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Antioxidant Activity and Phenolic Composition of Wild, Edible, and Medicinal Fennel from Different Mediterranean Countries

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Fennel (*Foeniculum vulgare* Mill.) is a typical aromatic plant of the Mediterranean area, long used as a medicinal and spice herb. Fennel is also well-known for its essential oil, which has been extensively studied for many years owing to its commercial importance. In this work, the antioxidant activity and the total phenolic and flavonoid contents, as well as the quantitative determination of individual flavonoids and phenolic acids of wild, edible, and medicinal fennel from different Mediterranean countries, have been determined. The antioxidant activity was measured as the free radical (DPPH), hydroxyl radical, and superoxide anion scavenging activities. Wild fennel was found to exhibit a radical scavenging activity, as well as a total phenolic and total flavonoid content, higher than those of both medicinal and edible fennels.

KEYWORDS: *Foeniculum vulgare*; Apiaceae; fennel; flavonoids; phenolic acids; radical scavenging activity; HPLC

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill., Apiaceae) is a well-known Mediterranean aromatic plant, which has long been considered as a medicinal and spice herb. Fennel and its herbal drug preparations are used for dyspeptic complaints such as mild, spasmodic gastric-intestinal complaints, bloating, and flatulence (*1*). *F. vulgare* can be an annual, biannual, or perennial plant species, depending on which species, *piperitum* or *vulgare*, or variety is examined. Subspecies *vulgare* includes three varieties: *vulgare*, *dulce*, and *azoricum*. The sweet (*dulce*) and bitter (*vulgare*) varieties grow wild in Mediterranean countries; however, it is the sweet fennel that is cultivated (*2*). The fennel fruit has also been found to be active as a diuretic, analgesic, and antipyretic (*3*), as well as to possess antioxidant activity (*4*).

Active oxygen molecules, such as superoxide ($O_2^{\bullet -}$, $OOH^{\bullet}$), hydroxyl ($OH^{\bullet}$), and peroxyl ($ROOH^{\bullet}$) radicals, play an important role in oxidative stress related to the pathogenesis of various important diseases. In healthy individuals, the production of free radicals is controlled by the balanced defense system. Oxidative stress is generated when the balance is in favor of free radicals as a result of an increased production or depletion of antioxidant levels. Oxidative damage, caused by the action of free radicals, may initiate and promote the progression of a number of chronic diseases, atherosclerosis, cataracts, and inflammation. The antioxidant effect of plant phenolics has also been studied in relation to the prevention of coronary disease and cancer, as well as age-related degenerative brain disorders (*5, 6*). Antioxidant activity is widely used as a parameter to characterize different plant materials. The mechanisms of this activity are classified as chain breaker (or free radical inhibitor), peroxide decomposer, metal inactivator, or oxygen scavenger (*7*).

Polyphenolic compounds are associated with the prevention of diseaes thought to be induced by oxidative stress, such as cardiovascular diseases, cancer, and inflammation. The possible protective effects reported are generally associated with the antioxidant activity of the polyphenolics (*8*). A positive correlation between phenolics and total antioxidant activity has been previously demonstrated for a variety of fruits and vegetables (*9–11*). Other studies showed that phenolics may be the major contributor to the total antioxidant activities of fruits (*11*).

Phenolic compounds possess a wide range of structures and are widely distributed in plants. Although there have been different approaches to their analysis, the separation and quantification of the phenolic compounds in a plant extract remain difficult, especially the simultaneous determination of different groups of phenolics via a single analysis. HPLC is the method of choice for the analysis of phenolic compounds because of its versatility, precision, and relatively low cost. Most

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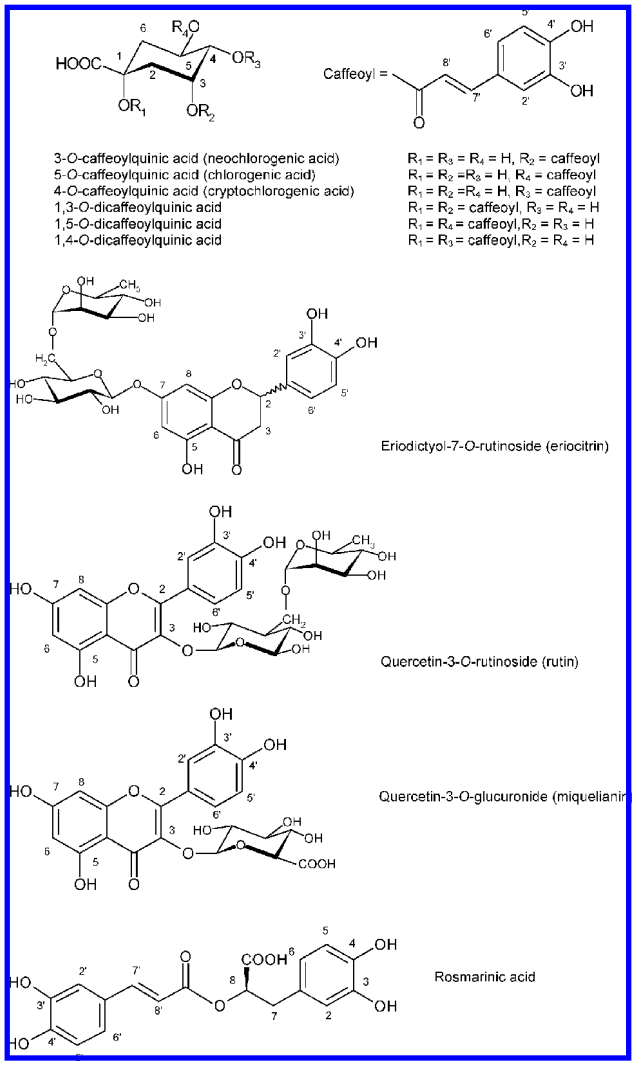

Figure 1. Phenolic structures.

frequently, the methods used employ reversed phase (RP) C_{18} columns, a binary solvent system containing acidified water, a polar organic solvent (acetonitrile or methanol), and UV−vis diode array detection (DAD) (*12, 13*).

The occurrence of phenolics in fennel has been recently reported (*14, 15*). The objective of this study, however, was to determine and to compare the antioxidant activity and the total content of phenolic compounds and flavonoids of wild, medicinal, and edible fennel from different Mediterranean countries: Italy, Spain, Greece, Turkey, and Egypt. The contents of six phenolic acids (3-*O*-, 4-*O*-, and 5-*O*-caffeoylquinic acids and 1,3-*O*-, 1,4-*O*-, and 1,5-*O*-dicaffeoylquinic acids), three flavonoids (eriodictyol-7-*O*-rutinoside, quercetin-3-*O*-rutinoside, and quercetin-3-*O*-glucuronide), and rosmarinic acid were determined by HPLC (*16*). Their structures are shown in **Figure 1**.

MATERIALS AND METHODS

Plant Material. Wild *F. vulgare* was collected in different parts of Italy, Greece, and Spain. Medicinal fennel (fruits) from Italy, Spain, Turkey, and Egypt was obtained from different suppliers. The Aboca sample was purchased in the market as tea bags. Different cultivars of edible fennel, *F. vulgare* subsp. *vulgare* var. *azoricum* Miller, which is an annual plant in which the hypertrophied sheaf of the basal leaves constitutes a bulb that is used as a vegetable, were supplied by producers from Italy and Spain. The different plant materials studied in this work were as follows: Wild fennel was obtained from Ascoli Piceno, Bologna, Chia, Gennargentu, Giara, Messina, San Basilio, and Terni (Italy); Calatayud, Ejea de los Caballeros, Peñaflor, and San Blas (Spain); Argos (Greece). Medicinal fennel was obtained from Aboca, Cannamela, and Toschi (Italy); Herboristería Amorós (Spain); Erboveneta (Turkey); and Herboristería Amorós and Erboveneta (Egypt). Edible fennel was obtained from Tusco 1, Tusco 2, and Carmo (Italy); and Amigo, Brando, Bravo, Latina, and Orio (Spain).

Chemicals. All of the chemicals used in this work were purchased from Sigma Aldrich (St. Louis, MO), with the exception of sodium hydroxide, sodium nitrite, and aluminum chloride hexahydrate, which were purchased from Scharlau (Barcelona, Spain), and the Folin−Ciocalteu reagent that was purchased from Panreac (Barcelona, Spain). External standards were purchased as follows: 5-*O*-caffeoylquinic acid (chlorogenic acid) and quercetin-3-*O*-rutinoside (rutin) from Sigma and rosmarinic acid from Extrasynthese (Genay, France). Quercetin-3-*O*-glucuronide (miquelianin), eriodictyol-7-*O*-rutinoside (eriocitrin), and 1,5-*O*-dicaffeoylquinic acid were isolated from fennel plants in our laboratory. The purity of the standards was >98%. Acetonitrile (HPLC grade) (SDS, Peypin, France), formic acid (analytical grade) (Probus, Badalona, Spain), and ultrapure water (Milli-Q) (Waters, Milford, MA) were used for mobile phase preparation. Analytical grade methanol was purchased from Panreac (Barcelona, Spain). The standard stock solution was prepared by dissolving the standards (2 mg each) in 15% aqueous methanol (2 mL). Lower concentrations for the calibration were prepared by dilution of the stock solutions with 20% aqueous methanol.

Sample Preparation and Extraction. The different plant materials were treated in the same way. Two hundred and fifty milligrams of dried and powdered material was sonicated with 25 mL of water/ethanol (80:20) for 20 min. After centrifugation at 7600*g* for 10 min, the supernatant was adjusted to 25 mL in a measuring flask. Samples were quantified immediately after extraction to avoid possible chemical alterations. In the case of edible fennel, it was first cut in small pieces and then dried in an oven at 40 °C to constant weight. Blanks and standards containing known concentrations were placed between the samples to monitor the quantification.

Preparation of the Defatted Fruits. Fennel fruits were ground in a mortar and then defatted by blending three times with hexane (1:5, w/v) for 10 min at room temperature. The resultant slurry was filtered, and the residue (defatted fruits) was dried in a oven at 35 °C to constant weight. The dried defatted fruits were extracted as described above.

Determination of Total Phenolic Content. Total soluble phenolics were determined according to the Folin−Ciocalteu method (*17*). The reaction mixture was composed of 0.1 mL of extract, 7.9 mL of distilled water, 0.5 mL of Folin−Ciocalteu reagent, and 1.5 mL of 20% sodium carbonate. The opaque flasks were mixed and allowed to stand for 2 h. The absorbance was measured at 765 nm in a Hitachi U-2000 spectrophotometer. The total phenolic content was determinated as gallic acid equivalents (GAE) per milligram of extract.

Determination of Total Flavonoid Content. Total flavonoid content was determined by a colorimetric method described previously (*18–20*). Briefly, 1 mL of phytochemical extract was diluted with 5 mL of distilled water. Then 0.3 mL of a 5% $NaNO_2$ solution was added to the mixture. After 6 min, 0.6 mL of a 10% $AlCl_3 \cdot 6H_2O$ solution was added. After 5 min, 2 mL of 1 M NaOH was added, and the total was made up to 10 mL with distilled water. The solution was mixed, and the absorbance was measured immediately against the prepared blank at 510 nm with a Hitachi U-2000 spectrophotometer. The flavonoid content was calculated using a quercetin calibration curve. The results were expressed as micrograms of quercetin equivalents (QE) per milligram of extract.

Free Radical Scavenging Activity (DPPH). The sample was measured in terms of hydrogen-donating or radical-scavenging ability using the stable radical $DPPH^{\bullet}$ (*21*). Briefly, 1.5 mL of a DPPH methanolic solution (20 mg/L) was added to 0.75 mL of extract, at different concentrations ranging from 10 to 200 μL/mL (methanol for the control). The absorbance was measured at 517 nm after 20 min of reaction. The percent of DPPH of the sample was calculated according to the following equation: % decolorization = $[1 - (Abs_{sample}/Abs_{control}) \times 100$. The decoloration was plotted against the sample extract

Table 1. Radical Scavenging Activity, Total Phenolic Content, and Total Flavonoid Content in Wild Fennel from Different Geographical Origins

	DPPH• radical scavenging activity, IC_{50} (μg/mL)	hydroxyl radical scavenging activity, IC_{50} (μg/mL)	superoxide anion scavenging activity (% of inhibition at 50 μg/mL)	total phenolic content (GAE/mg of extract)	total flavonoid content (QE/mg of extract)	TFlC/TPhC
			Italy[a]			
Ascoli Piceno	82.9 ± 4.2	50.1 ± 3.9	18.9 ± 1.3	78.2 ± 5.7	78.1 ± 3.4	1.00
Bologna	226.3 ± 7.5	134.7 ± 4.4	21.5 ± 1.9	34.9 ± 2.6	34.1 ± 0.8	0.98
Chia	46.1 ± 2.8	64.9 ± 2.1	32.6 ± 1.1	111.0 ± 4.0	95.8 ± 5.4	0.86
Gennargentu	65.8 ± 1.8	79.9 ± 5.8	16.9 ± 1.6	104.0 ± 3.8	80.2 ± 3.5	0.77
Giara	80.1 ± 3.5	97.1 ± 5.0	7.8 ± 0.9	82.1 ± 2.0	60.1 ± 3.9	0.73
Messina	92.7 ± 2.1	120.4 ± 4.7	14.4 ± 0.3	61.5 ± 2.5	54.6 ± 1.7	0.89
San Basilio	53.1 ± 2.6	72.1 ± 1.8	34.4 ± 0.9	106.7 ± 1.7	87.1 ± 1.8	0.82
Terni	116.8 ± 4.3	10.5 ± 0.4	28.1 ± 2.7	73.3 ± 1.9	60.0 ± 2.1	0.82
			Italy[b]			
Ascoli Piceno	123.0 ± 4.5	115.9 ± 6.0	31.1 ± 2.6	78.4 ± 5.3	70.1 ± 5.7	0.89
Bologna	411.6 ± 33.5	28.5 ± 0.4	11.3 ± 1.0	48.5 ± 3.6	27.2 ± 1.7	0.56
Chia	156.2 ± 6.3	111.8 ± 2.9	nd[d]	62.0 ± 2.8	51.2 ± 1.8	0.83
Gennargentu	158.6 ± 6.3	45.4 ± 3.4	11.6 ± 1.3	73.7 ± 3.1	58.4 ± 2.9	0.79
Giara	136.6 ± 6.9	93.9 ± 3.8	10.4 ± 0.8	67.1 ± 1.2	40.9 ± 1.5	0.61
Messina	161.5 ± 8.3	114.8 ± 11.6	21.9 ± 1.8	57.8 ± 2.5	39.3 ± 2.4	0.68
			Spain[c]			
Calatayud	143.2 ± 5.7	30.7 ± 1.9	29.5 ± 2.1	76.5 ± 2.2	56.7 ± 0.9	0.74
Ejea de los Caballeros	131.3 ± 8.6	39.2 ± 1.8	33.4 ± 2.6	70.7 ± 2.0	58.5 ± 2.7	0.83
Peñaflor	114.2 ± 3.6	48.9 ± 2.3	36.3 ± 1.4	78.1 ± 4.4	63.4 ± 2.7	0.81
San Blas	138.1 ± 6.5	116.0 ± 3.4	27.4 ± 1.3	73.1 ± 2.9	60.7 ± 2.8	0.83
			Greece[a]			
Argos	143.9 ± 5.3	107.6 ± 4.9	20.6 ± 1.5	63.3 ± 4.0	52.9 ± 2.2	0.84
			Greece[b]			
Argos	154.1 ± 8.6	44.4 ± 1.3	nd	73.8 ± 2.9	61.4 ± 2.9	0.83

[a] Aerial parts. [b] Fruits. [c] Whole plant. [d] Not detected.

concentration, and a logarithmic regression curve was established to calculate the IC_{50}, which is the amount of sample necessary to decrease by 50% the absorbance of DPPH.

Hydroxyl Radical Scavenging Activity (OH). The radical scavenging activity was determined through the Co(II)/EDTA/$^{\bullet}OH$/H_2O_2/luminol system (*22*). The intensity of chemiluminescence (CL) was measured as relative light (RLU), in a Turner Degigns' TD-20/20 luminometer. The highest CL intensity of reaction (control light) is decreased by hydroxyl radical scavenging substances. A 300 μL portion of buffer pH 9 Co(II) (2.6 mM) and EDTA (0.84 mM), 25 μL of buffer pH 9 luminol (0.56 mM), and 25 μL of extract at different concentrations ranging from 10 to 200 μL/mL (methanol for the control) were mixed in a test tube. Finally, 50 μL of H_2O_2 (0.52 mM) was added to start the reaction in dark conditions. CL intensity (RLU) was measured 30 min after the reaction started. The percent of inhibition of CL was calculated for each concentration according to the following equation: % inhibition = $[1 - (RLU_{sample}/RLU_{control}) \times 100$. The RLU was plotted against the sample extract concentration, and a linear regression was established to calculate the IC_{50}, which is the amount of sample necessary to decrease by 50% the CL intensity.

Superoxide Anion Scavenging Activity (SO). The superoxide radicals were generated in vitro by the hypoxanthine/xanthine oxidase system. The scavenging activity of the extract was determined by the nitroblue tetrazolium (NBT) reduction method. In this method, $O^{\bullet}_2$ reduces the yellow dye (NBT^{2+}) to produce the blue formazan, which is measured spectophotometrically at 560 nm. Antioxidants are able to inhibit the purple NBT formation (*23, 24*). A reaction mixture with a final volume of 632 μL was prepared with 50 mM phosphate buffer (pH 7.5) containing EDTA (0.05 mM), hypoxanthine (0.2 mM), 63 μL of NBT (1 mM), 63 μL of extract (distilled water for the control), and 63 μL of xanthine oxidase (1.2 units/μL). The xanthine oxidase was added last. For each sample, a blank was carried out. The subsequent rate of NBT reduction was determined on the basis of sequential spectrophotometric determinations of absorbance at 560 nm. Fresh solutions were prepared daily and kept from light. The results are expressed as the percentage inhibition of the NBT reduction with respect to the reaction mixture without sample (buffer only) and were calculated by the following equation: % inhibition = $\{[(C_{abs} - CB_{abs}) - (S_{abs} - SB_{abs})]/(C_{abs} - CB_{abs})\} \times 100$, where S_{abs}, SB_{abs}, C_{abs}, CB_{abs} were the absorbances of the sample, the blank sample, the control, and the blank control, respectively.

HPLC Analysis. Analyses were carried out in an Agilent 1100 series chromatograph equipped with an automatic injector and vacuum degasser. A 250 mm × 2 mm i.d., 5 μm, Luna $C_{18}(2)$ column (Phenomenex, Torrance, CA) was used for all of the separations. The mobile phase was a gradient prepared from 0.1% formic acid in water (A) and formic acid in acetonitrile (B). The composition of gradient was as follows: 0 min, 10% B; 40 min, 26% B; 47 min, 80%; 60 min, 100%. The flow rate was 0.2 mL/min, and the injection volume 50 μL. UV detection was performed at 330 nm.

Calibration. The content of active phenolic compound was determined using a calibration curve established with seven dilutions of each standard, at concentrations ranging from 5 to 150 μg/mL. Each concentration was measured in triplicate. The corresponding peak areas were plotted against the concentration of the injected phenolic compounds. Peak identification was achieved by comparison of the retention time. The reference substances were 5-*O*-caffeoylquinic acid (chlorogenic acid), 1,5-*O*-dicaffeoylquinic acid, quercetin-3-*O*-rutinoside (rutin), quercetin-3-*O*-glucuronide (miquelianin), eriodictyol-7-*O*-rutinoside (eriocitrin), and rosmarinic acid. The phenolic acids 4-*O*-caffeoylquinic acid and 3-*O*-caffeoylquinic acid were determined as 5-*O*-caffeoylquinic acid, whereas 1,3-*O*-dicaffeoylquinic and 1,4-*O*-dicaffeoylquinic acids were determined as 1,5-*O*-dicaffeoylquinic acid. For quantification purposes, detection of the phenolic compounds was carried out at 330 nm, with the exception of eriocitrin, which was measured at 280 nm.

The results belonging to the radical scavenging activity (**Tables 1**, **4**, and **6**) are the mean of four determinations ± SD (standard deviation), and those of individual phenolic compounds (**Tables 2**, **3**, **5**, and **7**) are the mean of three determinations ± SD.

RESULTS AND DISCUSSION

Wild Fennel. *Antioxidant Activity.* The highest DPPH scavenging activity of wild fennel was found in the aerial parts of the Italian populations, those of Chia and San Basilio being the most active ones, thus coinciding with the highest TPhC values they were found to contain. As for the total content of both phenolics and flavonoids, the samples of aerial parts and fruits of wild fennel from the Bologna site exhibited the lowest values of DPPH scavenging activity. The Greek samples of aerial parts and fruits,

Table 2. Phenolic Content in Different Samples of Wild Fennel[a]

	Italy								Spain				Greece
compound	Ascoli Piceno	Bologna	Chia	Gennargentu	Giara	Messina	San Basilio	Terni	Calatayud	Ejea de los Cab.	Peñaflor	San Blas	Argos (Argolidos)
3-*O*-caffeoylquinic acid (neochlorogenic acid)		8.7 ± 1.2	107.1 ± 7.2	41.3 ± 2.8	48.4 ± 5.1		51.4 ± 9.7	49.9 ± 3.8		28.1 ± 3.2	29.1 ± 4.4	28.2 ± 2.1	26.7 ± 2.5
4-*O*-caffeoylquinic acid (cryptochlorogenic acid)	14.2 ± 0.5		57.9 ± 4.7	51.3 ± 3.2	210.5 ± 17.8	traces	93.3 ± 12.7	11.7 ± 1.4		14.8 ± 0.9	17.1 ± 1.4		24.9 ± 5.8
5-*O*-caffeoylquinic acid (chlorogenic acid)	8.8 ± 0.2	1.5 ± 0.3	21.2 ± 2.6	17.4 ± 4.0	8.6 ± 0.4	71.8 ± 9.4	7.5 ± 1	traces	traces	10.0 ± 1.9	21.8 ± 2.6	4.3 ± 0.5	5.6 ± 0.2
subtotal of caffeoylquinic acids	*23.1 (14.2)*	*10.1 (13.1)*	*186.2 (4.5)*	*110.0 (4.7)*	*267.5 (17.0)*	*71.8 (6.3)*	*152.1 (8.2)*	*61.7* (11.4)	*traces*	*52.9 (10.7)*	*68.0 (12.6)*	*32.6 (11.2)*	*57.2 (5.1)*
eriodictyol-7-*O*-rutinoside (eriocitrin)	61.9 ± 2.6	24.0 ± 2.8	128.4 ± 9.9	95.5 ± 11.2	108.8 ± 9.5	52.0 ± 5.4	280.3 ± 17.9	31.9 ± 3.5	19.8 ± 5.2	143.9 ± 22.8	78.4 ± 12.5	49.4 ± 2.8	175.2 ± 18.4
quercetin-3-*O*-rutinoside (rutin)	27.4 ± 4.7	29.5 ± 3.0	255.0 ± 16.0	133.5 ± 13.3	183.4 ± 8.8	161.3 ± 16.9	183.9 ± 19.7	139.2 ± 10.7	26.3 ± 1.4	134.8 ± 16.0	176.1 ± 9.1	139.8 ± 13.9	224.9 ± 17.0
quercetin-3-*O*-glucuronide (miquelianin)		traces	1446.8 ± 49.1	1251.1 ± 27.0	819.9 ± 70.9	640.3 ± 68.9	671.8 ± 42.2	126.8 ± 11.5	68.9 ± 5.6	57.0 ± 7.9	83.1 ± 8.5	traces	381.9 ± 58.2
subtotal of flavonoids	*89.4 (54.9)*	*53.6 (69.4)*	*1830.2 (64.0)*	*1480.1 (63.0)*	*1112.0 (70.4)*	*853.5 (74.5)*	*1136.00 (61.1)*	*297.9 (55.0)*	*115.0 (94.0)*	*335.7 (68.0)*	*337.6 (62.4)*	*189.2 (65.3)*	*782.1 (70.0)*
1,3-*O*-dicaffeoylquinic acid		traces	284.2 ± 19.6	132.4 ± 7.8	60.1 ± 6.8	160.3 ± 7.0	174.5 ± 19.9	97.9 ± 7.3		37.9 ± 4.6	32.2 ± 5.3	38.9 ± 5.3	141.0 ± 10.8
1,4-*O*-dicaffeoylquinic acid	12.2 ± 0.6	traces	206.7 ± 6.8	290.9 ± 35.6	42.1 ± 3.5		167.1 ± 7.9	28.1 ± 3.5		24.4 ± 1.1	35.3 ± 1.8		74.1 ± 11.0
1,5-*O*-dicaffeoylquinic acid	18.4 ± 1.3	traces	324.5 ± 12.0	310.7 ± 10.7	80.3 ± 5.5	47.1 ± 3.8	221.3 ± 21.1	48.9 ± 4.2		28.4 ± 2.2	46.6 ± 4.3	20.2 ± 2.6	54.7 ± 12.3
subtotal of dicaffeoylquinic acids	*30.6 (18.8)*	*traces*	*815.4 (28.5)*	*734.0 (31.3)*	*182.6 (11.6)*	*207.5 (18.1)*	*562.9 (30.3)*	*174.8 (32.3)*		*90.6 (18.4)*	*114.0 (21.1)*	*59.1 (20.4)*	*269.8 (24.1)*
rosmarinic acid	19.7 ± 0.4 *(12.1)*	13.5 ± 0.6 *(17.5)*	26.5 ± 0.9 *(0.9)*	24.1 ± 2.0 *(1.0)*	17.7 ± 1.1 *(1.1)*	13.3 ± 1.3 *(1.2)*	9.5 ± 1.6 *(0.5)*	7.6 ± 0.2 *(1.4)*	7.3 ± 1.6 *(6.0)*	14.2 ± 3.0 *(2.9)*	21.8 ± 3.4 *(4.0)*	8.8 ± 1.0 *(3.1)*	8.3 ± 1.0 *(0.7)*

[a] Values are expressed as mg/100 g of DW ± SD (standard deviation). Values in parentheses are percentages referred to the sum of phenolics of each fennel material.

Table 3. Phenolic Content in Different Samples of Wild Fennel Fruits[a]

	Italy						Greece
compound	Ascoli Piceno	Bologna	Chia	Gennargentu	Giara	Messina	Argos
3-*O*-caffeoylquinic acid (neochlorogenic acid)				traces	traces	traces	
4-*O*-caffeoylquinic acid (cryptochlorogenic acid)						20.6 ± 3.1	
5-*O*-caffeoylquinic acid (chlorogenic acid)	traces						
subtotal of caffeoylquinic acids	*traces*			*traces*	*traces*	*20.6 (23.6)*	
eriodictyol-7-*O*-rutinoside (eriocitrin)	47.5 ± 8.5	traces	34.2 ± 3.6	213.5 ± 14.3	50.3 ± 9.0	20.4 ± 4.8	17.9 ± 2.6
quercetin-3-*O*-rutinoside (rutin)	28.3 ± 2.3	8.2 ± 2.9	10.8 ± 2.9	46.1 ± 6.2	49.7 ± 10.0	6.00 ± 1.1	13.8 ± 4.0
quercetin-3-*O*-glucuronide (miquelianin)	49.7 ± 13.1	traces		28.9 ± 2.7		16.2 ± 3.1	traces
subtotal of flavonoids	*125.5 (78.0)*	*8.2 (100)*	*45.01 (93.1)*	*288.6 (87.2)*	*100.0 (84.1)*	*42.6 (48.8)*	*31.7 (64.9)*
1,3-*O*-dicaffeoylquinic acid			traces	traces	traces	traces	
1,4-*O*-dicaffeoylquinic acid				14.8 ± 4.1	3.6 ± 0.7		
1,5-*O*-dicaffeoylquinic acid	29.0 ± 4.5			20.2 ± 3.5	11.1 ± 1.0	19.4 ± 3.1	13.0 ± 2.6
subtotal of dicaffeoylquinic acids	*29.0 (18.0)*		*traces*	*34.9 (10.5)*	*14.7 (12.4)*	*19.4 (22.2)*	*13.0 (26.7)*
rosmarinic acid	6.4 ± 1.0 *(4.0)*	traces	3.4 ± 0.6 *(6.9)*	7.4 ± 1.2 *(2.3)*	4.1 ± 1.0 *(3.5)*	4.7 ± 1.0 *(5.4)*	4.1 ± 0.4 *(8.4)*

[a] Values are expressed as mg/100 g of DW ± SD (standard deviation). Values in parentheses are percentages referred to the sum of phenolics of each fennel material.

as well as the Spanish ones of whole plants of fennel, were found to show an intermediate DPPH scavenging activity, lower than that of the aerial parts of the Italian samples (**Table 1**).

With regard to the OH scavenging activity, big differences were observed among the different samples of fennel collected in different countries. The aerial parts of fennel from the Terni site and the fruits from Bologna were found to be the most active, with IC_{50} values of 10.5 and 28.5 μg/mL, respectively (**Table 1**). Curiously, this high OH scavenging activity of the Bologna site is in contrast with its low DPPH scavenging activity and its low content of both total phenolics and flavonoids. With the exception of the San Blas site, the Spanish samples of whole plants of fennel also exhibited a relatively high OH scavenging activity. The fennel fruits of the Greek site of Argos were also found to show a OH scavenging activity close to that of the Spanish samples.

The SO scavenging activity in wild fennel was found to vary from 36.3% in the whole plants from the Spanish site Peñaflor to 7.8% in the aerial parts from the Italian location called Giara; it was not detected in fruits of the samples collected in Chia (Italy) and Argos (Greece) (**Table 1**). Aerial parts of fennel from Chia, Messina, and Terni locations and fruits from the Ascoli Piceno site exhibited a superoxide anion scavenging activity quite similar to that of whole plants from the Spanish samples.

Phenolic Composition. The values of the total phenolic content in the different samples of wild fennel varied from 34.9 to 111.0 GAE/mg of extract in the aerial parts from the Italian sites Bologna and Chia, respectively (**Table 1**). With the exception of this Bologna site, the highest TPhC values were found in the aerial parts of the Italian fennel. The aerial parts of the Greek wild fennel (Argos) contained a lower amount of phenolics (63.3 GAE/mg of extract). Among the fruits, the TPhC values of the Italian samples varied from 48.5 to 78.4 GAE/mg of extract. The total phenolic content of the Greek site (73.8 GAE/mg of extract) was higher than that of the Italian samples, with the exception of the Ascoli Piceno site. With regard to whole plant, no important variations were found among the Spanish samples, because values varied from 70.7 to 78.1 GAE/mg of extract.

The values of the ratio TFlC/TPhC of the different samples are also shown in **Table 1**. In general terms, the flavonoid content represents around 80% of the total phenolic content. Some exceptions are the aerial parts of the Italian sites Ascoli Piceno and Bologna, where almost all of the phenolic substances were found to be flavonoids, and fruits of the Italian populations Bologna, Giara, and Messina, where flavonoids represented <70% of the total phenolic compounds.

The composition of the individual phenolic substances of the Italian wild fennel varied enormously (**Table 2**). Thus, cryptochlorogenic acid was the most abundant phenolic acid in four of the nine sites of fennel studied, the highest being that of Giara (210.5 mg/100 g of DW). Chlorogenic and neochlorogenic acids were most abundant in the samples collected in Messina

Table 4. Radical Scavenging Activity, Total Phenolic Content, and Total Flavonoid Content in Edible Fennel from Different Geographical Origins

	DPPH$^{\bullet}$ radical scavenging activity, IC_{50} (μg/mL)	hydroxyl radical scavenging activity, IC_{50} (μg/mL)	superoxide anion scavenging activity (% inhibition at 50, μg/mL)	total phenolic content (GAE/mg of extract)	total flavonoid content (QE/mg of extract)	TFlC/TPhC
			Italy			
Tusco 1	931.7 ± 72.4	401.1 ± 21.7	nd[a]	21.1 ± 1.9	13.6 ± 0.7	0.64
Carmo	765.5 ± 47.8	81.2 ± 1.6	nd	22.2 ± 0.8	10.6 ± 0.7	0.48
Tusco 2	900.7 ± 36.3	289.2 ± 9.4	nd	20.9 ± 0.7	17.1 ± 0.8	0.82
			Spain			
Amigo	840.1 ± 25.0	nd	nd	19.5 ± 0.6	8.5 ± 0.8	0.44
Brando	667.9 ± 49.8	1023.6 ± 82.8	nd	14.3 ± 0.6	7.9 ± 0.4	0.55
Bravo	662.7 ± 45.1	621.2 ± 42.1	nd	15.9 ± 1.4	8.5 ± 0.5	0.54
Latina	813.0 ± 52.9	285.0 ± 47.1	nd	14.8 ± 1.3	7.4 ± 0.5	0.50
Orion	876.7 ± 36.1	417.6 ± 19.0	nd	12.3 ± 0.6	6.2 ± 0.1	0.51

[a] Not detected.

Table 5. Phenolic Content in Different Samples of Edible Fennel[a]

	Italy			Spain				
compound	Tusco 1	Carmo	Tusco 2	Amigo	Brando	Bravo	Latina	Orion
3-*O*-caffeoylquinic acid (neochlorogenic acid)								
4-*O*-caffeoylquinic acid (cryptochlorogenic acid)				8.8 ± 1.8	8.9 ± 1.4	17.8 ± 2.2	3.9 ± 0.7	1.8 ± 0.4
5-*O*-caffeoylquinic acid (chlorogenic acid)				traces	3.9 ± 0.6	37.0 ± 5.2	2.8 ± 0.9	13.5 ± 2.6
subtotal of caffeoylquinic acids				*8.8 (7.3)*	*12.8 (12.5)*	*54.8 (39.4)*	*6.7 (7.5)*	*15.3 (32.6)*
eriodictyol-7-*O*-rutinoside (eriocitrin)		13.1 ± 2.1		48.4 ± 6.4	38.9 ± 5.2	41.1 ± 3.6	40.4 ± 5.9	
quercetin-3-*O*-rutinoside (rutin)	8.8 ± 0.7	3.8 ± 0.7	5.2 ± 1.2	8.6 ± 0.4	3.3 ± 0.3	traces	2.2 ± 0.4	traces
quercetin-3-*O*-glucuronide (miquelianin)								
subtotal of flavonoids	*8.8 (68.2)*	*16.9 (74.1)*	*5.2 (64.1)*	*57.0 (47.4)*	*42.1 (41.0)*	*41.1 (29.6)*	*42.6 (47.9)*	*traces*
1,3-*O*-dicaffeoylquinic acid	2.6 ± 0.4	5.9 ± 0.7	2.9 ± 0.3	39.8 ± 6.0	35.5 ± 5.2	26.5 ± 3.9	35.5 ± 3.4	24.5 ± 3.4
1,4-*O*-cicaffeoylquinic acid				14.6 ± 1.2	12.3 ± 1.3	16.6 ± 1.6	6.4 ± 1.2	7.1 ± 0.8
1,5-*O*-dicaffeoylquinic acid								
subtotal dicaffeoylquinic acids	*2.6 (19.9)*	*5.9 (25.9)*	*2.9 (35.8)*	*54.4 (45.3)*	*47.8 (46.5)*	*43.1 (31.0)*	*41.8 (47.1)*	*31.6 (67.4)*
rosmarinic acid	1.5 ± 0.0 *(11.8)*							

[a] Values are expressed as mg/100 g of DW ± SD (standard deviation). Values in parentheses are percentages referred to the sum of phenolics of each fennel material.

(71.8 mg/100 g of DW) and Chia (107.1 mg/100 g of DW), respectively. The percentages of caffeoylquinic acids with regard to the other groups of phenolics varied from 6.5% (Chia) to 17% (Giara). Dicaffeoylquinic acids were also quite abundant in Italian wild fennel, with percentages of the total phenolic substances ranging from traces (Bologna) to 32.2% (Terni). 1,5-*O*-Dicaffeoylquinic acid was found to be the main of these compounds in five of the nine sites, especially in Chia and Gennargentu, with values of 324.5 and 310.7 mg/100 g of DW, respectively (**Table 2**). Flavonoids were the most abundant phenolic compounds, with contents ranging from 53.6 (Bologna) to 1830.2 (Chia) mg/100 g of DW. Eriocitrin was the most abundant flavonoid in fennel from Ascoli Piceno site, rutin in that of the Bologna and Terni sites, and miquelianin in the rest of Italian samples. The content of rosmarinic acid was very low in all of the samples, with values varying from 7.6 (Terni) to 26.5 (Chia) mg/100 g of DW. Curiously, it represented 17.5% of the total phenolic substances in the fennel sample from Bologna site (**Table 2**).

The phenolic composition of wild fennel from Greece and Spain also varied considerably (**Table 2**). The sample of the Greek site Argos was found to contain 70% of the total phenolics as flavonoids, mainly the quercetin derivatives miquelianin (381.9 mg/100 g of DW) and rutin (224.9 mg/100 g of DW). Dicaffeoylquininc acids were also quite abundant (24.1% of the total phenolics), especially 1,3-*O*-dicaffeoylquinic acid (141 mg/100 g of DW). Only 5.1% of the total phenolics were caffeoylquininc acids, whereas the occurrence of rosmarinic acid was also very low (8.3 mg/100 g of DW). Fennel from the Spanish site Calatayud was found to contain no dicaffeoylquinic acids and only traces of caffeoylquinic ones. The phenolic substances in this sample were represented by rosmarinic acid (6%) and flavonoids (94%), of which miquelianin was the most abundant one. The other three samples of Spanish fennel contained a similar phenolic composition: around 10–12% caffeoylquinic acids, 18–21% dicaffeoylquinic acids, 62–68% flavonoids, and 3–4% rosmarinic acid. As in the Greek sample, neochlorogenic acid was found to be the most abundant caffeoylquinic acid (28–29 mg/100 g of DW) in fennel from these three Spanish sites. With regard to dicaffeoylquinic acids, however, the highest content was that of 1,3-*O*-dicaffeoylquinic acid in Ejea de los Caballeros (37.9 mg/100 g of DW) and San Blas (38.9 mg/100 g of DW) sites and 1,5-*O*-dicaffeoylquinic acid in Peñaflor (46.6 mg/100 g of DW). The flavonoid proportion also varied considerably among the Spanish samples of fennel. Thus, eriodictyol-7-*O*-rutinoside (eriocitrin) was the most abundant flavonoid in fennel from Ejea de los Caballeros, whereas quercetin derivatives were the major flavonoids in samples from Peñaflor and San Blas. Curiously, the total contents of flavonoids were almost equal in fennel samples from Ejea de los Caballeros (335.7 mg/100 g of DW) and Peñaflor (337.6 mg/100 g of DW).

Table 6. Radical Scavenging Activity, Total Phenolic Content, and Total Flavonoid Content in Medicinal Fennel from Different Geographical Origin

	DPPH$^{\bullet}$ radical scavenging activity, IC_{50} (μg/mL)	hydroxyl radical scavenging activity, IC_{50} (μg/mL)	superoxide anion scavenging activity (% inhibition at 50, μg/mL)	total phenolic content (GAE/mg of extract)	total flavonoid content (QE/mg of extract)	TFIC/TPhC
			Italy			
Aboca[a]	228.7 ± 10.4	126.7 ± 6.1	nd[b]	48.0 ± 2.8	33.9 ± 1.6	0.71
Cannamela	142.5 ± 12.1	102.4 ± 5.6	18.8 ± 2.2	38.1 ± 1.2	40.5 ± 3.6	1.06
Toschi	122.7 ± 11.2	138.6 ± 8.6	24.6 ± 2.4	52.3 ± 2.2	47.6 ± 2.9	0.91
			Spain			
Amorós	134.6 ± 5.7	133.3 ± 4.3	24.4 ± 1.2	57.2 ± 3.0	48.2 ± 1.2	0.84
			Egypt			
Amorós	222.6 ± 11.3	32.2 ± 2.8	6.6 ± 0.4	49.7 ± 3.1	45.8 ± 2.8	0.84
Erboveneta	185.2 ± 10.7	149.5 ± 8.1	22.7 ± 2.1	52.9 ± 2.6	48.1 ± 3.4	0.91
			Turkey			
Erboveneta	151.2 ± 8.1	29.8 ± 2.9	20.5 ± 1.8	49.0 ± 2.0	41.9 ± 2.5	0.85

[a] Commercial product. [b] Not detected.

Table 7. Phenolic Content in Different Samples of Medicinal Fennel[a]

	Italy			Spain	Turkey	Egypt	
compound	Aboca[b]	Cannamela	Toschi	Herb. Amoros	Erboveneta	Herb. Amoros	Erboveneta
3-*O*-caffeoylquinic acid (neochlorogenic acid)							
4-*O*-caffeoylquinic acid (cryptochlorogenic acid)		46.3 ± 4.9	9.7 ± 1.9	11.0 ± 0.8	traces	10.7 ± 0.5	traces
5-*O*-caffeoylquinic acid (chlorogenic acid)	traces	51.7 ± 10.7	traces	3.7 ± 0.3		traces	traces
subtotal of caffeoylquinic acids	*traces*	*98.0 (27.8)*	*9.7 (6.8)*	*14.7 (5.2)*	*traces*	*10.7 (16.6)*	
eriodictyol-7-*O*-rutinoside (eriocitrin)	34.2 ± 6.3	54.8 ± 8.6	8.2 ± 0.8	23.0 ± 4.1	19.8 ± 5.7	14.2 ± 0.7	34.3 ± 7.2
quercetin-3-*O*-rutinoside (rutin)	19.1 ± 0.6	traces	28.4 ± 4.7	56.7 ± 6.1	traces	12.6 ± 3.6	7.2 ± 0.6
quercetin-3-*O*-glucuronide (miquelianin)		150.3 ± 32.6	90.5 ± 6.4	155.1 ± 14.9		15.1 ± 4.3	
subtotal of flavonoids	*53.3 (84.4)*	*205.0 (58.2)*	*127.1 (89.5)*	*234.7 (82.4)*	*19.8 (100)*	*41.9 (64.8)*	*41.5 (91.0)*
1,3-*O*-dicaffeoylquinic acid		traces		14.0 ± 2.3		traces	
1,4-*O*-dicaffeoylquinic acid		45.3 ± 10.1	5.2 ± 1.4	17.7 ± 3.8			
1,5-*O*-dicaffeoylquinic acid						8.9 ± 1.7	
subtotal of dicaffeoylquinic acids		*45.3 (12.9)*	*5.2 (3.7)*	*31.7 (11.1)*		*8.9 (13.8)*	
rosmarinic acid	8.4 ± 2.0 *(13.3)*	3.8 ± 0.5 *(1.1)*	traces	3.8 ± 0.2 *(1.3)*	traces	3.1 ± 0.8 *(4.7)*	4.1 ± 0.8 *(9.0)*

[a] Values are expressed as mg/100 g of DW ± SD (standard deviation). Values in parentheses are percentages referred to the sum of phenolics of each fennel material. [b] Commercial product.

Fruits of fennel analyzed separately were found to contain no caffeoylquinic acids, with the exception of the Messina site (Italy), which accumulated only cryptochlorogenic acid (**Table 3**). Flavonoids were especially abundant in the fruits of fennel, thus reaching percentages ranging from 48.8% (Messina) to almost 100% (Bologna) of the total phenolic compounds. Surprisingly, rutin was the only phenolic substance occurring in the fennel fruits from the Bologna site (8.2 mg/100 g of DW), together with traces of the other two flavonoids and rosmarinic acid. Eriocitrin was the main flavonoid in all of the fruit samples of fennel (values ranging from 17.9 to 213.5 mg/100 g of DW), with the exception of that of Ascoli Piceno, in which the main flavonoid was found to be miquelianin (49.7 mg/100 g of DW). It is curious that this flavonoid was found to be the lowest in the rest of the samples of fennel fruits, with the exception of Messina site, where the lowest flavonoid was found to be rutin. 1,5-*O*-Dicaffeoylquinic acid was the main dicaffeoylquinic acid occurring in the different samples of fennel fruits (the only one in Ascoli Piceno and Argos sites), although it was absent from those of Bologna and Chia sites, in which these compounds were not able to be quantified. Only samples from Gennargentu and Giara were found to contain 1,4-*O*-dicaffeoylquinic acid and also some traces of 1,3-*O*-dicaffeoylquinic acid. Percentages of rosmarinic acid with regard to total phenolic compounds in the different samples of fennel fruits varied from 2.3% (Gennargentu) to 8.4% (Argos, Greece).

Edible Fennel. *Antioxidant Activity.* The radical scavenging activity of the different samples of edible fennel was very low. Thus, no SO scavenging activity was observed in any of the samples (**Table 4**). Both the DPPH and OH tests also exhibited very low values of radical scavenging activity in all of the samples. Only the Italian sample of Carmo showed a moderate OH scavenging activity.

Phenolic Composition. The edible fennel was found to contain low amounts of phenolic substances, being higher in the Italian samples and lower in the Spanish ones (**Table 4**). The values varied from 22.2 GAE/mg of extract in the Italian sample of Carmo to 12.3 GAE/mg of extract in the Spanish Orion cultivar. Only the Amigo cultivar exhibited a total phenolic content quite similar to that of the Italian edible samples. Also, the total flavonoid content was lower in the Spanish samples of edible fennel. As an average of all the analyzed samples of edible fennel, the total content of flavonoids was about half of the total amount of phenolics, with the exception of the Italian sample Tusco 2, in which flavonoids represented 82% of the total phenolic substances, a value similar to that observed in the wild fennel samples.

After analysis by HPLC, the scarce content of quinic acid derivatives in the different varieties of Italian edible fennel is noteworthy. These samples were found to contain no caffeoylquinic acids and to contain only 1,3-*O*-dicaffeoylquininc acid, with values ranging from 2.6 to 5.9 mg/100 g of DW, representing percentages from 19.9 to 35.8% of the total phenolic compounds (**Table 5**). Flavonoids (mainly rutin and also eriocitrin in the Carmo variety) were the major phenolic substances occurring in the Italian edible fennel, with percentages ranging from 64.1 to 74.1% of the total phenolics.

The occurrence of phenolic substances in the Spanish varieties of edible fennel was more diverse than in the Italian ones. Thus, two caffeoylquinic acid derivatives (chlorogenic and cryptochlorogenic acids) were found in the five varieties, with total values ranging from 8.8 (Amigo) to 54.8 (Bravo) mg/100 g of DW, which represent percentages referred to total phenolics varying from 7.3 to 39.4%, respectively (**Table 5**). Only the flavonoids eriocitrin and rutin occurred in edible fennel materials, although the latter flavonoid was present only in trace amounts in both Bravo and Orion varieties. Whereas the contents of rutin were quite similar in both Italian and Spanish varieties of edible fennel, those of eriocitrin were remarkably higher in the Spanish samples, with values ranging from 38.9 (Brando) to 48.4 (Amigo) mg/100 g of DW. The percentages of total flavonoids with regard to total phenolics, however, were higher in the Italian samples due to the absence of other phenolic substances, namely, caffeoyl and dicaffeoylquinic acid derivatives.

The five Spanish samples of edible fennel contained amounts of dicaffeoylquinic acids higher than the Italian ones, the contents of 1,3-*O*-dicaffeoylquinic acid (values from 24.5 to 39.8 mg/100 g of DW in Orion and Amigo varieties, respectively) being higher than those of 1,4-*O*-dicaffeoylquinic acid (values from 6.4 to 16.6 mg/100 g of DW in Latina and Bravo varieties, respectively). 1,5-*O*-Dicaffeoylquinic acid and rosmarinic acid were found neither in Italian nor in Spanish samples of edible fennel, with the exception of the Italian variety Tusco 1, which contained 1.5 mg/100 g of DW of rosmarinic acid.

Medicinal Fennel. *Antioxidant Activity.* The antioxidant activity of the medicinal fennel was found to be higher than that of edible fennel but lower than that of wild fennel. The highest DPPH scavenging activity was found in the Italian Toschi sample (**Table 6**), although it was not so active as most of the Italian wild fennels (aerial parts). The highest OH scavenging activity was exhibited by the Turkish medicinal fennel (IC_{50} = 29.8) and by the Egyptian herb supplied by Herboristeria Amorós (IC_{50} = 32.2). The activity of these two samples was quite similar to that of the best samples of wild fennel (Bologna, Calatayud, and Ejea de los Caballeros). Curiously, the Egyptian medicinal fennel, as well as the Aboca commercial product, were found to exhibit the lowest SO scavenging activity. This antiradical activity was in general very low in all of the samples of medicinal fennel, those of Toschi (Italy) and Herboristeria Amorós (Spain) showing the highest percentages of SO scavenging activity.

Phenolic Composition. The total phenolic content of the different samples of medicinal fennel ranged from 38.1 GAE/mg of extract (material from Italian origin supplied by Cannamela) to 57.2 GAE/mg of extract (material from Spanish origin supplied by Herb. Amorós). The medicinal fennel from Egypt and Turkey was found to contain intermediate values of total phenolics (**Table 6**). The lowest total flavonoid content was observed in the Aboca commercial product, these compounds being around 71% of the total phenolics. In the rest of medicinal fennel samples, the TFlC values ranged from around 40 to 48 QE/mg of extract and represented >84% of the total phenolic substances.

Caffeoylquinic acids were quite abundant in the Italian medicinal fennel supplied by Cannamela (46.3 and 51.7 mg/100 g of DW of cryptochlorogenic and chlorogenic acids, respectively), although none of the analyzed samples were found to contain neochlorogenic acid (3-*O*-caffeoylquinic acid) (**Table 7**). Dicaffeoylquinic acids varied considerably in the different samples of medicinal fennel according to their origin. Thus, apart from traces found in some of the samples, 1,3-*O*-dicaffeoylquinic acid and 1,5-*O*-dicaffeoylquinic acid were found only in the Spanish (14 mg/100 g of DW) and Egyptian (8.9 mg/100 g of DW) samples, respectively, both supplied by Herb. Amorós. Values of 1,4-*O*-dicaffeoylquinic acid ranged from 5.2 (Toschi) to 45.3 (Cannamela) mg/100 g of DW. The proportion of dicaffeoylquinic acids with respect to the total phenolics is around 12% as an average among the different samples, with the exception of the Toschi material, which contained a low amount of these compounds.

Flavonoids were the most abundant compounds occurring in the different samples of medicinal fennel, with total amounts ranging from 19.8 (Turkish material supplied by Erboveneta) to 234.7 (Spanish material supplied by Herboristeria Amorós) mg/100 g of DW. In all of the samples containing quercetin-3-*O*-glucuronide, this flavonoid was the most abundant one. In other cases (absence of miquelianin), the most abundant flavonoid was eriocitrin. The percentages of flavonoids with regard to the total phenolics were quite high, ranging from 58.2% (Italian material supplied by Cannamela) to 100% (Turkish material supplied by Erboveneta). The levels of rosmarinic acid in the different materials of medicinal fennel were quite low; the only material containing a moderate amount of rosmarinic acid was the commercial product of Aboca, which was found to contain 13.3% of rosmarinic acid in relation to its total amount of phenolic substances.

Owing to the high value of fennel for the essential oil industry, much effort has been made to chemically characterize different plant materials and/or essential oils of fennel from different origins (*25*). Thus, estragole was found to be the major component in some natural populations in Spain (*26, 27*), Portugal (*28*), and a number of indigenous populations in Italy (*29*) and Israel (*30, 31*). Some Italian types of wild fennel, however, were not found to contain estragole and revealed that the latitude of the origin localities seems to influence the oil compositions (*32*). On the other hand, cultivated varieties of fennel contained a very low concentration of estragole and high levels of *trans*-anethole (*33*). Different chemotypes of already domesticated cultivars of *F. vulgare*, from different origins, were defined when grown together under the same conditions in Hungary (*33*), Germany (*34*), and Egypt (*35*). Some differences were also found in the phenolic composition of fennel material collected in different parts of Europe (*36*). Thus, whereas 3-glucuronides of both kaempferol and quercetin were found in all of the samples, only two-thirds had both quercetin and kaempferol 3-arabinosides.

As observed for these chemical differences in samples of fennel from different geographical origins, in this work some differences in the antioxidant activity of wild, edible, and medicinal fennel from different Mediterranean countries have also been found. The comparison of the total phenolic and flavonoid contents, as well as the antiradical activity of the three types of fennel, highlighted that wild fennel samples possessed higher values than those detected in medicinal or edible fennels. Higher phenolic contents of wild fennel (whole plants) than those found in fruits of medicinal fennel had been already observed in Spanish fennel plants (*16*). The lowest TPhC and TFlC values found in the edible fennel correlated well with the lowest radical scavenging activity exhibited by this plant material. In summary, both the phenolic content and the antioxidant activity of edible fennel were found to be lower than those of wild and medicinal fennels, independent of the geographical origin.

The identification of several caffeoylquinic and dicaffeoylquinic acid derivatives as well as flavonoids and rosmarinic acid in both wild and medicinal fennel reveals the connection between their radical scavenging activity and chemical composition. In addition, these results may contribute to the interpretation of the pharmacological effects of this medicinal and aromatic plant and support the possibility that fennel has protective effects on human health.

ABBREVIATIONS USED

CL, chemiluminescence; $DPPH^{\bullet}$, 2,2-diphenyl-1-picrylhydrazyl; GAE, gallic acid equivalents; IC_{50}, inhibitory concentration 50; QE, quercetin equivalents; RLU, relative light unit; TFlC, total flavonoid content; TPhC, total phenolic content.

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