The nutritional composition of fennel (*Foeniculum vulgare*): shoots, leaves, stems and inflorescences

LILLIAN BARROS, ANA MARIA CARVALHO, ISABEL C.F.R. FERREIRA*

Centro de Investigação de Montanha (CIMO), ESA, Instituto Politécnico de Bragança, *Campus* de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal.

* Author to whom correspondence should be addressed (e-mail: iferreira@ipb.pt telephone +351-273-303219; fax +351-273-325405).

ABSTRACT

The chemical composition and the nutritional value of different parts of *Foeniculum vulgare* (fennel): shoots, leaves, stems and inflorescences, were determined. The evaluation of chemical composition included the determination of moisture, total fat, crude protein, ash, carbohydrates, and nutritional value. The composition in individual sugars was determined, being fructose and glucose the most abundant sugars. The analysis of fatty acid composition, allowed the quantification of twenty one fatty acids. Polyunsaturated fatty acids were the main group in all the fennel parts; linoleic acid predominated in shoots, stems and inflorescences, while α-linolenic acid predominated in leaves. The higher levels of ω-3 fatty acids found in leaves contributed to its lowest ratio of ω-6 to ω-3 fatty acids. Also, the lower levels of ω-3 fatty acids found in inflorescences contributed to its highest ratio of ω-6 to ω-3 fatty acids.

KEYWORDS: Fennel, Macronutrients, Sugars, ω3 and ω6 Fatty acids

1. Introduction

Fennel (*Foeniculum vulgare* Mill.) is a hardy, perennial, umbelliferous (Apiaceae) herb generally considered native to the Mediterranean areas that has become widely naturalised elsewhere; actually it may be found growing feral in many parts of the world. Fennel is highly aromatic with a characteristic aniseed flavour. Ethnobotanical data currently available on wild useful plants in Portugal highlight the importance of fennel' culinary and medicinal uses (Camejo-Rodrigues et al., 2003; Novais et al., 2004; Carvalho, 2005; Santayana et al., 2007; Veigas, 2007). Roots, young shoots, leaves, flowering stems, mature inflorescences and fully ripened and dried seeds are commonly used for homemade remedies, being useful in the treatment of several complaints, specifically those of the digestive system. Fennel is also highly recommended for diabetes, bronchitis and chronic coughs, for the treatment of kidney stones, and is considered to have diuretic, stomachic and galactogogue properties (Camejo-Rodrigues et al., 2003; Novais et al., 2004; Carvalho, 2005; Salgueiro, 2004).

Different fennel parts are widely used in many of the culinary traditions of the world and particularly in Portugal (**Table 1**). Shoots, tender leaves and stems are chewed and sucked due to its exquisite aniseed flavour. All these parts are also commonly used as vegetables. They are added raw to salads, stewed with beans and chickpeas, used to stuff fish for grilling, put in soups and in traditional fish and bread bouillons. Besides seasoning, fennel is used to preserve food: stems are sometimes one of the ingredients of the brines prepared for olives' cure; leafy stems are boiled in the water where figs are soaked before being dried. Flowering stems, sugar and honey macerating in brandy produce a highly valorised spirit. Herbal teas prepared with fresh tender or dried flowering stems are drunk chilled or

hot, depending on the season (Carvalho, 2005; Santayana et al, 2007; Tardío et al., 2005; Tardío et al. 2006; Veigas, 2007). The culinary use and therapeutic effects of fennel were so large that it has been exported from country to country for centuries (Oktay, Gülçin, & Küfrevioğlu, 2003).

Fennel culinary value might be related to its organoleptic properties such as aroma and flavour, and also to its richness in carbohydrates, including sugars (Cataldi, Margiotta, & Zambonin, 1998), minerals (Özcan & Akbulut, 2007; Özcan, Ünver, Uçar, & Arslan, 2008) and essential fatty acids (Vardavas, Majchrzak, Wagner, Elmadfa, & Kafatos, 2006). Carbohydrates are important as short-term energy-storage compounds and also as major structural compounds in plant cell walls. Sugars such as glucose and fructose occupy key roles in energy metabolism and supply carbon skeletons for the synthesis of other compounds (Zubay, 2006). Polyunsaturated fatty acids from omega-6 and omega-3 families have strong biological properties in low concentrations (Gibney, Vorster, & Kok, 2002) and are biosynthetic precursors of eicosanoids (i.e. prostaglandins), which are signalling molecules with complex control over many body systems, having effects on cardiovascular diseases, triglycerides levels, blood pressure and arthritis (Zubay, 2006). A deficient intake of essential fatty acids can be responsible for many problems such as dermatitis, immunosuppression and cardiac dysfunctions (Kaplan, 1996). In the present study it is reported the valuable nutritional composition of different parts of *Foeniculum vulgare* (fennel) – shoots, leaves, stems and inflorescences –, particularly in sugars, monounsaturated, polyunsaturated and saturated fatty acids, total ω-3 and ω-6 fatty acids and ω-6 to ω-3 ratio. On the basis of the contents of moisture, proteins, fat, carbohydrates and ash, an estimation of their nutritional role was performed.

MATERIALS AND METHODS

Samples. Samples of shoots, leaves, stems and inflorescences were gathered in Bragança, Trás-os-Montes, north-eastern Portugal. The selected sites and gathering practices took into account local consumers gathering criteria for the use of fennel and the optimal growth stage. The plant material was collected in half shade sites at the edges of woods, in early spring (shoots), in June (leaves) and during and after the flowering period in July (stems and inflorescences). Shoots are the young stems that sprouted from the persistent and woody base in spring; leaves, fully expanded, were collected in the median nodes of the annual flowering stems; stems correspond to the herbaceous portion of the annual main stems; inflorescences are the fully developed compound umbels, with fertile flowers and immature seeds.

Morphological key characters from the Iberian Flora (Castroviejo, 2003) were used for plant identification. Voucher specimens were deposited in the Herbarium of the Escola Superior Agrária de Bragança, Portugal. The material was lyophilized (Ly-8-FM-ULE, Snijders, HOLLAND) and kept in the best conditions (-20ºC, ~30 days) for subsequent use.

Standards and reagents

Acetonitrile 99.9% pure of HPLC grade was purchased from Lab-Scan (Lisbon, Portugal). Methanol, diethyl ether, toluene and sulphuric acid were of analytical grade purity: The fatty acids methyl ester (FAME) reference standard mixture 37 (fatty acids C4 to C24; standard 47885-U) was from Supelco (Bellefonte, PA, USA) and purchased from Sigma (St. Louis, MO, USA), as well as other individual fatty acid isomers and the sugar standards. All the other chemicals were obtained from Sigma Chemical Co. (St. Louis, MO,

98 USA). Water was treated in a Mili-Q water purification system (TGI Pure Water Systems,
99 USA).
100
101 **Determination of macronutrients**
102 The samples were analysed for chemical composition (proteins, fat, carbohydrates and ash)
103 using the AOAC procedures (1995). The crude protein content (N × 6.25) of the samples
104 was estimated by the macro-Kjeldahl method; the crude fat was determined by extracting a
105 known weight powdered sample with petroleum ether, using a Soxhlet apparatus; the ash
106 content was determined by incineration at (600±15) ºC; reducing sugars were determined
107 by DNS (dinitrosalicylic acid) method. Total carbohydrates were calculated by difference:
108 Total carbohydrates = 100 – (moisture + proteins + fat + ash), where moisture, proteins, fat
109 and ash, stand for their masses respectively, expressed in units of 1 g. Total energy was
110 calculated according to the following equation: Energy (Kcal) = 4 × (proteins +
111 carbohydrates) + 9 × (fat), where proteins and carbohydrates stand for their masses,
112 respectively, expressed in units of 1 g.
113
114 **Determination of sugars by HPLC/RI**
115 *Preparation of standard solutions.* Individual solutions (~10 mg/ml) of L-arabinose, D-
116 fructose, L-fucose, D-galactose, D-glucose anhydrous, lactose 1-hydrate, maltose 1-
117 hydrate, maltulose monohydrate, D-mannitol, D-mannose, D-melezitose, D-melibiose
118 monohydrate, D-raffinose pentahydrate, L-rhamnose monohydrate, D-sucrose, D-trehalose,
119 D-turanose and D-xylose were prepared in water and stored at –20 ºC. A stock standard
120 mixture with fructose, glucose and sucrose was prepared in water with the final

concentration of 30 mg/ml. Melezitose was used as internal standard (IS), being prepared a stock solution (25 mg/ml in water) and kept at –20 ºC.

Extraction procedure. Dried sample powder (1.0 g) was spiked with the IS (5 mg/ml), and was extracted with 40 ml of 80% aqueous ethanol at 80 ºC for 30 min. The resulting suspension was centrifuged at 15,000 *g* for 10 min. The supernatant was concentrated at 60 ºC under reduced pressure and defatted three times with 10 ml of ethyl ether, successively. After concentration at 40 ºC, the solid residues were dissolved in water to a final volume of 5 ml, filtered through a 0.22 μm disposable LC filter disk, transferred into an injection vial and analysed by HPLC.

HPLC analysis. The HPLC equipment consisted of an integrated system with a Smartline pump 1000, a Smartline manager 5000 degasser system, a Smartline 2300 RI detector (Knauer, Germany), and an AS-2057 auto-sampler (Jasco, Japan). Data were analysed using Clarity 2.4 Software (DataApex). The chromatographic separation was achieved with an Eurospher 100-5 NH_2 column (4.6 mm × 250 mm, 5 mm, Knauer) operating at 35 ºC (7971R Grace oven). The mobile phase used was acetonitrile/deionized water, 7:3 (v/v) at a flow rate of 1 ml/min, and the injection volume was 20 μl. The compounds were identified by chromatographic comparisons with authentic standards. The results are expressed in g/100 g of fresh weight, and calculated by internal standard normalization of the chromatographic peak area.

Determination of fatty acids by GC/FID

144 Fatty acids were determined by gas chromatography with flame ionization detection
145 (GC/FID)/capillary column as described previously by the authors (Barros, Venturini,
146 Baptista, Estevinho, & Ferreira, 2008), and after the following trans-esterification
147 procedure: fatty acids were methylated with 5 ml of methanol:sulphuric acid:toluene 2:1:1
148 (v:v), during at least 12 h in a bath at 50 ºC with agitation (160 rpm); then 3 ml of
149 deionized water were added, to obtain phase separation; the FAME were recovered with 3
150 ml of diethyl ether by mixing in vortex , and the upper phase was passed through a micro-
151 column of anhydrous sodium sulphate, in order to eliminate the water; the sample was
152 recovered in a vial with a Teflon cap, and before injection the sample was filtered with 0.2
153 µm nylon filter from Millipore (MA, USA). The fatty acid profile was analyzed with a
154 DANI model GC 1000 instrument equipped with a split/splitless injector, a flame ionization
155 detector (FID) and a Macherey-Nagel (PA, USA) column (OPTIMA 225: 50%
156 cyanopropyl-methyl – 50% phenylmethylpolysiloxane) with 30 m × 0.32 mm ID × 0.25 µm
157 d_f. The oven temperature program was as follows: the initial temperature of the column was
158 50 ºC, held for 2 min, then a 10 ºC/min ramp to 240 ºC and held for 11 min. The carrier gas
159 (hydrogen) flow-rate was 4.0 ml/min (0.61 bar), measured at 50 ºC. Split injection (1:40)
160 was carried out at 250 ºC, and for each analysis 1 µl of the sample was injected. Fatty acid
161 identification was made by comparing the relative retention times from samples with
162 FAME peaks (standards). The results were recorded and processed using CSW 1.7 software
163 (DataApex 1.7) and expressed in relative percentage of each fatty acid.
164
165 **Statistical analysis**

166 For each part of the plant three samples were analysed and all the assays were carried out in
167 triplicate. The results are expressed as mean values and standard deviation (SD). The
168 results were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's
169 HSD Test with $\alpha = 0.05$. This treatment was carried out using SPSS v. 16.0 software.
170
171 **RESULTS AND DISCUSSION**
172 The macronutrients profiles and the energy contents (expressed on fresh weight basis) of
173 the different parts of fennel (shoots, leaves, stems and inflorescences) are shown in **Table**
174 **2**. Leaves and stems revealed the highest moisture content (76.36 and 77.46 g/100 g,
175 respectively), while inflorescences showed the lowest content (71.31 g/100 g).
176 Carbohydrates were the most abundant macronutrients in all the parts and ranged from
177 18.44 g/100 g in leaves to 22.82 g/100 g in inflorescences. Reducing sugars are only a
178 small part of carbohydrates due to the abundant presence of polysaccharides such as starch
179 (major polysaccharide used for energy storage in plant cells) and cellulose (structural
180 polysaccharide found as the major component of cell walls in plants) (Zubay, 2006).
181 Proteins and fat were the less abundant macronutrients; proteins varied between 1.08 g/100
182 g in stems and 1.37 g/100 g in inflorescences. Once more, inflorescences revealed the
183 highest fat content (1.28 g/100 g) among all the fennel parts. On the basis of the proximate
184 analysis, it can be calculated that a fresh portion of 100 g of these parts yields, on average,
185 94 Kcal. The highest values were obtained for inflorescences, while leaves and stems gave
186 the lowest energetic contribution (**Table 2**).
187 The highest ash content was found in leaves (3.43 g/100 g), while the lowest value was
188 found in stems (1.62 g/100 g). This is in agreement with other authors who reported higher
189 levels of minerals in fennel leaves than in fruits (Özcan & Akbulut, 2007). Several minerals

190 could be included in ash content and particularly, Ag, Al, As, B, Ba, Ca, Cd, Co, Cr, Cu,
191 Fe, In, K, Li, Mg, Mn, Na, Ni, P, Pb, Se, Sr, Tl, V and Zn were already described in fennel
192 (Özcan et al., 2008). The most abundant minerals found in this plant were K, Ca, Mg, P and
193 Na.
194
195 In what concerns sugars composition (**Table 3**), fructose, glucose and sucrose were
196 detected in all the fennel parts, with the exception of sucrose in stems. These sugars are
197 naturally occurring and widely distributed in plants. Glucose was the most abundant sugar
198 in all the parts, despite the reports of sucrose as the most important sugar in plants. In this
199 study, some percentage of sucrose could have suffered hydrolyze to their monosaccharide's
200 constituents, contributing to an increase in glucose and fructose levels (**Table 3**). This is in
201 agreement with the results described by Cataldi et al. (1998) reporting D-glucose and D-
202 fructose as mains sugars in fennel. These authors used a different methodology for the
203 analysis: high performance anion-exchange chromatography (HPAEC) coupled with
204 integrated pulsed amperometry using gold working electrodes. In the present study, the
205 separation of all the sugars by HPLC/RI was achieved in only 15 min, faster than the 25-35
206 min described by other authors (Cataldi et al., 1998).
207 Shoots revealed the highest concentration of sugars (6.57 g/100 g) due to the contribution
208 of fructose, glucose and sucrose. Otherwise, leaves revealed the lowest content (1.29 g/100
209 g). This decrease in sugars content could be explained by the fact that the collected leaves
210 were in a mature growth stage, consuming sugars for the photosynthetic process.
211 Total sugars (**Table 3**) were higher than reducing sugars (**Table 2**) due to the contribution
212 of non reducing sugars such as sucrose.
213

214 The results of fatty acid composition, total saturated fatty acids (SFA), monounsaturated
215 fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) of the different parts of fennel
216 are shown in **Table 4**. The most abundant fatty acid in shoots, stems and inflorescences was
217 linoleic acid (C18:2), followed by α-linolenic (C18:3) and palmitic (C16:0) acids.
218 Otherwise, α-linolenic acid predominated in leaves (43.55%). Vardavas et al. (2006) also
219 reported the prevalence of α-linolenic acid followed by oleic and palmitic acids in a Greece
220 fennel sample. Besides the three main mentioned fatty acids, eighteen more were identified
221 and quantified. PUFA were the main group of fatty acids in all the fennel parts (**Table 4**).
222 Other authors reported MUFA as the main group of fatty acids in fennel (Vardavas et al.,
223 2006). Nevertheless, UFA ranged from 66% to 80%, and predominated over SFA.
224 Linoleic acid is an essential fatty acid and originates the omega-6 fatty acids series. The
225 dietary ω-6 fatty acids are associated with a lower prevalence of hypertension and lower
226 systolic blood pressure (Djousse et al., 2005). Studies reveal that dietary ω-6 fatty acids
227 play a role in nerve conduction velocity due to their incorporation in membrane
228 phospholipids (Coste et al., 1999) and posses antitumor properties against prostate (Bidoli
229 et al., 2005), breast (Menendez, Ropero, Lupu, & Colomer, 2004) and pancreas cancers
230 (Agombar, Cooper, & Johnson, 2004), among others.
231 α-Linolenic is an essential fatty acid and it is precursor of the omega-3 fatty acids series in
232 humans. Essential ω-3 fatty acids revealed antitumor properties against various types of
233 cancers including breast (Klein et al., 2000), prostate (Terry, Terry, & Rohan, 2004) and
234 colorectal cancers (Reddy 2004). Furthermore, dietary ω-3 fatty acids possibly play a vital
235 role in inflammatory diseases, hypertension and coronary heart disease (Dokholyan et al.,
236 2004; Wijendran & Hayes, 2004).

237 The highest concentration of n-3 fatty acids was found in fennel leaves, while the lowest
238 concentration was found in inflorescences (**Table 5**). The ratio of ω-6 to ω-3 fatty acids has
239 an important role in the human diet, and is also presented in **Table 5**. The highest levels of
240 n-3 fatty acids found in leaves contributed to its lowest ratio of ω-6 to ω-3 fatty acids. The
241 lowest levels of n-3 fatty acids found in inflorescences contributed to its highest ratio of ω-
242 6 to ω-3 fatty acids. Leaves were the only part presenting a ratio lower than 1 (0.53), and
243 even lower than the ratio reported by Vardavas et al. (2006) in a Greece sample of fennel
244 (0.89). Those authors stated that low ratios could reduce the potential for lung cancer,
245 asthma and may prevent thrombosis and atherosclerosis; while a high serum n-6:n-3 ratio is
246 associated with major depression and may increase the risk of coronary heart disease
247 (Vardavas et al., 2006).
248
249 The studied plant plays an important role in the traditional diet of the Portuguese rural
250 areas, mainly in Trás-os-Montes and Alentejo since fennel is daily consumed, raw in salads
251 and snacks, or stewed, boiled, grilled or baked in several dishes and drunk as herbal teas or
252 spirits. A diet rich in this perennial umbelliferous herb could bring potential health benefits
253 due to their valuable nutritional composition in essential fatty acids. The sugars identified
254 in the samples, such as glucose and fructose, occupy key roles in the energetic metabolism
255 and supply carbon skeletons for the synthesis of other compounds. As far as we know,
256 nothing has been reported on macronutrients composition of all the fennel parts: shoots,
257 leaves, stems and inflorescences.
258
259 **ACKNOWLEDGEMENTS**

The authors are grateful to the Foundation for Science and Technology (Portugal) for financial support to the research centre CIMO and L. Barros grant (SFRH/BPD/4609/2008).

LITERATURE CITED

Agombar, A., Cooper, A. J., & Johnson, C. D. (2004). An aqueous formulation of gamma-linolenic acid with anti-proliferative action on human pancreatic cancer cell lines. *Anticancer Drugs*, *15*, 157–160.

AOAC. (1995). Official methods of analysis (16th Ed.). Arlington VA, USA: Association of Official Analytical Chemists.

Barros, L., Venturini, B., Baptista, P., Estevinho, L., & Ferreira, I.C.F.R. (2008). Chemical composition and biological properties of Portuguese wild mushrooms: a comprehensive study. *Journal of Agricultural and Food Chemistry*, *56*, 3856-3862.

Bidoli, E., Talamini, R., Bosetti, E., Negri, E., Maruzzi, D., Montella, M., et al. (2005). Macronutrients, fatty acids, cholesterol and prostate cancer risk. *Annals of Oncology*, *16*, 152–157.

Camejo-Rodrigues, J. S., Ascensão, L. BoneT, M. À. & Vallès, J. (2003). An ethnobotanical study of medicinal and aromatic plants in the Natural Park of Serra de S. Mamede (Portugal). *Jornal of Ethnopharmacology*, *89*, 199-209.

Carvalho, A.M. (2005). *Etnobotánica del Parque Natural de Montesinho. Plantas, tradición y saber popular en un territorio del nordeste de Portugal*. Madrid: Universidad Autónoma.

Castroviejo S. (coord.). 2003. *Flora Iberica*. Madrid: Real Jardín Botánico, CSIC).

283 Cataldi, T.R.I., Margiotta, G., & Zambonin, C.G. (1998). Determination of sugars and
284 alditols in food samples by HPAEC with integrated pulsed amperometric detection
285 using alkaline eluents containing barium or strontium ions. *Food Chemistry, 62*, 109-l
286 15.
287 Coste, T., Pierlovisi, M., Leonardi, J., Dufayet, D., Gerbi, A., Lafont, H., et al. (1999).
288 Beneficial effects of gamma linolenic acid supplementation on the nerve conduction
289 velocity, Na^+, K^+ ATPase activity, and membrane fatty acid composition in sciatic
290 nerve of diabetic rats. *Journal of Nutritional Bio-Chemistry*, *10*, 411–420.
291 Djousse, L., Arnett, D. K., Pankow, J. S., Hopkins, P. N., Province, M. A., & Ellison, R. C.
292 (2005). Dietary linolenic acid is associated with a lower prevalence of hypertension in
293 the NHLBI family heart study, *Hypertension*, *45*, 368-373.
294 Dokholyan, R. S., Albert, C. M., Appel, L. J., Cook, N. R., Whelton, P., & Hennekens, C. H.
295 (2004). A trial of omega-3 fatty acids for prevention of hypertension. *American*
296 *Journal of Cardiology*, *93*, 1041-1043.
297 Gibney, M.J., Vorster, H.H., & Kok, F.J. (2002). Introduction to human nutrition, Blackwell
298 Science, Oxford.
299 Kaplan (1996). Clinical Chemistry- Theory, Analysis, Correlation, Mosby Ed., Missouri,
300 3rd Ed.
301 Klein, V., Chajes, V., Germain, E., Schulgen, G., Pinauk, M., Malvy, D., et al. (2000). Low
302 alpha-linolenic acid content of adipose breast tissue is associated with an increased
303 risk of breast cancer. *European Journal of Cancer*, *36*, 335–340.
304 Menendez, J.A., Ropero, S., Lupu, R., & Colomer, R. (2004). Omega-6 polyunsaturated
305 fatty acids gamalinoleic acid (18:3 n-6) enhances docetaxel (Taxotere) cytotoxicity in

306 human breast carcinoma cells: relationship to lipid peroxidation and HER-2/neu
307 expression. *Oncology Reports*, *11*, 1241-1252.
308 Novais, H.M., Santos, I, Mendes, S., & Pinto-Gomes, C. (2004). Studies on pharmaceutical
309 ethnobotany in Arrábida Natural Park. *Journal of Ethnopharmacology*, *93*, 183–195.
310 Oktay, M., Gülçin, I., & Küfrevioğlu, Ö.I. (2003). Determination of in vitro antioxidant
311 activity of fennel (*Foeniculum vulgare*) seed extracts. *Lebensm.-Wiss. U.-Technology*,
312 *36*, 263-271.
313 Özcan, M.M., & Akbulut, M. (2007). Estimation of minerals, nitrate and nitrite contents of
314 medicinal and aromatic plants used as spices, condiments and herbal tea. *Food*
315 *Chemistry*, *106*, 852–858.
316 Özcan, M.M., Ünver, A., Uçar, T., & Arslan, D. (2008). Mineral content of some herbs and
317 herbal teas by infusion and decoction. *Food Chemistry*, *106*, 1120–1127.
318 Reddy, B. S. (2004). Omega-3 fatty acids in colorectal cancer prevention. *International*
319 *Journal of Cancer*, *112*, 1–7.
320 Salgueiro, J. (2004). *Ervas, usos e saberes. Lisboa*: MARCA, Associação de
321 Desenvolvimento Local.
322 Santayana, M.P., Tardio, J., Blanco, Emilio, Carvalho, A. M., Lastra, J. J., San Miguel. E.,
323 & Morales, R. (2007). Traditional knowledge of wild edible plants used in the
324 northwest of the Iberian Peninsula (Spain and Portugal): a comparative study. *Journal*
325 *of Ethnobiology and Ethnomedicine*, *3*, 27-37.
326 Tardío, J., Pardo de Santayana, M., & Morales, R. (2006). Ethnobotanical review of wild
327 edible plants in Spain. *Botanical Journal of the Linnean Society*, 152, 27–71.
328 Tardío, J., Pascual H., M., & Morales, R. (2005). Wild food plants traditionally used in the
329 province of Madrid, Central Spain. *Economic Botany* 59(2), 122–136.

330 Terry, P. D., Terry, J. B., & Rohan, T. E. (2004). Long-chain (n-3) fatty acid intake and risk
331 of cancers of the breast and prostate: recent epidemiological studies, biological
332 mechanisms, and directions for future research. *Journal of Nutrition*, *134*, 3412S–
333 3420S.
334 Vardavas, C.I., Majchrzak, D., Wagner, K.H., Elmadfa, I., & Kafatos, A. (2006). Lipid
335 concentrations of wild edible greens in Crete. *Food Chemistry*, *99*, 822–834.
336 Veigas, M. (2007). *Aromas e sabores de Cuba*. Évora: Câmara Municipal de Cuba.
337 Wijendran, V., & Hayes, K. C. (2004). Dietary n-6 and n-3 fatty acid balance and
338 cardiovascular health. *Annual Review of Nutrition*, *24*, 597–615.
339 Zubay, G. (2006). Biochemistry, 5th edition, Wm. C. Brown Publishers.
340

341 **Table 1**. Uses of fennel as food as reported in Portuguese ethnobotanical studies.

Portuguese Region	Local name	Plant part and edible uses
Trás-os-Montes (northeast)	Fiolho, fionho, erva-doce	Shoots, tender leaves and stems – snacks, salads, soups, stews, spices Flowering stems – beverages, spirits, spices Stems – brochettes, herbal teas Seeds – spices, flavour for cakes, biscuits, sweets and chestnuts
Arrábida and Açor (center)	Funcho, erva-doce	Seeds – flavour for cakes and pastries and for cooking chestnuts
Alentejo and Algarve (south)	Funcho, fiolho, funcho-doce, funcho-amargo	Shoots, tender leaves and stems – fried with eggs, omelettes, fish stuff, stewed with different kinds of beans and chickpeas, fish and bread bouillons, soups, sauces Tender leafy stems – grilled fish and fish dishes in general Seeds – spices, flavour for cakes, bread and biscuits, chestnuts Whole plant – olives brines, figs preserves and for aromatizing brandy

342

343 **Table 2.** Macronutrients composition (g/100 g) and energetic value (Kcal/100 g) of the
344 different parts of fennel in a fresh weight basis (mean ± SD; n=3). In each row, different
345 letters mean significant differences ($p<0.05$).
346

	Shoots	Leaves	Stems	Inflorescences
Moisture	73.88 ± 0.83 ba	76.36 ± 0.33 a	77.46 ± 1.03 a	71.31 ± 4.01 b
Ash	2.39 ± 0.02 c	3.43 ± 0.04 a	1.62 ± 0.12 d	3.23 ± 0.02 b
Fat	0.49 ± 0.05 b	0.61 ± 0.16 b	0.45 ± 0.07 b	1.28 ± 0.28 a
Proteins	1.33 ± 0.04 a	1.16 ± 0.03 b	1.08 ± 0.00 b	1.37 ± 0.05 a
Carbohydrates	21.91 ± 0.55 ba	18.44 ± 0.06 b	19.39 ± 0.65 ba	22.82 ± 3.06 a
Reducing sugars	1.14 ± 0.10 b	0.72 ± 0.04 c	1.49 ± 0.29 a	1.20 ± 0.19 b
Energy	97.37 ± 2.44 ba	83.90 ± 1.34 b	85.91 ± 3.02 b	108.23 ± 10.37 a

347

Table 3. Sugars composition (g/100 g of fresh weight) of the different parts of fennel (mean ± SD; n=3). In each row, different letters mean significant differences ($p<0.05$).

	Shoots	Leaves	Stems	Inflorescences
Fructose	1.51 ± 0.06 a	0.49 ± 0.05 c	1.49 ± 0.04 a	1.10 ± 0.04 b
Glucose	4.71 ± 0.15 a	0.76 ± 0.12 d	3.43 ± 0.20 b	2.94 ± 0.11 c
Sucrose	0.35 ± 0.06 a	0.04 ± 0.00 b	*nd*	0.03 ± 0.00 b
Total sugars	6.57 ± 0.17 a	1.29 ± 0.20 d	4.92 ± 0.23 b	4.07 ± 0.16 c

nd- not detected.

359 **Table 4.** Percentages of the total detected fatty acids in the different parts of fennel. The
360 results are expressed as mean ± SD (n=3). In each column different letters mean significant
361 differences (p<0.05).
362

	Shoots	Leaves	Stems	Inflorescences
C6:0	0.06 ± 0.00	0.02 ± 0.00	0.19 ± 0.01	0.41 ± 0.02
C8:0	0.33 ± 0.00	0.08 ± 0.00	0.48 ± 0.03	0.37 ± 0.01
C10:0	0.06 ± 0.00	0.04 ± 0.00	0.13 ± 0.01	0.09 ± 0.00
C11:0	0.07 ± 0.00	0.25 ± 0.02	0.04 ± 0.00	0.29 ± 0.01
C12:0	0.21 ± 0.02	0.31 ± 0.02	0.11 ± 0.01	0.43 ± 0.06
C14:0	0.75 ± 0.03	1.43 ± 0.01	0.49 ± 0.06	1.68 ± 0.10
C14:1	0.17 ± 0.03	0.61 ± 0.04	0.37 ± 0.04	0.28 ± 0.02
C15:0	0.18 ± 0.00	0.17 ± 0.00	0.41 ± 0.04	0.35 ± 0.03
C16:0	12.78 ± 0.09	20.15 ± 0.09	25.43 ± 0.00	23.89 ± 0.07
C17:0	0.24 ± 0.02	0.74 ± 0.00	0.61 ± 0.04	0.58 ± 0.02
C18:0	1.53 ± 0.08	1.61 ± 0.08	1.99 ± 0.06	2.62 ± 0.04
C18:1n9c	2.55 ± 0.33	4.35 ± 0.37	4.35 ± 0.52	5.05 ± 0.00
C18:2n6c	39.99 ± 0.68	23.25 ± 0.07	38.22 ± 0.68	38.94 ± 0.23
C18:3n3	36.84 ± 0.52	43.55 ± 0.40	22.86 ± 1.31	17.55 ± 0.00
C20:0	1.06 ± 0.09	0.56 ± 0.00	0.84 ± 0.03	1.78 ± 0.06
C20:1c	*nd*	*nd*	0.06 ± 0.00	0.26 ± 0.03
C20:2c	0.38 ± 0.07	0.08 ± 0.01	0.14 ± 0.00	0.31± 0.01
C20:3n3+C21:0	0.12 ± 0.01	0.16 ± 0.02	0.19 ± 0.00	0.15 ± 0.01
C22:0	1.12 ± 0.02	0.77 ± 0.04	1.20 ± 0.03	1.52 ± 0.04
C23:0	0.36 ± 0.15	0.82 ± 0.13	0.68 ± 0.01	1.89 ± 0.11
C24:0	1.20 ± 0.08	1.03 ± 0.04	1.21 ± 0.02	1.58 ± 0.02
Total SFA	19.95 ± 0.12 d	27.99 ± 0.02 c	33.81 ± 0.06 b	37.47 ± 0.25 a
Total MUFA	2.72 ± 0.36 c	4.96 ± 0.40 ba	4.78 ± 0.57 b	5.59 ± 0.13 a
Total PUFA	77.33 ± 0.24 a	67.05 ± 0.42 b	61.41 ± 0.62 c	56.94 ± 0.12 d

363 *nd*- not detected

Caproic acid (C6:0); Caprylic acid (C8:0); Capric acid (C10:0); Undecanoic acid (C11:0); Lauric acid (C12:0); Myristic acid (C14:0); Myristoleic acid (C14:1); Pentadecanoic acid (C15:0); Palmitic acid (C16:0); Heptadecanoic acid (C17:0); Stearic acid (C18:0); Oleic acid (C18:1n9c); Linoleic acid (C18:2n6c); α-Linolenic acid (C18:3n3); Arachidic acid (C20:0); Eicosanoic acid (C20:1); *cis*-11,14-Eicosadienoic acid (C20:2c); *cis*-11,14,17-Eicosatrienoic acid + Heneicosanoic acid (C20:3n3+C21:0); Behenic acid (C22:0); Tricosanoic acid (C23:0); Lignoceric acid (C24:0).

373 **Table 5.** ω3 and ω6 content (percent) in the different parts of fennel. The results are
374 expressed as mean ± SD (n=3). In each row different letters mean significant differences
375 (p<0.05).
376

	Shoots	Leaves	Stems	Inflorescences
ω3	36.96 ± 0.51 b	43.72 ± 0.36 a	23.04 ± 1.30 c	17.69 ± 0.01 d
ω6	39.99 ± 0.68 a	23.25 ± 0.07 c	38.22 ± 0.68 b	38.94 ± 0.23 b
ω6/ω3	1.08 ± 0.03 c	0.53 ± 0.00 d	1.66 ± 0.12 b	2.20 ± 0.01 a

377

378

379