0.05$) in antioxidant capacity of boiled artichokes measured by DPPH in comparison with raw artichokes were found. However, when using ABTS assay these cooking treatments produced losses of 18%. The highest losses in antioxidant capacity were observed after frying and griddling, being higher in griddled artichokes when antioxidant capacity was analyzed with DPPH and in fried artichokes when using ABTS (50% of losses in both cases). Differences in antioxidant capacity measured by DPPH and ABTS among cooking methods as well as the lower antioxidant capacity in raw artichokes, when using DPPH assay, may be due to differences in compounds' reactivity against $DPPH^{\bullet}$ and $ABTS^{\cdot+}$ radicals. ABTS assay has higher sensibility than DPPH assay (Gouveia and Castilho, 2012) and many phenolic compounds with low redox potential are able to react with $ABTS^{\cdot+}$ radical as well as some non-phenolic compounds (Prior et al., 2005).

Lutz et al. (2011) found an increase in TPC of artichokes after boiling. However they use tannic acid as the reference compound. Şengül et al. (2014) measured TPC in different vegetables using gallic acid as reference, and they reported variations depending on the vegetable and the heat treatment. While they found losses in all vegetables analyzed after boiling, stir-frying provoked a decrease of TPC only in red cabbage but an increase in every other vegetable (turnip, black radish, broccoli and white cabbage) (Şengül et al., 2014). These results suggest that cooking methods impact differently on TPC depending on the food source and matrix, highlighting the importance of studying the effects of heat treatments on individual foods, as well as on individual (poly) phenolic compounds.

Studies in artichokes showed losses in DPPH antioxidant capacity after boiling (Guillén et al., 2017) but also increases (Lutz et al., 2011). Palermo et al. (2014) showed increases in ABTS antioxidant capacity in five of six microwaved artichokes from different origin in comparison with raw ones. However, Jiménez-Monreal et al. (2009) found no changes in artichokes ABTS antioxidant capacity after microwaving, boiling, griddling and frying. These controversy results are probably due to differences in the intensity and duration of heat treatments, as well as methodology differences in the techniques used for measuring antioxidant capacity.

Heating causes profound changes in the structure of food (Miglio et al., 2008) and in the phenolic compounds profile as has been already discussed. Changes in the phenol structure, such as isomerization, has been reported to change their antioxidant activity (Kweon et al., 2001). Further, incorporation of phenolics into melanoidins or similar structures as well as conversion of phenolics into, not yet identified, very active antioxidants (Ferracane et al., 2008), might explain the differences in TPC and AOC observed in griddled and fried artichokes when comparing with phenolic compounds measured by LC-MS/MS. However, TPC and AOC measurements do not necessarily reflect biological activity and further *in-vitro* and *in-vivo* studies should be carried out to elucidate whether changes in phenolic structure and possible interactions with food matrix also alter their biological activity.

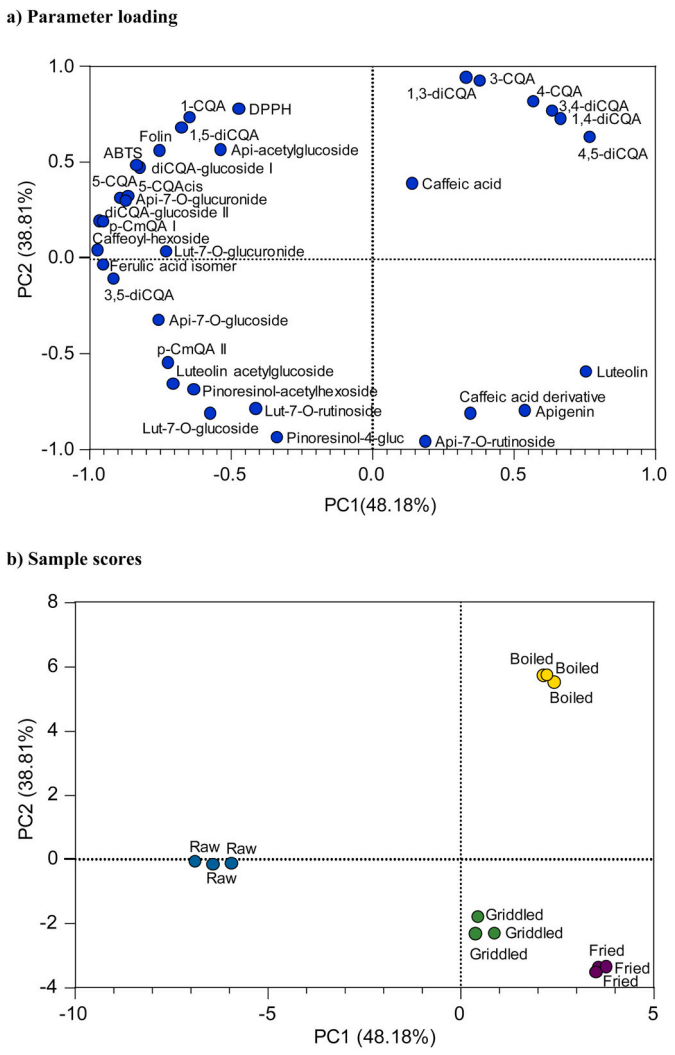

Fig. 2. Principal Component Analysis (PCA) of artichokes before and after different heat treatments. (a) Parameter loadings. (b) Sample scores.

Principal Component Analysis (PCA)

PCA was applied to evaluate at a glance the influence of heat treatment on the (poly)phenolic compounds and antioxidant capacity in artichokes. This statistical procedure allows establishing the correlation among (poly)phenolic compounds and antioxidant capacity measured by different methods. Fig. 2 shows the bidimensional representation of the analyzed variables (Fig. 2a) and the distribution of the raw and heat-treated artichokes samples (Fig. 2b). The PCA resulted in a two-component model that explained 86,99% of the total variance. Principal Component 1 (PC1) accounts for 48.18% of the total variance while Principal Component 2 (PC2) accounts for 38.81% of the total variance. Raw artichokes are located along the PC1 axis on the left side (Fig. 2b middle left half) and characterised therefore by high levels of most of the (poly)phenolic compounds and antioxidant capacity measured by DPPH and ABTS, which are also located in the left half graph. On the other hand, the artichokes prepared by the three culinary techniques are diametrically opposed to raw samples on the PC1 axis (Fig. 2b) and are separated among themselves by PC2. Interestingly, boiling (Fig. 2b top right corner) is characterised by high levels of some CQA and diCQA isomers (3-CQA, 4-CQA, 1,3-diCQA, 3,4-diCQA, 1,4-diCQA and 4,5-diCQA) which are clustered in Fig. 2a top right corner. These CQAs were markedly higher in boiled samples than in raw ones, probably due to transesterification from other CQAs. Meanwhile, griddled and fried artichokes (Fig. 2b bottom right corner) presented similar (poly)phenol profiles, with the highest levels of luteolin, caffeic acid derivative, apigenin and apigenin-7-O-rutinoside, but opposite to all the main CQAs, showing the lowest content of total (poly)phenolic compounds.

In conclusion, all three culinary techniques applied to artichokes produced structural changes leading to alterations in (poly)phenolic compounds. Caffeoylquinic acids (CQAs) were the major (poly)phenols among the ones quantified in this study. However, with the different cooking processes applied, these compounds suffered redistribution, probably due to isomerization and hydrolysis reactions. Frying and griddling showed the lowest content of (poly)phenolic compounds and antioxidant capacity suggesting that higher temperatures induce degradation of phenolic compounds, while losses observed for boiling were mainly due to leaching of phenolic compounds into the water. Boiling was the heat treatment that best preserved (poly)phenolic compounds in artichokes due to a higher presence of isomers derived from transesterification reactions.

It seems that phenolic acids presented in artichokes are more affected as the temperature increases (losses were lower in boiling than in frying and griddling); however, flavonoids and lignans present in artichokes seem to be more affected by leaching rather than by high temperatures (losses were higher in boiling than frying and griddling).

Nevertheless, to what extend the changes in phenolic composition during heat-treatment affect their bioaccessibility, bioavailability and biological activity are of great interest and objective of ongoing research.

Author contributions

Maite Domínguez-Fernández: Methodology, Formal Analysis, Investigation, Writing – Original Draft, Writing - Review & Editing; **Ángel Irigoyen**: Methodology; **Angelina Vargas**: Investigation; **Iziar A. Ludwig**: Conceptualization, Project Administration, Supervision, Writing - Review & Editing; **María-Paz De Peña**: Funding acquisition, Writing - Review & Editing; **Concepción Cid**: Conceptualization, Supervision, Writing - Review & Editing, Project Administration, Funding acquisition.

Declaration of competing interest

None.

Acknowledgements

We thank the Spanish Ministry of Science and Innovation (AGL2014-52636-P) and Plan de Investigación de la Universidad de Navarra, PIUNA (2018–09) for the financial support. M. Domínguez expresses her gratitude to Dept. of Education of the Government of Navarra (944/2016) and to the Spanish Ministry of Education (FPU16/03280) for the grants received.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgfs.2021.100389.

References

Abu-Reidah, I.M., Arraez-Roman, D., Segura-Carretero, A., Fernandez-Gutierrez, A., 2013. Extensive characterisation of bioactive phenolic constituents from globe artichoke (Cynara scolymus L.) by HPLC-DAD-ESI-QTOF-MS. Food Chem 141, 2269–2277. https://doi.org/10.1016/j.foodchem.2013.04.066.

Alarcón-Flores, M.I., Romero-González, R., Martínez Vidal, J.L., Garrido Frenich, A., 2014. Determination of phenolic compounds in artichoke, garlic and spinach by ultra-high-performance liquid chromatography coupled to tandem mass spectrometry. Food Anal. Methods 7, 2095–2106. https://doi.org/10.1007/s12161-014-9852-4.

Bekedam, E.K., Schols, H.A., Van Boekel, M.A.J.S., Smit, G., 2008. Incorporation of chlorogenic acids in coffee brew melanoidins. J. Agric. Food Chem. 56, 2055–2063. https://doi.org/10.1021/jf073157k.

Brand-Williams, W., Cuvelier, M.E., Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. LWT- Food Sci. Technol. 28, 25–30.

Colantuono, A., Vitaglione, P., Ferracane, R., Campanella, O.H., Hamaker, B.R., 2017. Development and functional characterization of new antioxidant dietary fibers from pomegranate, olive and artichoke by-products. Food Res. Int. 101, 155–164. https://doi.org/10.1016/j.foodres.2017.09.001.

De Santiago, E., Domínguez-Fernández, M., Cid, C., De Peña, M.P., 2018. Impact of cooking process on nutritional composition and antioxidants of cactus cladodes (Opuntia ficus-indica). Food Chem 240, 1055–1062. https://doi.org/10.1016/j.foodchem.2017.08.039.

Del Rio, D., Rodriguez-Mateos, A., Spencer, J.P., Tognolini, M., Borges, G., Crozier, A., 2013. Dietary (poly)phenolics in human health: structures, bioavailability, and evidence of protective effects against chronic diseases. Antioxid. Redox Signal. 18, 1818–1892. https://doi.org/10.1089/ars.2012.4581.

Domínguez-Fernández, M., Ludwig, I.A., De Peña, M.P., Cid, C., 2021. Bioaccessibility of Tudela artichoke (Cynara scolymus cv. Blanca de Tudela) (poly)phenols: the effects of heat treatment, simulated gastrointestinal digestion and human colonic microbiota. Food Funct 12. https://doi.org/10.1039/d0fo03119d, 1996–2011.

Eurostat, 2019. Crop production in EU standard humidity accessed 11.26.20. https://ec.europa.eu/eurostat/databrowser/view/APRO_CPSH1__custom_271246/default/table?lang=en.

Ferracane, R., Pellegrini, N., Visconti, A., Graziani, G., Chiavaro, E., Miglio, C., Fogliano, V., 2008. Effects of different cooking methods on antioxidant profile, antioxidant capacity, and physical characteristics of artichoke. J. Agric. Food Chem. 56, 8601–8608. https://doi.org/10.1021/jf800408w.

Fratianni, F., Tucci, M., Palma, M. De, Pepe, R., Nazzaro, F., 2007. Polyphenolic composition in different parts of some cultivars of globe artichoke (Cynara cardunculus L. var. scolymus (L.) Fiori). Food Chem 104, 1282–1286. https://doi.org/10.1016/j.foodchem.2007.01.044.

Galanakis, C.M., 2018. Polyphenols: Properties, Recovery, and Applications. Woodhead Publishing.

Gao, Y., Ma, S., Wang, M., Feng, X.Y., 2017. Characterization of free, conjugated, and bound phenolic acids in seven commonly consumed vegetables. Molecules 22. https://doi.org/10.3390/molecules22111878.

Gouveia, S.C., Castilho, P.C., 2012. Phenolic composition and antioxidant capacity of cultivated artichoke, Madeira cardoon and artichoke-based dietary supplements. Food Res. Int. 48, 712–724. https://doi.org/10.1016/j.foodres.2012.05.029.

Grebe, S.K., Singh, R.J., 2011. LC-MS/MS in the clinical laboratory - where to from here? Clin. Biochem. Rev. 32, 5–31.

Guillén, S., Mir-Bel, J., Oria, R., Salvador, M.L., 2017. Influence of cooking conditions on organoleptic and health-related properties of artichokes, green beans, broccoli and carrots. Food Chem 217, 209–216. https://doi.org/10.1016/j.foodchem.2016.08.067.

Juániz, I., Ludwig, I.A., Bresciani, L., Dall'Asta, M., Mena, P., Del Rio, D., Cid, C., de Peña, M.-P., 2017. Bioaccessibility of (poly)phenolic compounds of raw and cooked cardoon (Cynara cardunculus L.) after simulated gastrointestinal digestion and fermentation by human colonic microbiota. J. Funct. Foods 32, 195–207. https://doi.org/10.1016/j.jff.2017.02.033.

Jiménez-Monreal, A.M, García-Diz, L., Martínez-Tomé, M., Mariscal, M., Murcia, M., 2009. Influence of cooking methods on antioxidant activity of vegetables. J. Food Sci. 74, 97–103. https://doi.org/10.1111/j.1750-3841.2009.01091.x.

Juániz, I., Ludwig, I.A., Bresciani, L., Dall'Asta, M., Mena, P., Del Rio, D., Cid, C., de Peña, M.-P., 2016a. Catabolism of raw and cooked green pepper (Capsicum annuum) (poly)phenolic compounds after simulated gastrointestinal digestion and faecal fermentation. J. Funct. Foods 27, 201–213. https://doi.org/10.1016/J.JFF.2016.09.006.

Juániz, I., Ludwig, I.A., Huarte, E., Pereira-Caro, G., Moreno-Rojas, J.M., Cid, C., Peña, M.-P. De, 2016b. Influence of heat treatment on antioxidant capacity and (poly)phenolic compounds of selected vegetables. Food Chem 197, 466–473. https://doi.org/10.1016/j.foodchem.2015.10.139.

Kweon, M.H., Hwang, H.J., Sung, H.C., 2001. Identification and antioxidant activity of novel chlorogenic acid derivatives from bamboo (Phyllostachys edulis). J. Agric. Food Chem. 49, 4646–4655. https://doi.org/10.1021/jf010514x.

Lattanzio, V., Kroon, P.A., Linsalata, V., Cardinali, A., 2009. Globe artichoke: a functional food and source of nutraceutical ingredients. J. Funct. Foods 1, 131–144. https://doi.org/10.1016/j.jff.2009.01.002.

Li, Y.J., Zhang, C.F., Ding, G., Huang, W.Z., Wang, Z.Z., Bi, Y.A., Xiao, W., 2015. Investigating the thermal stability of six caffeoylquinic acids employing rapid-resolution liquid chromatography with quadrupole time-of-flight tandem mass spectrometry. Eur. Food Res. Technol. 240, 1225–1234. https://doi.org/10.1007/s00217-015-2425-y.

Lombardo, S., Pandino, G., Mauromicale, G., Knödler, M., Carle, R., Schieber, A., 2010. Influence of genotype, harvest time and plant part on polyphenolic composition of globe artichoke [Cynara cardunculus L. var. scolymus (L.) Fiori]. Food Chem 119, 1175–1181. https://doi.org/10.1016/j.foodchem.2009.08.033.

Ludwig, I.A., De Peña, M.P., Cid, C., Crozier, A., 2013. Catabolism of coffee chlorogenic acids by human colonic microbiota. BioFactors 39, 623–632. https://doi.org/10.1002/biof.1124.

Lutz, M., Henríquez, C., Escobar, M., 2011. Chemical composition and antioxidant properties of mature and baby artichokes (Cynara scolymus L.), raw and cooked. J. Food Compos. Anal. 24, 49–54. https://doi.org/10.1016/j.jfca.2010.06.001.

MAPAMA, 2010. I.G.P. Alcachofa de Tudela accessed 10.2.18. http://www.mapama.gob.es/es/alimentacion/temas/calidad-agroalimentaria/calidad-diferenciada/dop/hortalizas/IGP_alcachofatudela.aspx.

Miglio, C., Chiavaro, E., Visconti, A., Fogliano, V., Pellegrini, N., 2008. Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. J. Agric. Food Chem. 56, 139–147. https://doi.org/10.1021/jf072304b.

Monente, C., Ludwig, I.A., Irigoyen, A., De Peña, M.P., Cid, C., 2015. Assessment of total (Free and Bound) phenolic compounds in spent coffee extracts. J. Agric. Food Chem. 63, 4327–4334. https://doi.org/10.1021/acs.jafc.5b01619.

Moreira, A.S.P., Coimbra, M.A., Nunes, F.M., Passos, C.P., Santos, S.A.O., Silvestre, A.J.D., Silva, A.M.N., Rangel, M., Domingues, M.R.M., 2015. Chlorogenic acid-arabinose hybrid domains in coffee melanoidins: Evidences from a model system. Food Chem 185, 135–144. https://doi.org/10.1016/j.foodchem.2015.03.086.

Palermo, M., Colla, G., Barbieri, G., Fogliano, V., 2013. Polyphenol metabolite profile of artichoke is modulated by agronomical practices and cooking method. J. Agric. Food Chem. 61, 7960–7968. https://doi.org/10.1021/jf401468s.

Palermo, M., Pellegrini, N., Fogliano, V., 2014. The effect of cooking on the phytochemical content of vegetables. J. Sci. Food Agric. 94, 1057–1070. https://doi.org/10.1002/jsfa.6478.

Pandino, G., Lombardo, S., Lo Monaco, A., Mauromicale, G., 2013. Choice of time of harvest influences the polyphenol profile of globe artichoke. J. Funct. Foods 5, 1822–1828. https://doi.org/10.1016/j.jff.2013.09.001.

Pérez-Jiménez, J., Torres, J.L., 2011. Analysis of nonextractable phenolic compounds in foods: the current state of the art. J. Agric. Food Chem. 59, 12713–12724. https://doi.org/10.1021/jf203372w.

Prior, R.L., Wu, X., Schaich, K., 2005. Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. J. Agric. Food Chem. 53, 4290–4302. https://doi.org/10.1021/jf0502698.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., Rice-Evans, C., 1999. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic. Biol. Med. 26, 1231–1237.

Rodriguez-Mateos, A., Vauzour, D., Krueger, C.G., Shanmuganayagam, D., Reed, J., Calani, L., Mena, P., Del Rio, D., Crozier, A., 2014. Bioavailability, bioactivity and impact on health of dietary flavonoids and related compounds: an update. Arch. Toxicol. 88, 1803–1853. https://doi.org/10.1007/s00204-014-1330-7.

Sánchez-Salcedo, E.M., Mena, P., García-Viguera, C., Martínez, J.J., Hernández, F., 2015. Phytochemical evaluation of white (Morus alba L.) and black (Morus nigra L.) mulberry fruits, a starting point for the assessment of their beneficial properties. J. Funct. Foods 12, 399–408. https://doi.org/10.1016/j.jff.2014.12.010.

Scalbert, A., Manach, C., Morand, C., Rémésy, C., Jiménez, L., 2005. Dietary polyphenols and the prevention of diseases. Crit. Rev. Food Sci. Nutr. 45, 287–306. https://doi.org/10.1080/1040869059096.

Şengül, M., Yildiz, H., Kavaz, A., 2014. The effect of cooking on total polyphenolic content and antioxidant activity of selected vegetables. Int. J. Food Prop. 17, 481–490. https://doi.org/10.1080/10942912.2011.619292.

Shahidi, F., Yeo, J.D., 2016. Insoluble-bound phenolics in food. Molecules 21. https://doi.org/10.3390/molecules21091216.

Singleton, V., Rossi, J., 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am. J. Enol. Vitic. 16, 144–158.

Tomás-Barberán, F.A., Espín, J.C., 2001. Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. J. Sci. Food Agric. 81, 853–876. https://doi.org/10.1002/jsfa.885.

White, B.L., Howard, L.R., Prior, R.L., 2010. Release of bound procyanidins from cranberry pomace by alkaline hydrolysis. J. Agric. Food Chem. 58, 7572–7579. https://doi.org/10.1021/jf100700p.

Zaupa, M., Scanzzina, F., Dall'Asta, M., Del Rio, D., Bianchi, M.A., Brighenti, F., 2014. In vitro bioaccessibility of phenolics and vitamins from durum wheat aleurone fractions. J. Agric. Food Chem. 62, 1543–1549. https://doi.org/10.1021/jf404522a.