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A comparison study of the nutritional, mineral and volatile compositions of three dry forms of ginger rhizomes, and antioxidant properties of their ethanolic and aqueous extracts

Aicha Jelled[1,2], Hassiba Chahdoura[2,3], Guido Flamini[4,5], Amira Thouri[2], Amira El Arem[2], Khawla Adouni[2] , Zohra Haouas[1], Isabel C. F. R. Ferreira[3], Lotfi Achour[2], Hassen Ben Cheikh[1*]

[1]*Laboratory of Histology and Cytogenetics (UR12ES10), Faculty of Medicine, University of Monastir, Monastir, Tunisia*

[2]*Laboratory of Bioressources, Integrative Biology and Valorisation (LR14ES06), High Institute of Biotechnology, University of Monastir, Monastir, Tunisia*

[3]*Mountain Research Centre, Higher Agricultural School, Polytechnic Institute of Bragança, Campus of Santa Apolonia, 1172, 5301-855 Bragança, Portugal*

[4]*Department of Pharmacy, Street Bonanno 33, 56126 Pisa, Italy*

[5]*Interdepartmental Research Centre "Nutraceutical and Food for Health", University of Pisa, Pisa, Italy*

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ABSTRACT

Objective: To compare the most accessible dry forms of ginger rhizomes (*Zingiber officinale*) used as a spice and as a remedy in order to choose the best ginger for medicinal purpose.
Methods: Freshly air dried ginger, commercially dry rhizomes and ginger available in powder form are investigated in terms of nutritional values (proximate and mineral compositions) and volatiles profile. Ethanolic and aqueous extracts (decoctions and infusions) were prepared for total phenolic, flavonoid and tannin contents determination. Also, three standard tests were established in order to estimate the best extract with the better antioxidant potential.
Results: The results showed unlike proximate composition revealing different nutritional values. In fact, freshly dried ginger contained much ash, while already dry samples contained much protein. In addition, mineral contents of studied samples indicated their dissimilar richness especially in Ca, Mg, Na, K, Cu, Fe, and Mn. Solid phase micro-extraction gave volatile profiles with many interesting compounds, only 26 from the 51 identified components were common to studied samples with bioactive compounds predominance in freshly dried sample. Also, the antioxidant potential established by three different tests was higher in already dry samples and was positively correlated with their higher contents in the determined phytochemicals. The ethanolic extracts showed higher antioxidant activities than aqueous extracts. Decoctions and infusions were almost similar proving that long cooking time did not affect ginger antioxidant potential.
Conclusions: This work highlighted the benefits of traditional preparations of ginger as sources of bioactive compounds, namely antioxidants, and proved that the available commercial samples are not identical and encouraged analyzing samples before uses depending on needs.

1. Introduction

Human protector, antioxidant systems, seems to be not totally efficient. That is why including non-toxic antioxidants in human diet has become increasingly interesting. Phenolic compounds from plants, due to their high antioxidant potency, are excellent examples[1].

Rhizomes of ginger (*Zingiber officinale* Roscoe) plants have been used as a spice for over 2000 years, and also for its medicinal properties[2,3]. Ginger is famous around the world and even in countries that do not produce it. This spice is used in traditional Chinese medicine to treat many diseases including stomachache, toothache, diarrhea, diabetes, asthma, and arthritis[4,5]. In addition, ginger has been reported to exhibit powerful anti-inflammatory, antilipidemic, antidiabetic, antitumor and antioxidant activities due to its bioactive components[6].

The constituents of ginger can be affected by drying procedures

*Corresponding author: Hassen Ben Cheikh, Laboratory of Histology and Cytogenetics (UR12ES10), Faculty of Medicine, University of Monastir. Monastir, Tunisia.
Tels: 00216 94 859 933 (A Jelled); 00216 73 462 200 (HB Cheikh)
Fax: 00216 73 460 737
E-mails: jelledaicha@gmail.com (A Jelled); hassen.bencheikh@fmm.rnu.tn (HB Cheikh)

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and the geographic origin[7], making accessible forms available in market which are different in terms of smell, taste and bioactivities. To the best of the author's knowledge, there are no studies comparing minerals and volatiles of commercially available ginger samples stored and packaged in different conditions. Furthermore, despite the previously reported antioxidant properties in ginger alcoholic and hydroalcoholic extracts, and essential oil[1,7,8], its most adequate forms for consumption (aqueous extracts prepared by infusions or decoctions), have not been properly evaluated.

Therefore, the present study intends to compare the nutritional and volatile compositions of three different forms of dry ginger, namely freshly home dried ginger, dried rhizome and powdered ginger, and to evaluate the *in vitro* antioxidant properties of ethanolic (obtained by maceration) and aqueous (obtained by infusions and decoctions) extracts of the three forms, correlating the results with total phenolic, flavonoid and tannin contents.

2. Materials and methods

2.1. Standards and reagents

2,2-Diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt (ABTS), gallic acid and Folin-Ciocalteu's reagent were purchased from Sigma-Aldrich Co. (St. Louis, France).

2.2. Samples

Different forms of Chinese ginger rhizomes: fresh ginger (FDG), dried ginger (DG) and powdered dried ginger (PDG) were purchased from the local market. Fresh ginger was washed, cleaned, cuted into small pieces and air-dried under constant weight. FDG and DG samples (obtained after a natural shade drying process) were further reduced to a fine dried powder for subsequent analyses. The characterization of the samples in terms of free sugars, organic acids, fatty acids and tocopherols was previously described by the authors[7].

2.3. Nutritional value

2.3.1. Proximate composition

The samples were analyzed for proteins, fat and ash as previously described[9]. Total carbohydrates were calculated by difference. Energy was calculated according to the following equation:

Energy (kcal) = 4 × [protein (g) + carbohydrates (g)] + 9 × fat (g)

2.3.2. Mineral composition

The minerals determined were Na, Ca, Mg, K, Fe, Zn, Cu, and Mn. A sample of 1 g was incinerated with high pressure in a microwave oven for 5 h at 550 ˚C. The residue of incineration was extracted with HNO_3 (50%, v/v) and made up to an appropriate volume with distilled water, where Fe, Cu, Mn, Zn, Ca, Mg and K were directly measured by inductively coupled plasma-optical emission analytical spectrometry (Perkin Elmer Model Optima 2100 DV). When needed, an additional dilution of 1/10 v/v of the sample extracts and standards was performed to avoid interferences between different elements. Na is assayed by flame spectrophotometry, using the flame spectrophotometer Sherwood model 410 by direct passage of the solution above obtained[10].

2.4. Volatile compounds analysis

Solid phase microextraction (SPME) analyses were performed as previously described[11] with slight modifications. SPME analyses: Supelco SPME devices coated with polydimethylsiloxane (100 μm) were used to sample the headspace of dry ginger inserted into a 5 mL vial and allowed to equilibrate for 30 min. SPME sampling was performed using the same new fiber, preconditioned according to the manufacturer instructions, for all the analyses. After the equilibration time, the fiber was exposed to the headspace for 25 min. Once sampling was finished, the fiber was withdrawn into the needle and transferred to the injection port of the gas chromatography-mass spectrometer system. Blanks were performed before each first SPME extraction and randomly repeated during each series. Quantitative comparisons of relative peaks areas were performed between the same chemicals in the different samples. Gas chromatography-electron impact-mass spectrometry analyses were performed with a Varian (Palo Alto, CA) CP 3800 gas chromatograph equipped with a DB-5 capillary column (30 mm × 0.25 mm × 0.25 μm; Agilent) and a Varian Saturn 2000 ion trap mass detector. Analytical conditions were as follows: injector and transfer line temperatures were 250 and 240 ˚C, respectively; oven temperature was programmed from 60 to 240 ˚C at 3 ˚C/min; carrier gas was helium at 1 mL/min; splitless injection.

The constituents identification was based on a comparison of the retention times with those of authentic samples, comparing their linear retention indices on computer matching against commercial (NIST 98 and Adams) and homemade library mass spectra, and MS literature data[12]. Moreover, the molecular weights of all the substances identified were confirmed by gas chromatography with chemical ionization mass spectrometry, using methanol as ionizing gas.

2.5. Antioxidant properties

2.5.1. Extracts preparation

Aqueous and ethanolic extracts were prepared for each sample. For the ethanolic extracts preparation, each sample (1 g) was extracted by maceration in 40 mL of ethanol for 2 days. This procedure was repeated three times. The combined ethanolic extracts were subsequently filtered through a Whatman No. 4 paper and then evaporated at 40 ˚C (rotary evaporator IKA RV 10 Digital) till dryness. Various concentrations from ethanolic extracts were prepared for further analyses.

The aqueous extracts were prepared following infusion and decoction procedures. For infusion, 1 g from each sample was mixed with 100 mL of boiling distilled water and allowed to cool[9]. For decoction preparation, the same amount (1 g) decoction was

boiled for a long time (1 h) to estimate the effect of long cooking time on the antioxidant properties. Infusion and decoction solutions were then lyophilized and various concentrations were prepared for antioxidant analyses .

2.5.2. Antioxidant compounds content

Total phenolic compounds (TPC) in the extracts were estimated by a colorimetric assay[13]. Absorbance was measured at 765 nm (BOECO, S-22UV-Vis Spectrophotometer, Germany). Gallic acid was used to obtain the standard curve and the reduction of the Folin-Ciocalteu reagent by the samples was expressed as milligram of gallic acid equivalents (GAE) per gram of extract.

Total flavonoids (TF) were determined by measuring the absorbance at 510 nm[14]. Catechin was used as standard and the results were expressed as milligram of catechin equivalents (CE) per gram of the extract.

Total tannins (TT) were determined using the modified vanillin-HCl assay[15]. The absorbance was measured at 500 nm. CE was also used to express tannins, being used in the standard curve. The results were expressed as milligram of CE per gram of the extract.

2.5.3. Antioxidant activity assays

2.5.3.1. DPPH radical-scavenging activity (RSA)

Various concentrations of ginger extracts (0.25 mL) were mixed with 0.75 mL of methanolic solution containing DPPH radicals (6×10^{-5} mol/L). The mixture was shaken vigorously and left to stand for 30 min in the dark until stable absorbance values were obtained. The reduction of the DPPH radical was determined by reading the absorbance at 515 nm. The RSA was calculated as a percentage of DPPH discoloration, using the equation:

$$RSA\ (\%) = [(A_{DPPH} - A_S)/A_{DPPH}] \times 100$$

where A_S was the absorbance of the solution when the sample extract was added at a particular level and A_{DPPH} was the absorbance of the DPPH solution[13]. The extract concentration providing 50% of RSA (EC_{50}) was calculated from the graph of RSA percentage against the extract concentration.

2.5.3.2. ABTS radical cation scavenging activity

The antioxidant activity was measured using an improved ABTS method[16]. The ABTS radical cation ($ABTS^{\bullet+}$) solution was prepared through the reaction of 7 mmol/L ABTS and 2.45 mmol/L potassium persulphate, and incubated at 23 °C in the dark for 12–16 h. The $ABTS^{\bullet+}$ solution was then diluted with 80% ethanol to obtain an absorbance of 0.700 ± 0.002 at 734 nm. After that, 3.9 mL of $ABTS^{\bullet+}$ solution was added to 0.1 mL of the test sample and mixed vigorously. The reaction mixture was allowed to stand at 23 °C for 6 min and the absorbance at 734 nm was immediately recorded. A standard curve was obtained by using Trolox standard solution at various concentrations (ranging from 0 to 15 μm) in 80% ethanol. The extract concentration providing 50% of RSA (EC_{50}) was calculated.

2.5.3.3. Reducing power

Various concentrations of ginger extracts (0.5 mL) were mixed with 0.5 mL of 200 mmol/L sodium phosphate buffer (pH 6.6) and 0.5 mL of 1% potassium ferricyanide. The mixture was incubated at 50 °C for 20 min. After that, 0.5 mL of 10% trichloroacetic acid (w/v) was added and the mixture was centrifuged at 1 000 r/min for 8 min. The upper layer (0.8 mL) was mixed with 0.8 mL of deionised water and 0.16 mL of 0.1% of ferric chloride, and the absorbance was measured at 690 nm[13]. The extract concentration providing 0.5 of absorbance (EC_{50}) was calculated from the graph of absorbance at 690 nm against extract concentration.

2.6. Statistical analysis

The results were expressed as means ± SD. For each form of dried ginger rhizomes, three samples were analyzed and all parameters were determined in triplicate. Statistical analysis was performed with SPSS 18.0. ANOVA and Duncan's test ($P < 0.05$) were used to determine significant differences between means. Correlation analysis was performed employing Pearson's test.

3. Results

3.1. Nutritional compositions of dried ginger rhizome forms

The results of proximate composition and energetic contribution of the studied ginger samples were shown in Table 1. Ash and fat contents were much higher in FDG while the crude protein content in DG was higher than those in the other samples. Compared with the other samples, PDG showed the highest total carbohydrate content. Energetic values were similar in DG and PDG.

Table 1

Proximate and mineral compositions and energetic values of the studied ginger dried forms.

Category	FDG	DG	PDG
Fat (g/100 g)	3.98 ± 0.01^a	3.52 ± 0.01^b	2.34 ± 0.01^c
Protein (g/100 g)	3.12 ± 0.11^c	7.64 ± 0.35^a	4.90 ± 0.22^b
Ash (g/100 g)	8.00 ± 0.19^a	4.68 ± 0.18^b	3.29 ± 0.53^c
Carbohydrates (g/100 g)	84.90 ± 0.21^b	84.16 ± 0.40^b	89.47 ± 0.32^a
Energetic value (kcal/100 g)	387.91 ± 0.54^b	398.85 ± 0.52^a	398.52 ± 1.49^a
Ca (mg/100 g)	151.00 ± 1.03^b	143.00 ± 0.91^a	162.00 ± 0.75^c
Mg (mg/100 g)	478.00 ± 1.76^c	288.00 ± 0.80^b	245.00 ± 1.35^a
Na (mg/100 g)	19.10 ± 0.06^c	18.80 ± 0.02^b	16.50 ± 0.03^a
K (mg/100 g)	5 060.00 ± 1.50^c	1 760.00 ± 2.00^b	1 500 ± 2.50^a
Cu (mg /100 g)	0.88 ± 0.02^c	0.62 ± 0.03^b	0.50 ± 0.07^a
Fe (mg /100 g)	5.71 ± 0.04^a	27.90 ± 0.05^c	8.41 ± 0.01^b
Mn (mg /100 g)	129.00 ± 2.00^c	31.30 ± 0.15^b	25.30 ± 0.09^a
Zn (mg /100 g)	0.020 ± 0.001^a	0.050 ± 0.001^b	nd

nd: Not detected. In each line, different letters mean significant differences ($P < 0.05$).

The mineral analysis of the three ginger samples, illustrated in Table 1, indicated their richness in Ca, Mg, Na, K, Cu, Fe, Mn and Zn. The Ca amount was nearly similar in the studied dry ginger samples (between 143.00 mg/100 g and 162.00 mg/100 g). Markedly, FDG contained the highest levels of K, Mg, Mn, Na and Cu with significant difference ($P < 0.05$) compared with DG and PDG. FDG was especially rich in K (5 060.00 mg/100 g), Mg (478.00 mg/100 g) and Mn (129.00 mg/100 g). Comparing samples ferric content, the DG showed the highest amount (27.90 mg/100 g). Zn was the least abundant mineral in the studied ginger samples (Table 1).

3.2. Volatile compounds analysis in dried ginger rhizome forms

Each one of the dried ginger samples, analyzed by the mentioned methodology (headspace solid phase microextraction), showed a different composition in volatiles (Table 2).

Table 2
Volatile compounds identified in the studied ginger dried forms.

Compound	LRI	FDG	DG	PDG
2-Heptanol	898	0.30 ± 0.06	0.50 ± 0.10	0.40 ± 0.06
α-Thujene	933	0.30 ± 0.01	-	0.80 ± 0.15
α-Pinene	941	2.70 ± 0.21	0.80 ± 0.17	8.10 ± 0.47
Camphene	955	17.60 ± 1.04	3.50 ± 0.30	34.10 ± 1.30
β-Pinene	982	0.40 ± 0.06	-	1.00 ± 0.26
6-Methyl-5-hepten-2-one	987	1.30 ± 0.15	0.20 ± 0.00	0.20 ± 0.06
Myrcene	993	-	0.40 ± 0.06	0.30 ± 0.10
α-Phellandrene	1 006	0.10 ± 0.00	0.20 ± 0.06	0.20 ± 0.00
β-Phellandrene	1 033	1.70 ± 0.31	3.70 ± 0.26	19.60 ± 0.95
1,8-Cineole	1 035	24.90 ± 1.58	8.60 ± 0.97	3.10 ± 0.32
Terpinolene	1 090	-	0.20 ± 0.10	0.10 ± 0.01
2-Nonanone	1 093	0.10 ± 0.06	0.20 ± 0.06	-
Linalool	1 101	1.10 ± 0.31	1.60 ± 0.26	0.90 ± 0.15
trans-p-Menta-2.8-dien-1-ol	1 125	0.20 ± 0.06	0.20 ± 0.06	-
Camphor	1 145	0.70 ± 0.21	0.40 ± 0.17	0.40 ± 0.17
Camphene hydrate	1 150	0.40 ± 0.10	0.30 ± 0.06	0.20 ± 0.06
Isoborneol	1 158	0.10 ± 0.06	-	-
Borneol	1 168	3.80 ± 0.38	3.30 ± 0.40	1.80 ± 0.32
Rosefuran epoxide	1 176	-	-	0.60 ± 0.21
4-Terpineol	1 179	0.50 ± 0.1	0.40 ± 0.12	-
α-Terpineol	1 191	1.00 ± 0.29	0.70 ± 0.26	0.60 ± 0.20
Myrtenol	1 195	0.10 ± 0.00	-	-
Cumin aldehyde	1 241	0.10 ± 0.12	1.30 ± 0.31	-
Neral	1 242	0.60 ± 0.17	-	0.80 ± 0.26
Carvone	1 244	0.30 ± 0.10	-	-
Geranial	1 271	0.50 ± 0.10	0.20 ± 0.00	0.80 ± 0.25
Isobornyl acetate	1 287	0.40 ± 0.15	0.90 ± 0.17	-
2-Undecanone	1 293	0.20 ± 0.06	0.50 ± 0.10	0.10 ± 0.01
δ-Elemene	1 340	-	0.20 ± 0.06	-
Cyclosativene	1 369	0.50 ± 0.15	0.80 ± 0.23	0.30 ± 0.15
Longicyclene	1 373	0.20 ± 0.00	0.30 ± 0.15	-
α-Copaene	1 377	1.00 ± 0.15	1.70 ± 0.31	0.70 ± 0.25
Geranyl acetate	1 383	-	0.30 ± 0.06	-
β-Elemene	1 392	0.90 ± 0.06	1.00 ± 0.44	0.60 ± 0.23
Italicene	1 404	0.30 ± 0.06	0.40 ± 0.10	0.20 ± 0.06
β-Caryophyllene	1 419	0.20 ± 0.00	0.30 ± 0.06	-
β-Copaene	1 430	0.10 ± 0.06	0.20 ± 0.15	-
γ-Elemene	1 434	0.30 ± 0.06	0.40 ± 0.17	-
trans-α-Bergamotene	1 437	0.10 ± 0.00	0.20 ± 0.00	-
α-Guaiene	1 440	-	-	0.70 ± 0.17
α-Himachalene	1 449	-	0.30 ± 0.06	-
α-Neoclovene	1 455	0.10 ± 0.06	-	-
Alloaromadendrene	1 462	0.80 ± 0.21	1.30 ± 0.26	-
γ-Muurolene	1 478	2.00 ± 0.26	2.90 ± 0.32	1.10 ± 0.38
ar-Curcumene	1 483	5.00 ± 0.75	6.30 ± 0.70	3.40 ± 0.32
Valencene	1 492	1.20 ± 0.15	2.20 ± 0.26	0.90 ± 0.12
α-Zingiberne	1 496	14.30 ± 0.92	28.50 ± 1.27	8.80 ± 0.61
β-Bisabolene	1 508	5.70 ± 0.61	10.80 ± 0.92	3.80 ± 0.31
7-*epi*-α-Selinene	1 519	0.20 ± 0.06	0.40 ± 0.15	0.20 ± 0.06
β-Sesquiphellandrene	1 525	6.10 ± 0.32	10.60 ± 0.85	3.80 ± 0.38
(E)-γ-Bisabolene	1 533	0.20 ± 0.06	0.40 ± 0.17	0.10 ± 0.06
Monoterpene hydrocarbons		22.80	8.80	64.20
Oxygenated monoterpenes		34.70	18.20	9.20
Sesquiterpene hydrocarbons		39.20	69.20	24.60
Others		1.90	1.40	0.70
Total identified (%)		98.60	97.60	98.70

Results are expressed by mean ± SD. LRI: Linear retention index.

Among the 51 identified volatile components, 44 compounds were identified in FDG and 42 compounds in DG, while PDG gave only 33 components. Only 26 components were common through all the three studied dried forms of ginger. The major compounds of the FDG were 1,8-cineole (24.90%), camphene (17.60%) and α-zingiberene (14.30%). DG showed higher content of α-zingiberene (28.50%), β-bisabolene (10.80%) and β-sesquiphellandrene (10.60%). However, PDG gave camphene (34.10%) and β-phellandrene (19.60%) as the major compounds.

3.3. Contents in antioxidant compounds of dried ginger extracts

TPC of ginger extracts were shown in Table 3. Significant differences ($P < 0.05$) in TPC values were observed between samples and between different extracts (ethanolic and aqueous extracts obtained by decoction or infusion). The highest level was found in ethanolic extracts especially in the DG one (118.10 mg GAE/g extract). Whereas, the lowest level was observed in the decocted FDG sample (27.61 mg GAE/g extract).

Maximum concentrations of TF in ginger samples were also observed in the ethanolic extracts (Table 3). The highest TF content was noted in the ethanolic extracts of DG and PDG (59.84 and 99.60 mg CE/g extract, respectively) while the lowest ones were observed for infusions of FDG and PG (9.10 and 9.72 mg CE/g extract, respectively).

TT content was also estimated in all the extracts (Table 3), being very low in all of them. As observed for TPC and TF, PDG and DG ethanolic extracts had the highest TT content (13.26 and 12.39 mg equivalent CE/g of extract, respectively). The lowest TT content was shown in DG decoction extract with 2.30 mg equivalent CE/g of extract.

3.4. Antioxidant activity of dried ginger extracts

The results of DPPH scavenging activity of the ethanolic and aqueous extracts were shown with the corresponding EC_{50} values in Table 4. The lowest EC_{50} values were found in PDG ethanolic extract and decoction, and in DG infusion (0.02, 0.10 and 0.09 mg/mL, respectively), corresponding to the highest scavenging effects. Despite the best results in the ethanolic extracts, decoctions and infusions also showed a considerable antioxidant power.

The highest ABTS scavenging activity was obtained for the ethanolic extracts, followed by decoction or infusion, depending on the corresponding sample. The differences between the EC_{50} values of all extracts were statistically significant, *i.e,* the EC_{50} of ABTS of the ethanolic extract of PDG (0.08 mg/mL) was much lower than that of the FDG extract (0.18 mg/mL) and DG extract (0.19 mg/mL). For infusions, DG and PDG showed similar results (EC_{50} =1.31 mg/mL), but FDG had the lowest activity (EC_{50} = 2.45 mg/mL) (Table 4), whilst in the case of decoctions, the EC_{50} values of the three samples

Table 3

Content of total antioxidant compounds in the ethanolic and aqueous extracts prepared from the studied ginger dried forms.

Samples	Ethanolic			Decoction			Infusion		
	FDG	DG	PDG	FDG	DG	PDG	FDG	DG	PDG
TPC (mg GAE/g of extract)	49.63 ± 1.08^{a}	118.10 ± 0.75^{c}	101.48 ± 0.18^{b}	27.61 ± 0.85^{a}	30.49 ± 0.49^{b}	33.55 ± 0.22^{c}	33.42 ± 0.36^{b}	31.66 ± 0.67^{a}	31.39 ± 0.58^{a}
TF (mg CE/g of extract)	40.35 ± 0.50^{a}	59.84 ± 2.83^{b}	99.60 ± 0.25^{c}	10.60 ± 1.25^{a}	13.60 ± 1.00^{b}	14.35 ± 0.75^{b}	9.10 ± 0.01^{a}	11.72 ± 0.62^{b}	9.72 ± 0.62^{a}
TT (mg CE/g of extract)	6.06 ± 0.37^{a}	13.26 ± 0.56^{c}	12.39 ± 0.06^{b}	9.84 ± 0.37^{c}	2.30 ± 0.18^{a}	8.34 ± 0.24^{b}	6.47 ± 0.24^{c}	2.80 ± 0.06^{a}	3.19 ± 0.07^{b}

In each line and for each extract, different letters mean significant differences ($P < 0.05$). TPC was expressed in mg GAE/g of extract; TF and TT were in mg CE/g of extract.

Table 4

Antioxidant activity EC50 values of the ethanolic and aqueous extracts prepared from the studied ginger dried forms.

Sample	Ethanolic			Decoction			Infusion		
	FDG	DG	PDG	FDG	DG	PDG	FDG	DG	PDG
DPPH	0.03 ± 0.00^{c}	0.03 ± 0.00^{b}	0.02 ± 0.00^{a}	0.27 ± 0.01^{c}	0.21 ± 0.01^{b}	0.10 ± 0.01^{a}	0.25 ± 0.02^{c}	0.09 ± 0.01^{a}	0.18 ± 0.00^{b}
ABTS	0.18 ± 0.01^{b}	0.19 ± 0.01^{b}	0.08 ± 0.00^{a}	1.64 ± 0.01^{a}	1.55 ± 0.13^{a}	1.75 ± 0.18^{a}	2.45 ± 0.10^{b}	1.32 ± 0.04^{a}	1.31 ± 0.13^{a}
FRAP	0.21 ± 0.01^{c}	0.14 ± 0.01^{b}	0.08 ± 0.00^{a}	1.63 ± 0.08^{b}	0.88 ± 0.01^{a}	0.88 ± 0.11^{a}	1.80 ± 0.05^{c}	0.79 ± 0.03^{b}	0.69 ± 0.02^{a}

The results of the antioxidant activity are presented in EC_{50} values (mg/mL). In each line and for each extract, different letters mean significant differences ($P < 0.05$).

were similar.

Ferric reducing antioxidant power (FRAP): EC_{50} values of the examined ginger extracts were presented in Table 4. The highest FRAP values were found in the ethanolic extracts. For DG and PDG, the decoctions of both samples showed higher EC_{50} values than the infusions, while the infusion of FDG gave higher EC_{50} than the the corresponding decoction.

3.5. Correlation analysis between the antioxidant activity and total antioxidant contents

Pearson test was used to evaluate the correlations between the antioxidant activity and TPC, TF and TT contents and the results were presented in Table 5. A strong significant correlation ($P < 0.01$) was found between the TPC, TF and TT, and also between the antioxidant activity and both TPC and TF contents (Table 5). In particular, it can be evidenced that TT content was significantly correlated with DPPH and ABTS ($P < 0.05$). The Pearson correlation between FRAP and TT was not significant. Among the antioxidant capacities, correlation was strong ($P < 0.01$) between ABTS and both DPPH (r = 0.859) and FRAP (r = 0.919). The same correlation ($P < 0.01$) existed between DPPH and FRAP (r = 0.915).

Table 5

Pearson correlation coefficients between EC_{50} (mg/mL) from DPPH, ABTS and FRAP and contents of TPC (mg GAE/g), TF and TT (mg CE/g).

	TPC	TF	TT	DPPH	ABTS	FRAP
TPC	1					
TF	0.89**	1				
TT	0.77**	0.71**	1			
DPPH	–0.71**	–0.74**	–0.42*	1		
ABTS	–0.77**	–0.82**	–0.48*	0.85**	1	
FRAP	–0.67**	–0.73**	–0.28	0.90**	0.92**	1

**: Correlation is significant at the 0.01 level; *: Correlation is significant at the 0.05 level.

4. Discussion

Proximate composition variation between studied samples showed that FDG contained more ash, it was probably in consequence of its higher level of minerals. For protein content, our result is in agreement with the results previously reported[17] in sun dried ginger (7.9 g/100 g). However, another study reported much lower values of crude protein in air-dried gingers available in Taiwan (0.93 g/100 g in Chu-ginger and 1.05 g/100 g dried weight in Guangdong ginger)[18]. Also, fat levels were higher than those obtained in the previously mentioned study with the two varieties from Taiwan, Chu-ginger and Guangdong ginger (0.52 and 0.55 g/100 g, respectively)[18]. In addition, obtained carbohydrates values were lower than the levels reported for Chu-ginger and Guangdong ginger (97.19 and 97.26 g/100 g, respectively)[18]. Energetic values are very close to the ones reported in literature (385.6 kcal/100 g)[17].

The observed variations among ginger samples may be related with the drying method. Air-drying at low temperature aims to preserve the heat sensitive components, resulting in improved quality and nutritive values of final dried products[19].

For mineral contents, minerals seem to be preserved in newly dried ginger which will be effectively recommended to supply the daily requirements. In fact, the daily basis of Ca required for man is 800 mg[20]. Ferric content is required with a daily amount of 6.2 mg for blood formation[20,21]. Zn prevents growth and mental retardation in humans with daily requirement of 6.2 mg[20,21]. Zn needed in human cannot be provided from ginger.

Considering aroma volatile compounds, aromatic compounds are naturally occurring molecules that have an odor affecting the senses of taste and smell. The headspace solid-phase micro-extraction apparatus is a solvent-free, rapid and sensitive technique that has become popular in volatile flavor analysis[22]. Coupled to gas chromatography–mass spectrometry, it has been successfully used for qualitative and quantitative analysis of volatile compounds[11,23]. The storage and manufacturing procedures applied to DG and PDG samples could be related to the decrease in volatile components, in comparison with FDG. Among the common components, 1,8-cineole is a remarkable chemical compound offering strong therapeutic

properties namely healing potential[24]. It is proved to possess gastroprotective activity on rats, an effect that is related to both the antioxidant and lipoxygenase inhibitory effects of this oxygenated monoterpene[25]. The presence of 1,8-cineole in ginger essential oil has been previously reported[26].

Zingiberene, herein a major component in DG, has a warm, woody-spicy and very tenacious odor. Furthermore, camphene, herein high in PDG, has a terpeney-camphoraceous taste. Also, α-curcumene, that is present in similar amounts in FDG, DG and PDG, shows a characteristic odor of turmeric and a slightly pungent bitter taste, whereas neral and geranial are widely used as powerful lemon-fragrant chemicals[18]. The constituents of ginger are numerous and vary depending on the geographic origin and on the freshness of the rhizomes[27]. Also the drying process changes the flavor of the product, but the exact chemical nature of these changes is still not clear. Due to the differences in their volatilities, the levels of volatile components may change. Also, the procedures associated to drying process and isolating methods may affect the final product[2].

For antioxidant potential evaluation, the choice of the extraction solvent was based on the fact that both ethanol and water are non-polluting, cheaper and non-toxic compared to other solvents[28]. Previous works on TPC reported 11.2 mg GAE/g dry material in an ethanolic extract and estimated 23.5 mg GAE/g of TPC in aqueous ginger extract. TF content in ginger ethanolic extract was 5.33 mg CE per dry weight[29,30].

Result of photochemical content could be due to the higher solubility of phenolics and flavonoids in ethanol in comparison with water. In fact, the solubility of phenolic compounds is governed by the type of solvent (polarity) used, degree of polymerization of phenolics, as well as interaction of phenolics with other food constituents and formation of insoluble complexes[31].

Decoction and infusion similarities meant that hot water did not damage the antioxidant ability of ginger phenolic molecules after prolonged exposure to hot water (decoction time). This hypothesis was proved in a previous study[18] reporting that the hot water extracts of two ginger rhizomes were more effective than the ethanolic extracts.

These variations can be either due to intrinsic factors, mainly genetics, or extrinsic factors, such as storage, type of soil, agronomic practices, climatic factors and technological packaging treatments[8]. Antioxidant activities are highly dependent on the extracting solvent and concentration[32], but they also vary within the samples. It is interesting to note that the powdered ginger which has significant DPPH and ABTS radical scavenging activities, showed the lowest ferric-reducing power. It appears that care should be taken when using free radicals as a basis for antioxidant activity tests because it seems that the measured antioxidant activity of a biological sample depends on the free radical or oxidant used in the assay. Alternatively, the FRAP assay should be used being the only one that directly measures antioxidants or reductants in a sample[33].

Thus, the antioxidant capacity of ginger appears to be largely influenced by the total phenolic levels. A causative relationship was previously demonstrated between the TPC and antioxidant activity[34]. Therefore, the extracts containing the higher phenolic content, such as ethanolic extracts, were estimated to show the highest antioxidant activity.

The present work described and compared the nutritional values and the volatile compositions of three different forms of dry ginger rhizome available in local markets. Freshly air-dried sample had the highest amount of minerals (namely K, Mg and Mn) and it contained the highest amount of bioactive volatiles such as 1,8-cineole, camphene and α-zingiberene. Furthermore, the antioxidant potential of ethanolic and aqueous extracts was evaluated. Ethanolic extracts showed the highest antioxidant activity in different *in vitro* assays. Little differences were observed in the concentrations of phenolics in the different aqueous extracts (obtained following decoction or infusion procedures). Moreover, the expected degradation of compounds in decoctions was not always observed. Freshly air dried sample had the lowest values for antioxidant parameters. This unexpected drop in antioxidant properties could be linked to different geographical origin. It is clear that the mineral and volatile profiles and also the antioxidant potential of the samples were dissimilar and, therefore, it is strongly recommended to analyze the commercially available samples to choose the most appropriate for each purpose.

Conflict of interest statement

We declare that we have no conflict of interest.

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