DOI:10.1021/jf903311j

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY ARTICLE

Caffeoylquinic Acids and Flavonoids in the Immature Inflorescence of Globe Artichoke, Wild Cardoon, and Cultivated Cardoon

GAETANO PANDINO,[†,‡] FRASER L. COURTS,[‡] SARA LOMBARDO,[†] GIOVANNI MAUROMICALE,[†] AND GARY WILLIAMSON*,[‡]

[†]Dipartimento di Scienze Agronomiche, Agrochimiche e delle Produzioni Animali, Sezione Scienze Agronomiche, Università degli Studi di Catania, via Valdisavoia 5, 95123 Catania, Italy and [‡]School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, United Kingdom

The species *Cynara cardunculus* is consumed as part of the Mediterranean diet and consists of the globe artichoke [var. *scolymus* (L.) Fiori], the cultivated cardoon (var. *altilis* DC.), and the wild cardoon [var. *sylvestris* (Lamk) Fiori]. The objective of this study was to investigate, in immature inflorescences, the main flavonoids and phenolic acids (caffeoylquinic acids, apigenin, and luteolin derivatives) by HPLC/diode array detection/mass spectrometry. Apigenin derivatives represented the major class in all samples investigated, highest in cardoon forms. Caffeoylquinic acids and luteolin derivatives were observed in var. *scolymus* only. Data allowed discrimination of globe artichoke from the related species on the basis of the profile of compounds analyzed. Our results suggest the possible use of cultivated and wild cardoon as a source of phenolic acids and flavonoids and indicate that artichoke consumption is an excellent dietary source of apigenin and other flavones.

KEYWORDS: ***Cynara cardunculus*; cardoon; globe artichoke; flavonoids; caffeoylquinic acids; HPLC/DAD/MS**

INTRODUCTION

Cynara cardunculus L. is a complex species, belonging to the Asteraceae (ex Compositae) family, and native to the Mediterranean Basin. According to Rottenberg and Zohary (*1*), it consists of the globe artichoke [var. *scolymus* (L.) Fiori], the cultivated cardoon (var. *altilis* DC.), and the wild cardoon, also called an artichoke thistle [var. *sylvestris* (Lamk) Fiori]. Phenotypic considerations (*2*), along with inferences based on isoenzyme (*3*) and DNA-based marker (*4*) alleles, suggest that both globe artichoke and the cultivated cardoon are closely related to the wild cardoon, which is the ancestor of both domesticated forms. The three *C. cardunculus* varieties are fully compatible with one another, and their F1 hybrids are fertile. From this wild relative, divergent selection criteria, one for the width of the foliar midrib and the other for a large capitulum, have led to the present day cultivated cardoon and globe artichoke (*5*). Recent molecular and morphological analyses included numerous genotypes of the three botanical varieties collected from different sites in Sicily, one of the possible centers of globe artichoke domestication (*6*). In fact, the earliest report of the presence of *C. cardunculus* in Sicily and Greece dates back to Theophrastus (371−287 B.C.).

Globe artichoke is characterized by a high degree of heterozygosity (*7*), which reflects the great variation within the botanical variety germplasm. Conversely, the wild and cultivated cardoons show limited varietal diversity, characterized by small green capitula and large spiny leaves for the wild cardoon (*5*). The wild cardoons, which are distributed over the west and central part of the Mediterranean Basin (Portugal to west Turkey), as well as the Canary Islands, usually have no food uses but, if properly prepared, are edible (as is the globe artichoke). Both wild and cultivated cardoon are suitable for the production of lignocellulosic biomass for energy or paper pulp (*8*,*9*), their seeds could also be used to extract food quality oil (*10*), and their flowers are widely employed in the making of cheeses (*11*−*13*). The globe artichoke is an important herbaceous species widely distributed in the Mediterranean Basin (*14*), where its commercial production makes a significant contribution to the agricultural economy. Annual global production is currently ~1320 Kt generated from a cropping area of ~130 Kha. The edible part of the plant is the immature inflorescence (called capitulum or head), and it is consumed in both fresh and canned forms. Furthermore, *C. cardunculus* is well-known to contain a high content of bioactive compounds, such as flavonoids and phenolic acids (including caffeoylquinic acids). These are widely studied due to their multiple biological activities (*15*). The phenolic compounds are abundant in the plant kingdom (*16*) and are divided into several classes, that is, hydroxybenzoic acids, phenolic acids, flavonoids (anthocyanins, proanthocyanidins, flavonols, flavones, flavanols, and flavanones), isoflavones, stilbenes, and lignans (*17*). In the genus *Cynara*, mono- and dicaffeoylquinic acids and luteolin and apigenin derivatives have been documented

*To whom correspondence should be addressed. Address: School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, U.K. Fax: +44 113 3432982. Telephone: +44 113 3438380. E-mail: g.williamson@leeds.ac.uk.

Published on Web 12/22/2009
© 2009 American Chemical Society

as the major compounds (*18*). Previous studies have focused on the phenolic profile in the globe artichoke, but, to our knowledge, little is known about either wild or cultivated cardoon (*19*). As described in the literature, wild cardoon shows the highest genetic divergence from globe artichoke, while the cultivated form has some characteristics close to the wild cardoon and others to the globe artichoke (*20*). Recently, similar results were reported (*6*) in a type of globe artichoke ("Cimiciusa di Mazzarino") cultivated in Sicilian small-holdings. This form has kinship both with cultivated forms, by its amplified fragment length polymorphism (AFLP) fingerprint, or wild cardoon, on the basis of its simple sequence repeats (SSR) profile. The objective, therefore, of the present study was to analyze the phenolic profile in the capitulum of the three botanical varieties, including cultivated and wild forms, of *C. cardunculus*.

MATERIALS AND METHODS

Reagents and Solvents. Reagents and solvents were purchased from VWR (Leighton Buzzard, U.K.) and were of analytical or HPLC grade. Apigenin-7-*O*-glucoside, apigenin, luteolin-7-*O*-glucoside, luteolin, 5-*O*-caffeoylquinic acid (chlorogenic acid), and hesperetin were obtained from Extrasynthese (Lyon, France), cynarin (1,3-di-*O*-caffeoylquinic acid) was from Roth GmbH (Karlsruhe, Germany), and butylated hydroxytoluene (BHT) was purchased from Sigma Chemicals Co. (St. Louis, MO). Milli-Q system (Millipore Corp., Bedford, MA) ultrapure water was used throughout this research.

Plant Material, Management Pratices, and Capitula Sampling. The following were analyzed: Two cultivars of globe artichoke, "Violetto di Sicilia", belonging to the "Catanese" group, and "Tondo di Paestum", belonging to the "Romaneschi" group; two accessions of wild cardoon, "Sylvestris Creta", collected in Crete, Greece, and "Sylvestris Kamaryna", collected in Sicily; one selection of cultivated cardoon selected by Catania University; and a globe artichoke Sicilian landrace "Cimiciusa di Mazzarino". All were collected in Sicily in a field at the experimental station of Catania University, on Catania Plain (10 m a.s.l., 37°25′ N, 15° 30′ E), a typical area for globe artichoke cultivation in Italy, and where the wild cardoon grows naturally. Each one was planted in the form of either semidormant offshoots ("ovoli") or seeds (achenes) in August 2007. The plant material was arranged in a randomized block experimental design with four replicates. Each field plot consisted of 10 plants, spaced 0.80 m apart with a row spacing of 1.25 m. Crop management (fertilization, irrigation, weed, and pest control) was performed according to the standard local commercial practice. At least five capitula per replicate, at the usual marketing stage, regardless of their size, were harvested disease-free and washed with tap water. At this stage, the length of the central global flower buds was < 2 mm. They were combined, cut, and then blended using a domestic food processor at 0 °C (Kenwood multipro, Milan, Italy). Finally, each sample was freeze-dried using a Genevac vacuum centrifugal drier (Ipswich, U.K.), divided into three samples, and stored at −20 °C until analysis.

Extraction Procedure. The dried samples (100 mg) were suspended and extracted in 1 mL of 70% methanol, containing 1 mM butylated hydroxytoluene, to preserve compounds during extraction, and hesperetin (1 mM), as internal standard, for 1 h at room temperature, with shaking. After centrifugation, the supernatant was transferred to a microfuge tube and the pellet was centrifuged once more with 0.25 mL of 70% methanol. The supernatants were combined and kept at −20 °C until analysis.

Preparation of Standard for HPLC Analysis. All standards were dissolved in ethanol/water (1:1) at a concentration of 1 mg/mL and stored at −20 °C as stock solutions. Calibration curves of peak area against amount showed a good linear correlation with r^2 > 0.999. For each standard, the limit of detection (LOD) and the limit of quantification (LOQ) were established at their wavelength of maximum UV−vis absorbance (**Table 1**).

HPLC Analysis. Each extract (20 μL) was analyzed using a series 1200 HPLC instrument (Agilent Technologies, Palo Alto, CA) equipped with ChemStation software (B.03.01), a model G1379B degasser, a model G1312B binary gradient pump, a model G1367C thermoautosampler, a model G1316B column oven, and a model G1315C diode array detection system. Separations were achieved on a Zorbax Eclipse XDB-C_{18} (4.6 × 50 mm; 1.8 μm particle size), operated at 30 °C, with a 0.2 μm stainless steel in-line filter.

The method was adapted from Määttä et al. (*21*): the mobile phase was 1% formic acid in water (solvent A) and in acetonitrile (solvent B) at a flow rate of 0.5 mL/min. The gradient started with 5% B to reach 10% B at 5 min, 40% B at 20 min, 90% B at 25 min, 90% B at 29 min. Chromatograms were recorded at 280, 310, and 350 nm from diode array data collected between 200 and 600 nm. All samples were assayed in triplicate.

HPLC-MS Analysis. Analyses were performed using the HPLC system described above, coupled in-line with an Agilent 6410 Triple Quadrupole mass spectrometer equipped with Mass Hunter software (version B.01.04) (Agilent Technologies, Palo Alto, CA). HPLC effluent was diverted to waste for the first 2 min of each chromatographic run, after which negative electrospray (ESI(−)) was used to ionize compounds eluting from the column. Nitrogen was used both as drying gas at a flow rate of 6 L/min and as nebulizing gas at a pressure of 55 psi. The drying gas temperature was 300 °C, and a potential of 4000 V was applied across the capillary. The fragmentor voltage was 120 V, and the collision voltage was 20 V. Quadrupole 1 filtered the calculated *m*/*z* of each compound of

Table 1. Validation of Standards by HPLC[a]

standards	correlation coefficient (r^2)	LOD (mg/L)	LOQ (mg/L)
5-caffeoylquinic acid	0.9998	0.22	0.67
cynarin	1	0.20	1.00
luteolin-7-*O*-glc	1	0.67	2.00
luteolin	0.9985	0.45	2.00
apigenin-7-*O*-glc	0.9991	0.32	0.50
apigenin	0.9999	1.67	2.70

[a] LOD = limit of detection; LOQ = limit of quantification; glc = glucoside.

Table 2. UV Spectra and Molecular Weight of Caffeoylquinic Acids and Flavones in *C. cardunculus*

no.	compound	retention time (min)	HPLC-DAD λ_{max} (nm)	molecular weight	comparison with standard
1	1-caffeoylquinic acid	3.6	244, 300sh, 329	354	no
2	5-caffeoylquinic acid	7.0	244, 300sh, 329	354	yes
3	luteolin-7-*O*-rut[a]	11.6	255, 267sh, 350	594	no
4	luteolin-7-*O*-glc[b]	12.0	255, 267sh, 350	448	yes
5	luteolin-7-O-glr[c]	12.3	255, 267sh, 350	462	no
6	apigenin-7-*O*-rut	12.9	268, 338	578	no
7	1,5-dicaffeoylquinic acid	13.0	245, 300sh, 327	516	no
8	apigenin-7-*O*-glc	13.5	268, 338	432	yes
9	apigenin-7-*O*-glr	13.7	268, 338	446	no
10	apigenin malonyl-glc	15.1	268, 338	518	no
11	luteolin	16.5	254, 266, 292sh, 347	286	yes
12	apigenin	18.6	268, 300sh, 338	270	yes
13	hesperetin	19.3	287, 333sh	302	yes

[a] rut = rutinoside. [b] glc = glucoside. [c] glr = glucuronide.

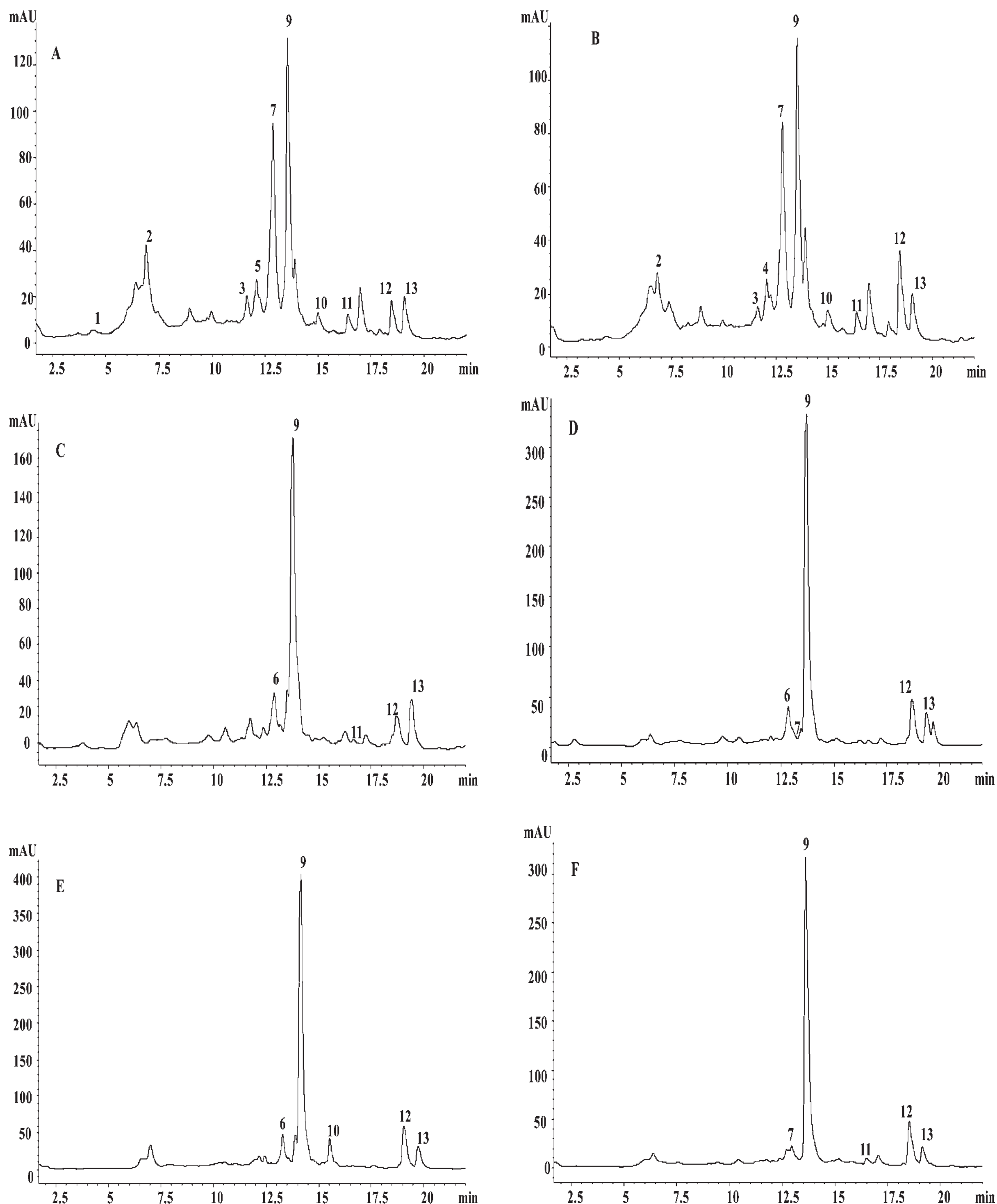

Figure 1. HPLC-DAD chromatograms of an extract of *C. cardunculus* capitula at 280 nm: (**A**) "Violetto di Sicilia"; (**B**) "'Tondo di Paestum"; (**C**) "Sylvestris Creta"; (**D**) "Sylvestris Kamaryna"; (**E**) "Altilis"; and (**F**) "Cimiciusa di Mazzarino". For peak assignments, see **Table 2**.

interest, while quadrupole 2 scanned for ions produced by nitrogen collision of these ionized compounds in the range 100−1000 m/z at a scan time of 500 ms/cycle.

Phenolic Compound Identification and Quantification. Identification of individual flavonoids and phenolic acids was carried out using their retention times, comparison with commercially available standards, and both UV and MS spectra. Peaks with a LOD $\geq 3 \times$ noise were considered, and each compound with LOQ $\geq 10 \times$ noise was quantified relative to the calibration curve. Amounts of mono- and dicaffeoylquinic acids were calculated at 310 nm using 5-caffeoylquinic acid and cynarin as references, respectively. Luteolin-7-*O*-glucuronide and luteolin-7-*O*-rutinoside were quantified using luteolin-7-*O*-glucoside as a reference at 350 nm. Finally, apigenin-7-*O*-rutinoside and apigenin-7-*O*-glucuronide were estimated at 310 nm, using apigenin-7-*O*-glucoside as a reference. All peak areas and retention times were expressed relative to the internal standard of hesperetin added prior to extraction of samples (**Table 2**). Peak area and retention times showed a coefficient of variability (CV) of $<15\%$ and $\sim 0.1\%$, respectively. All data are presented as mean $\pm$ standard deviation of three individual experiments ($n = 3$), and results are expressed as mg/kg of dry matter (DM).

RESULTS AND DISCUSSION

Our objective was to investigate possible differences in flavonoid and phenolic acid composition of capitulum among the

Table 3. Phenolic Content (mg/kg of DM) of *C. cardunculus* Capitula

	cultivated cardoon	wild cardoon		globe artichoke		
compound	Altilis	Sylv. Creta	Sylv. Kamaryna	Cimiciusa	Tondo di Paestum	Violetto di Sicilia
1-caffeoylquinic acidc	nd[a]	nd	nd	nd	nd	trace
5-caffeoylquinic acid	nd	nd	nd	nd	950 ± 82	1975 ± 180
1,5-dicaffeoylquinic acid	nd	21 ± 1	trace	71 ± 5	331 ± 31	539 ± 64
total caffeoylquinic acid	–	21	–	71	1281	2514
luteolin rut[c]	nd	nd	nd	nd	68 ± 5	129 ± 1
lutuolin glc[d]	nd	nd	nd	nd	300 ± 30	nd
luteolin glr[e]	nd	nd	nd	nd	nd	303 ± 6
luteolin	nd	15	trace	25 ± 2	64 ± 3	60 ± 1
total luteolin	–	15	–	25	432	492
apigenin rut[c]	430 ± 41[b]	459 ± 41	trace	nd	nd	nd
apigenin glc[d]	nd	nd	nd	nd	nd	nd
apigenin glr[e]	7068 ± 688	3348 ± 231	4609 ± 417	6457 ± 705	1901 ± 42	2229 ± 71
apigenin malonylglc[d]	549 ± 48	nd	nd	trace	120 ± 3	102 ± 1
apigenin	1060 ± 59	364 ± 30	964 ± 54	1021 ± 110	623 ± 4	337 ± 23
total apigenin	9107	4170	7573	7478	2644	2668
total measured polyphenols	9107	4207	7573	7574	4357	5674

[a] nd = not detected. [b] Standard error of the mean, $n = 3$. [c] rut = rutinoside. [d] glc = glucoside. [e] glr = glucuronide.

species *C. cardunculus*. Samples were selected according to their genetic variation on the basis of their AFLP fingerprint and SSR profile as well as their earliness of head development, size of plant, and shape and size of head, and consequently, few genotypes per botanical variety were enough to represent the genetic variability in *C. cardunculus*. HPLC coupled to MS/MS was used to identify glycosides and isomers of these compounds based on already published identification on compounds from globe artichoke (*22–25*). In this paper, the caffeoylquinic acids are presented according to the recommended IUPAC numbering system (*26*). In each extract, we identified caffeoylquinic acids and flavones as the main compounds (**Figure 1**), specifically 5-*O*-caffeoylquinic acid, dicaffeoylquinic acid (which we propose to be 1,5- based on ref *18*), luteolin-7-*O*-rutinoside, luteolin-7-*O*-glucoside, luteolin-7-*O*-glucuronide, luteolin, apigenin-7-*O*-glucuronide, apigenin aglycone, and apigenin-malonylglucoside.

The quantification of each compound is shown in **Table 3** and indicates that "Sylvestris Creta" (wild cardoon) exhibits the lowest content of total measured flavonoids and phenolic acids. The wild cardoon "Sylvestris Kamaryna", native of Sicily, was the richest in total measured flavonoids and phenolic acids, closely followed by cultivated cardoon "Altilis" and by the globe artichoke Sicilian landrace "Cimiciusa di Mazzarino". All of the above-mentioned genotypes were, however, low in caffeoylquinic acids and in luteolin glycosides, with most of the total measured flavonoids derived from apigenin and glycosides. In contrast, the globe artichoke cultivars "Tondo di Paestum" and "Violetto di Sicilia" were high in caffeoylquinic acids and luteolin glycosides, with luteolin-7-*O*-glucuronide being unique to "Violetto di Sicilia". Recent research on these artichoke genotypes demonstrated that these substances were particularly rich in the receptacle (*27*).

It is known that the content of flavonoids and phenolic acids may depend on many aspects, such as environment, agrotechnical processes, stress, and genetic factors. In globe artichoke, the genetic aspect appears to be the main factor affecting the content of flavonoids and phenolic acids (*28*), as already reported in potato and in blackberry (*29, 30*).

Our data may confirm it, since each genotype was cultivated in the same place and collected from disease-free plants and indicates the possible use of "phenolic fingerprinting" in order to discriminate the botanical variety *scolymus* from other *C. cardunculus* varieties. Our findings are in contrast with a previous report, where the authors found that major compounds in globe artichoke and cultivated cardoon were the same (*31*). This discrepancy might be explained by the different part of plant considered and, also, because they did not consider luteolin-7-*O*-rutinoside and luteolin-7-*O*-glucuronide, which are not commercially available and require mass spectrometry for identification.

From our data, the flavones were the most abundant compounds with percentages ranging from 56% ("Violetto di Sicilia") to 100% ("Altilis" and "Sylvestris Kamaryna") of the total measured flavonoid and phenolic acid content. We report, for the first time, the phenolic profile in the whole head of cultivated and wild cardoon. The only previous work to our knowledge is the phenolic profile in the leaves of cultivated and wild cardoon (*19*, *32*, *33*). In whole globe artichoke, other authors reported a higher content of caffeoylquinic acids than flavones. This difference might be due to genotype and maturity of the stage of artichoke heads considered (*18, 25*).

The predominant flavone was apigenin-7-*O*-glucuronide, followed by apigenin. In particular, the highest amount was in "Sylvestris Kamaryna", with values of 7068 and 1060 mg/kg DM for apigenin-7-*O*-glucuronide and apigenin, respectively. Compound **10**, mainly present in "Altilis" (549 mg/kg of DM), was identified as an apigenin malonylglucoside by the deprotonated molecule $[M - H]^-$ (m/z 517), by mass spectrometric fragmentation (fragment of m/z 269) (**Figure 2**) and by UV spectra (data not shown), and has not been previously reported in *C. cardunculus*.

The data on the phenolic compounds of the analyzed samples appear related to genetic distances between wild cardoon and globe artichoke. In contrast, the phenolic profile was not able to establish divergences between wild and cultivated cardoon, as reported in genetic tests. On the basis of our results, "Cimiciusa di Mazzarino" seemed closer to cardoon form than globe artichoke at least on the basis of phenolic composition (**Figure 1**).

Nevertheless, this paper clearly demonstrates that the "phenolic fingerprint" may be used to indicate differences between globe artichoke and cardoon forms. It also shows the potential of artichoke as a raw material for nonfood applications requiring

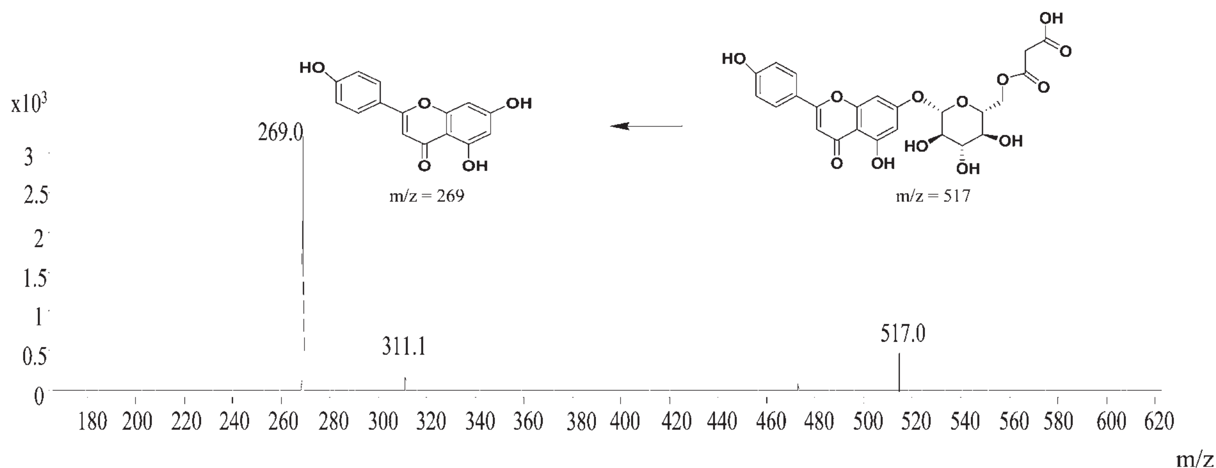

Figure 2. Negative ion mass spectrum of apigenin 7-*O*-(6-malonyl-β-D-glucoside) acquired during LC-MS/MS analysis. The 7 position is shown as the most likely point of attachment, but the substitution could be at the 5 or 4′ positions.

phenolics and as possible medicinal herbal products. In addition, it indicates the potential use of the capitula of cardoon forms, which grow naturally in the wild in the Mediterranean Basin, as natural sources of apigenin, an important but relatively rare flavonoid which has several biological, pharmacological, and antimicrobial activities (*34*).

LITERATURE CITED

(1) Rottenberg, A.; Zohary, D. The wild relatives and the wild ancestry of the cultivated artichoke. *Genet. Resour. Crop Evol.* **1996**, *43*, 53–58.

(2) Foury C. Quelques aspects du développement de l'artichaut (Cynara scolymus L.) issu de semences: analyse plus particulière de la floraison en conditions naturelles. Thèse de Doctorat d'Etat, Univ. Pierre et Marie Curie, Paris VI, France, 1987.

(3) Rottenberg, A.; Zohary, D.; Nevo, E. Isozyme relationships between cultivated artichoke and the wild relatives. *Genet. Resour. Crop Evol.* **1996**, *43*, 59–62.

(4) Acquadro, A.; Portis, E.; Lee, D.; Donini, P.; Lanteri, S. Development and characterisation of microsatellite markers in *Cynara scolymus* L. *Genome* **2005**, *48*, 217–225.

(5) Portis, E.; Mauromicale, G.; Barchi, L.; Mauro, R.; Lanteri, S. Population structure and genetic variation in autochthonous globe artichoke germplasm from Sicily Island. *Plant Sci.* **2005**, *168*, 1591–1598.

(6) Mauro, R.; Portis, E.; Acquadro, A.; Lombardo, S.; Mauromicale, G.; Lanteri, S. Genetic diversity of globe artichoke landraces from Sicilian small-holdings: implications for evolution and domestication of the species. *Conserv. Genet.* **2009**, *10*, 431–440.

(7) Mauromicale, G.; Ierna, A. Panorama varietale e miglioramento genetico del carciofo. *Inform. Agrar.* **2000**, *56*, 39–45.

(8) Gominho, J.; Fernández, J.; Pereira, H. *Cynara cardunculus* L. − a new fibre crop for pulp and paper production. *Ind. Crops Prod.* **2001**, *13*, 1–10.

(9) Mauromicale, G.; Ierna, A. Biomass and grain yield in *Cynara cardunculus* L. genotypes grown in a permanent crop with low input. *Acta Hortic.* **2004**, *660*, 593–598.

(10) Maccarone, E.; Fallico, B.; Fanella, F.; Mauromicale, G.; Raccuia, S. A.; Foti, S. Possible alternative utilization of *Cynara* spp II. Chemical characterization of their grain oil. *Ind. Crops Prod.* **1999**, *10*, 229–237.

(11) Silva, S. V.; Malcata, F. X. Studies pertaining to coagulant and proteolytic activities of plant proteases from *Cynara cardunculus*. *Food Chem.* **2005**, *89*, 19–26.

(12) Fernández, J.; Curt, M. D.; Aguado, P. L. Industrial application of *Cynara cardunculus* L. For energy and other uses. *Ind. Crops Prod.* **2006**, *24*, 222–229.

(13) Barbagallo, R. N.; Chisari, M.; Spagna, G.; Ierna, A.; Patanè, A.; Occhipinti, A.; Mauromicale, G. Caseinolytic activity expression in flowers of *Cynara cardunculus* L. *Acta Hortic.* **2007**, *730*, 195–200.

(14) Mauromicale, G.; Ierna, A. Effects of gibberellic acid and sowing date on harvest time and yields of seed-grown globe artichoke (*Cynara scolymus* L.). *Agronomie* **2005**, *15*, 527–538.

(15) Williamson, G.; Holst, B. Dietary reference intake (DRI) value for dietary polyphenols: are we heading in the right direction? *Br. J. Nutr.* **2008**, *99*, S55–S58.

(16) Kähkönen, M. P; Hopia, A. I.; Vuorela, H. J.; Rauha, J. P.; Pihalaja, K.; Kujala, T. S.; Heinonen, M. Antioxidant activity of plant extracts containing phenolic compounds. *J. Agric. Food Chem.* **1999**, *47*, 3954–3962.

(17) Manach, C.; Williamson, G.; Morand, C.; Scalbert, A.; Rémésy, C. Bioavailability and bioefficacy of polyphenols in humans. I. Review of 97 bioavailability studies. *Am. J. Clin. Nutr.* **2005**, *81*, 230S–242S.

(18) Schütz, K.; Kammerer, D.; Carle, R.; Schieber, A. Identification and quantification of caffeoylquinic acids and flavonoids from artichoke (*Cynara scolymus* L.) heads, juice, and pomace by HPLC-DAD-ESI/MS^n. *J. Agric. Food Chem.* **2004**, *52*, 4090–4096.

(19) Fratianni, F.; Tucci, M.; De Palma, M.; Pepe, R.; Nazzaro, F. Polyphenolic composition in different parts of some cultivars of globe artichoke (*Cynara cardunculus* L. var. *scolymus* (L.) Fiori). *Food Chem.* **2007**, *104*, 1282–1286.

(20) Lanteri, S.; Saba, E.; Cadinu, M.; Mallica, G. M.; Baghino, L.; Portis, E. Amplified fragment length polymorphism for genetic diversity assessment in globe artichoke. *Theor. Appl. Genet.* **2004**, *108*, 1534–1544.

(21) Määttä, K. R.; Kamal-Eldin, A.; Törrönen, A. R. High-performance liquid chromatography (HPLC) analysis of phenolic compounds in berries with diode array and electrospray ionization mass spectrometric (MS) detection: *Ribes* species. *J. Agric. Food Chem.* **2003**, *51*, 6736–6744.

(22) Clifford, M.; Johnston, K. J.; Knight, S.; Kuhnert, N. A hierarchical scheme for LC-MS^n identification of chlorogenic acids. *J. Agric. Food Chem.* **2003**, *51*, 2900–2911.

(23) Clifford, M.; Knight, S.; Kuhnert, N. Discriminating between the sux isomers of dicaffeoylquinic acid by LC-MS^n. *J. Agric. Food Chem.* **2005**, *53*, 3821–3832.

(24) Sànchez-Rabaneda, F.; Jàuregui, O.; Lamuela-Raventós, R. M.; Bastida, J.; Viladomat, F.; Codina, C. Identification of phenolic compounds in artichoke waste by high-performance liquid chromatography-tandem mass spectrometry. *J. Chromatogr., A* **2003**, *1008*, 57–72.

(25) Wang, M.; Simon, J. E.; Aviles, I. F.; He, K.; Zheng, Q.; Tadmor, Y. Analysis of antioxidative phenolic compounds in artichoke (*Cynara scolymus* L.). *J. Agric. Food Chem.* **2003**, *51*, 601–608.

(26) IUPAC. Nomenclature of cyclitols. *Biochem. J.* **1976**, *153*, 23−31.

(27) Lombardo, S.; Pandino, G.; Mauromicale, G.; Knödler, M.; Carle, R.; Schieber, A. Influence of genotype, harvest time and plant part

on polyphenolic composition of globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori]. *Food Chem.* **2010**, *119*, 1175–1181.

(28) Moglia, A.; Lanteri, S.; Comino, C.; Acquadro, A.; De Vos, R.; Beekwilder, J. Stress-induced biosynthesis of dicaffeoylquinic acids in globe artichoke. *J. Agric. Food Chem.* **2008**, *56*, 8641–8649.

(29) Connor, A. M.; Finn, C. E.; McGhie, T. K.; Alspach, P. A. Genetic and environmental variation in anthocyanins and their relationship to antioxidant activity in blackberry and hybridberry cultivars. *J. Am. Soc. Hortic. Sci.* **2005**, *130*, 680–687.

(30) Reddivari, L.; Hale, A. L.; Miller, C. Genotype, location, and year influence antioxidant activity, carotenoid content, phenolic content, and composition in speciality potatoes. *J. Agric. Food Chem.* **2007**, *55*, 8073–8079.

(31) Seabra, R.; Valentão, P.; Federes, F.; Andrade, P. Phenolic profiles in the definition of natural products authenticity: cardoon versus artichoke profile. In *Natural Products in the New Millenium: Prospects and Industrial Applications*; Rauter, A. P., Palma, F. B., Justino, J., Araujo, H. E., Dos Santos, S. P., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, **2002**; pp 183−194.

(32) Pinelli, P.; Agostini, F.; Comino, C.; Lanteri, S.; Portis, E.; Romani, A. Simultaneous quantification of caffeoyl esters and flavonoids in wild and cultivated cardoon leaves. *Food Chem.* **2007**, *105*, 1695–11701.

(33) Comino, C.; Lanteri, S.; Portis, E.; Acquadro, A.; Romani, A.; Hehn, A.; Larbat, R.; Bourgaud, F. Isolation and functional characterization of a cDNA coding a hydroxycinnamoyltransferase involved in phenylpropanoid biosynthesis in *Cynara cardunculus*. *BMC Plant Biol.* **2007**, 7–14.

(34) Avallone, R.; Zanoli, P.; Puia, G.; Kleinschnitz, M.; Schreier, P.; Baraldi, M. Pharmacological profile of apigenin, a flavonoid isolated from *Matricaria chamomilla*. *Biochem. Pharmacol.* **2000**, *59*, 1387–1394.

Received for review September 18, 2009. Revised manuscript received December 2, 2009. Accepted December 05, 2009. We thank the "Università degli Studi di Catania" for a research award to G.P.