Aqueous extracts of 30 plants were investigated for their antioxidant properties using DPPH and ABTS radical scavenging capacity assay, oxygen radical absorbance capacity (ORAC) assay, superoxide dismutase (SOD) assay, and ferric reducing antioxidant potential (FRAP) assay. Total phenolic content was also determined by the Folin–Ciocalteu method. Antioxidant properties and total phenolic content differed significantly among selected plants. It was found that oak (*Quercus robur*), pine (*Pinus maritima*), and cinnamon (*Cinnamomum zeylanicum*) aqueous extracts possessed the highest antioxidant capacities in most of the methods used, and thus could be potential rich sources of natural antioxidants. These extracts presented the highest phenolic content (300–400 mg GAE/g). Mate (*Ilex paraguariensis*) and clove (*Eugenia caryophyllus clovis*) aqueous extracts also showed strong antioxidant properties and a high phenolic content (about 200 mg GAE/g). A significant relationship between antioxidant capacity and total phenolic content was found, indicating that phenolic compounds are the major contributors to the antioxidant properties of these plants.

**KEYWORDS:** Plant extract; antioxidant activity; total phenolic content; DPPH, ABTS; FRAP; ORAC; SOD
The aim of the present study was to determine the total phenolic content and to characterize the antioxidant activities using DPPH, ABTS, FRAP, ORAC, and SOD assays of 30 selected plants currently used in the industry for fragrance, cosmetic, and food flavoring applications, in order to determine their potential in nutraceutical formulations.

MATERIALS AND METHODS

Plant Material. The following plants were obtained from Biolandes’s collection of plants: Abelmoschus moschatus (Malvaceae, India), Actinidia chinensis (Actinidiaceae, France), Cananga odorata (Annonaceae, Madagascar), Carica papaya (Caricaceae, Madagascar), Ceratonia siliqua (Fabaceae, Morocco), Cinnamonum zeylanicum (Lauraceae, Madagascar), Cistus ladaniferus (Cistaceae, Spain), Coffea arabica (Rubiaceae, Brazil), Daucus carota (Apiaceae, France), Eucalyptus globulus (Myrtaceae, Spain), Eugenia caryophyllus clavus (Myrtaceae, Madagascar), Hexaqueria aurantiaca (Aquilifoliaceae, Brazil), Jasminum grandiflorum (Oleaceae, Morocco), Juniperus communis (Cupressaceae, Bulgaria), Laurus nobilis (Lauraceae, Morocco), Lavandula angustifolia (Lamiaceae, France), Lavandula hybrida grosso (Lamiaceae, France), Liriodendron tulipferum (Magnoliaceae, France), Matricaria recutita (Asteraceae, Morocco), Myrocarpus fastigiatus (Fabaceae, Paraguay), Pinus maritima (Pinaceae, France), Populus nigra (Salicaceae, China), Quercus robur (Fagaceae, France), Ribes nigrum (Grossulariaceae, France), Rosa damascena (Rosaceae, Bulgaria), Salvia sclarea (Lamiaceae, France), Styxys benjoin (Styraceae, Laos), Trigonella foenum graecum (Fabaceae, Morocco), Vanilla planifolia (Orchidaceae, Madagascar) and Zingiber officinalis (Zingiberaceae, India).

Chemicals. 2,2-Diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), potassium persulfate, fluorescein, 2,2'-azobis(2-methylpropionamide) dihydrochloride (AAHP), phosphate buffer, 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ), iron (III) chloride hexa-hydrate, and Folin–Ciocalteu reagent were purchased from Sigma-Aldrich (France), Sodium acetate dihydrochloride (AAPH), phosphate buffer, 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ), fluorescein, 2,2'-azobis(2-methylpropionamide) dihydrochloride (AAHP), phosphate buffer, 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ), iron (III) chloride hexa-hydrate, and Folin–Ciocalteu reagent were purchased from Sigma-Aldrich (France). Sodium acetate dihydrochloride (AAPH), phosphate buffer, 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ), iron (III) chloride hexa-hydrate, and Folin–Ciocalteu reagent were purchased from Sigma-Aldrich (France).

Spectrophotometric and Spectrofluorometric Measurements. Absorbance and fluorescence measurements were respectively done using a UV mini-1240 Shimadzu spectrophotometer (Fischer Bioblock, France) and a Cary Eclipse spectrofluorometer (Varian, France). The absorbance measurements for the SOD assay were done using a Dynex plate reader (Seralab Technologies, France).

Sample Preparation. The plant materials were ground using a Retsch GM 200 mill (Fischer Bioblock, France) and a Cary Eclipse spectrofluorometer (Varian, France). Ground plant material (125 g) was used for phenolic extraction with distilled water at 50 °C under agitation. After filtration, the water was removed in a Buchi R124 rotary evaporator (Fischer Bioblock, France) at 50 °C to obtain a powder. These powders were then used to determine antioxidant activities. All analyses were realized as much as possible in an area protected against light.

Determination of Antioxidant Capacity. Free Radical Scavenging by the Use of the DPPH Radical. The DPPH radical scavenging capacity of each extract was determined according to the method of Brand-Williams modified by Miliusus (20, 15). DPPH radicals have an absorption maximum at 515 nm, which disappears with reduction by an antioxidant compound. The DPPH• solution in methanol (6 × 10^-5 M) was prepared daily, and 3 mL of this solution was mixed with 100 µL of methanolic solutions of plant extracts. The samples were incubated for 20 min at 37 °C in a water bath, and then the decrease in absorbance at 515 nm was measured (A515). A blank sample containing 100 µL of methanol in the DPPH• solution was prepared daily, and its absorbance was measured (A0). The experiment was carried out in triplicate. Radical scavenging activity was calculated using the following formula:

\[ \% \text{ inhibition} = \left( \frac{A_0 - A_2}{A_0} \right) \times 100 \]  

where A0 is absorbance of the blank sample, and A2 is absorbance of the plant extract.

Free Radical Scavenging by the Use of the ABTS Radical. The free radical scavenging capacity of plant extracts was also studied using the DPPH radical cation decolorization assay (21), which is based on the reduction of ABTS+• radicals by antioxidants of the plant extracts tested. ABTS was dissolved in deionized water to a 7 mM concentration. ABTS radical cation (ABTS+) was produced by reacting ABTS solution with 2.45 mM potassium persulfate (final concentration) and allowing the mixture to stand in the dark at room temperature for 12–16 h before use. For the study, the ABTS+• solution was diluted in deionized water or ethanol to an absorbance of 0.7 ± (±0.02) at 734 nm. An appropriate solvent blank reading was taken (A0). After the addition of 100 µL of aqueous or ethanolic (according to solubility) plant extract solutions to 3 mL of ABTS+• solution, the absorbance reading was taken at 30 °C 10 min after initial mixing (A0). All solutions were used on the day of preparation, and all determinations were carried out in triplicate. The percentage of inhibition of ABTS+• was calculated using above formula (eq 1).

Free Radical Scavenging by the Oxygen Radical Absorbance Capacity (ORAC) Assay. The ORAC assay is based on the scavenging of peroxy radicals generated by AAPH, which prevent the degradation of the fluorescein probe and, consequently, prevent the loss of fluorescence of the probe. The ORAC assay was applied according to the method of Ou modified by Dávalos (22, 23). The reaction was carried out in 75 mM phosphate buffer (pH 7.4) in fluorescence glass cuvettes. Three hundred microliters of plant extract solutions and 1.8 µL of fluorescein (70 nM final concentration) were mixed in the cuvette and preincubated for 5 min at 37 °C. Nine hundred microliters of AAPH solution (12 mM final concentration) was then added, and the fluorescence was recorded for 60 min at excitation and emission wavelengths of 485 and 530 nm, respectively. A sample containing 300 µL of phosphate buffer in the reaction mix was prepared simultaneously and measured daily. Four calibration solutions of Trolox (1, 3, 5, 7 µM final concentration) was also tested to establish a standard curve. All samples were analyzed in triplicate. The area under the curve (AUC) was calculated for each sample by integrating the relative fluorescence curve. The net AUC of the sample was calculated by subtracting the AUC of the blank. The regression equation between net AUC and Trolox concentration was determined, and ORAC values were expressed as µmol Trolox equivalents/g of plant extract using the standard curve established previously.

Free Radical Scavenging by the Superoxide Dismutase (SOD) Assay. The superoxide anion scavenging activity of plant extracts was determined by the WST (2-(4,iodophenyl)-3-(4-nitropheno)-5-(2,4-disulphophenyl)-2H-tetrazolium, monosodium salt) reduction method, using the SOD assay kit-WST. In this method O2− reduces WST-1 to produce the yellow formazan, which is measured spectrophotometrically at 450 nm. Antioxidants are able to inhibit yellow WST formation. All measurements were done in triplicate. The percentage of inhibition of superoxide radicals was calculated using above formula (eq.1).

Ferric Reducing Antioxidant Potential (FRAP) Assay. The ferric reducing power of plant extracts was determined using a modified version of the FRAP assay (24). This method is based on the reduction, at low pH, of a colorless ferric complex (Fe3+-tripryridyltriazine) to a blue-colored ferrous complex (Fe2+-tripryridyltriazine) by the action of electron-donating antioxidants. The reduction is monitored by measuring the change of absorbance at 593 nm. The working FRAP reagent was prepared daily by mixing 10 volumes of 300 mM acetate buffer, pH 3.6, with 1 volume of 10 mM TPTZ (2,4,6-tri(2-pyridyl)-s-triazine) in 40 mM hydrochloric acid and with 1 volume of 20 mM ferric chloride. A standard curve was prepared using various concentrations of FeSO4 × 7H2O. All solutions were used on the day of preparation. One hundred microliters of sample solutions and 300 µL of deionized water were added to 3 mL of freshly prepared FRAP reagent. The reaction mixture was incubated for 30 min at 37 °C in a water bath. Then, the absorbance of the samples was measured at 593 nm. A sample blank reading using acetate buffer was also taken. The difference between sample absorbance and blank absorbance was calculated and used to
calculate the FRAP value. In this assay, the reducing capacity of the plant extracts tested was calculated with reference to the reaction signal given by a Fe²⁺ solution. FRAP values were expressed as mmol Fe²⁺/g of sample. All measurements were done in triplicate.

**Determination of Total Phenolic Content.** The total phenolic concentration in aqueous extracts was determined according to the Folin-Ciocalteu method (25) using gallic acid as the standard. Four hundred microliter aqueous solutions of gallic acid and 1.6 mL of sodium carbonate (7.5% in deionized water) were added to 2 mL of Folin-Ciocalteu reagent (diluted 10-fold in deionized water). Four hundred microliter aqueous solutions of plant extract were mixed with the same reagents as described above. After incubation for 1 h at room temperature, the absorbance was measured at 765 nm. All determinations were carried out in triplicate, and the results are expressed as mg gallic acid equivalent (GAE) /g of extract.

**Statistical Analysis.** Results were expressed as means ± standard deviation (SD) of three measurements. Statistical analysis was performed using Student’s t-test and P < 0.05 was considered to be significant. Correlations among data obtained were calculated using the MS Excel software correlation coefficient statistical option.

**RESULTS**

In order to evaluate the efficiency of the plant extracts, a commercial pine bark extract currently used in nutraceutical formulations has also been tested.

**Radical Scavenging Capacity.** Radical scavenging capacities were determined using DPPH, ABTS, ORAC, and SOD assays. Results are shown in Tables 1 and 2.

DPPH radical scavenging activities of plant extracts varied from 0.19 to 94.51%, which represents a variation of approximately 500-fold. Pine (*Pinus maritima*) extract showed the highest antioxidant capacity (94.51% of DPPH inhibition), followed by pine commercial extract (92.79%), oak (*Quercus robur*) extract (88.60%), cinnamon (*Cinnamomum zeylanicum*) extract (84.43%), and mate (*Ilex paraguariensis*) extract (71.75%). Sage (*Salvia sclarea*) extract showed the lowest antioxidant capacity (0.19%).

In the ABTS assay, values ranged from 0.15 to 99.80%, which represents a higher variation than in the DPPH assay of approximately 665-fold. Oak extract possessed the highest antioxidant capacity (99.80% of ABTS inhibition) followed by the pine extracts (83.68% and 76.71% for commercial and aqueous extracts, respectively), cinnamon extract (64.88%), and clove (*Eugenia caryophyllus clovis*) extract (46.68%). As observed with the DPPH assay, the sage extract showed the lowest antioxidant capacity (0.15%).

ORAC values varied from 183 to 8515 µmol Trolox equivalent per gram of sample, which represents a variation of about 47-fold. The plant extracts that showed the highest antioxidant capacities were cinnamon extract (8515 µmol/g), followed by the pine extracts (7727 and 6506 µmol/g for commercial and aqueous extracts respectively), cabreuva (*Myrciaria chlorofusa*) extract (5422 µmol/g), mate extract (5092 µmol/g), and oak extract (3850 µmol/g). In this assay, juniper (*Juniperus communis*) showed the lowest antioxidant potential (183 µmol/g).

SOD superoxide radical scavenging capacities of plant extracts tested varied from 0.15 to 81.20%, which represents a variation of about 540-fold. Oak extract showed the highest antioxidant capacities (81.20%), followed by commercial pine extract (60.32%), cabreuva extract (58.59%), pine extract (53.48%), mate extract (52.44%), cinnamon extract (51.79%), and clove extract (51.75%). In this assay, lavender (*Lavandula angustifolia*) showed the lowest antioxidant potential (0.15%).

**Ferric Reducing Potential.** Results of ferric reducing capacities of selected plant extracts are presented in Table 2. The trend for the ferric ion reducing activities of the 30 plant extracts tested did not vary markedly from their DPPH and ABTS

Table 1. Radical Scavenging Capacity of 30 Aqueous Plant Extracts

<table>
<thead>
<tr>
<th>plant</th>
<th>part of plant</th>
<th>DPPH inhibition %</th>
<th>ABTS inhibition %</th>
<th>ORAC (µmol Trolox/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abelmoschus moschatus</td>
<td>seed</td>
<td>2.30 ± 0.59</td>
<td>1.48 ± 2.02</td>
<td>213 ± 4</td>
</tr>
<tr>
<td>Actinidia chinensis</td>
<td>flower</td>
<td>2.29 ± 0.33</td>
<td>2.12 ± 1.56</td>
<td>887 ± 56</td>
</tr>
<tr>
<td>Cananga odorata</td>
<td>flower</td>
<td>3.57 ± 0.16</td>
<td>4.13 ± 1.04</td>
<td>560 ± 10</td>
</tr>
<tr>
<td>Carica papaya</td>
<td>leaf</td>
<td>2.22 ± 1.02</td>
<td>1.38 ± 0.46</td>
<td>348 ± 17</td>
</tr>
<tr>
<td>Ceratonia siliqua</td>
<td>pod</td>
<td>7.70 ± 1.00</td>
<td>9.75 ± 0.56</td>
<td>225 ± 11</td>
</tr>
<tr>
<td>Cinnamomum zeylanicum</td>
<td>bark</td>
<td>84.43 ± 3.48</td>
<td>64.88 ± 3.74</td>
<td>8515 ± 300</td>
</tr>
<tr>
<td>Cistus ladaniferus</td>
<td>leaf</td>
<td>5.06 ± 1.03</td>
<td>26.83 ± 1.96</td>
<td>1410 ± 53</td>
</tr>
<tr>
<td>Coffea arabica</td>
<td>seed</td>
<td>41.21 ± 0.08</td>
<td>26.45 ± 0.22</td>
<td>3511 ± 57</td>
</tr>
<tr>
<td>Daucus carota</td>
<td>seed</td>
<td>1.22 ± 0.24</td>
<td>2.68 ± 1.02</td>
<td>435 ± 16</td>
</tr>
<tr>
<td>Eucalyptus globulus</td>
<td>leaf</td>
<td>27.43 ± 0.35</td>
<td>41.14 ± 0.51</td>
<td>284 ± 134</td>
</tr>
<tr>
<td>Eugenia caryophyllus</td>
<td>flower-bud</td>
<td>31.58 ± 7.37</td>
<td>46.68 ± 0.73</td>
<td>3084 ± 65</td>
</tr>
<tr>
<td>Ilex paraguariensis</td>
<td>leaf</td>
<td>71.75 ± 1.22</td>
<td>32.73 ± 3.51</td>
<td>5092 ± 314</td>
</tr>
<tr>
<td>Jasminum grandiflorum</td>
<td>flower</td>
<td>14.35 ± 4.65</td>
<td>10.20 ± 0.98</td>
<td>2330 ± 64</td>
</tr>
<tr>
<td>Juniperus communis</td>
<td>fruit</td>
<td>1.92 ± 1.81</td>
<td>0.97 ± 0.94</td>
<td>183 ± 18</td>
</tr>
<tr>
<td>Laurus nobilis</td>
<td>leaf</td>
<td>18.93 ± 1.20</td>
<td>18.61 ± 0.44</td>
<td>2963 ± 35</td>
</tr>
<tr>
<td>Lavandula augustifolia</td>
<td>flower</td>
<td>1.46 ± 0.25</td>
<td>2.38 ± 0.17</td>
<td>697 ± 27</td>
</tr>
<tr>
<td>Lavandula hybrida groso</td>
<td>flower</td>
<td>2.84 ± 0.17</td>
<td>8.32 ± 0.08</td>
<td>1181 ± 28</td>
</tr>
<tr>
<td>Liriodendron tulipifera</td>
<td>leaf</td>
<td>3.99 ± 0.08</td>
<td>9.99 ± 0.2</td>
<td>1146 ± 37</td>
</tr>
<tr>
<td>Matricaria reculata</td>
<td>flower</td>
<td>0.67 ± 0.38</td>
<td>5.97 ± 0.16</td>
<td>588 ± 29</td>
</tr>
<tr>
<td>Myrciaria chlorofusa</td>
<td>wood</td>
<td>39.73 ± 0.14</td>
<td>29.68 ± 0.65</td>
<td>5422 ± 78</td>
</tr>
<tr>
<td>Pinus maritima</td>
<td>bark</td>
<td>94.51 ± 0.01</td>
<td>76.71 ± 0.37</td>
<td>6506 ± 120</td>
</tr>
<tr>
<td>Pinus maritima (commercial extract)</td>
<td>bark</td>
<td>92.79 ± 0.69</td>
<td>83.68 ± 0.80</td>
<td>7727 ± 135</td>
</tr>
<tr>
<td>Populus nigra</td>
<td>bud</td>
<td>19.82 ± 2.28</td>
<td>16.76 ± 0.07</td>
<td>2738 ± 43</td>
</tr>
<tr>
<td>Quercus robur</td>
<td>wood</td>
<td>88.60 ± 2.04</td>
<td>99.80 ± 0.07</td>
<td>3850 ± 121</td>
</tr>
<tr>
<td>Rhus nigrum</td>
<td>bud</td>
<td>7.35 ± 0.58</td>
<td>21.87 ± 7.24</td>
<td>1138 ± 26</td>
</tr>
<tr>
<td>Rosa damascena</td>
<td>flower</td>
<td>36.95 ± 2.30</td>
<td>30.01 ± 1.18</td>
<td>2382 ± 62</td>
</tr>
<tr>
<td>Salvia sclarea</td>
<td>herb</td>
<td>0.19 ± 0.08</td>
<td>0.15 ± 0.26</td>
<td>330 ± 8</td>
</tr>
<tr>
<td>Stytra benjoin</td>
<td>resin</td>
<td>8.10 ± 0.30</td>
<td>27.79 ± 0.06</td>
<td>3635 ± 18</td>
</tr>
<tr>
<td>Trigonella foenum graecum</td>
<td>seed</td>
<td>9.23 ± 0.66</td>
<td>13.27 ± 0.62</td>
<td>4114 ± 132</td>
</tr>
<tr>
<td>Vanilla planifolia</td>
<td>pod</td>
<td>0.89 ± 0.29</td>
<td>2.56 ± 0.18</td>
<td>1593 ± 12</td>
</tr>
<tr>
<td>Zingiber officinalis</td>
<td>root</td>
<td>0.25 ± 0.94</td>
<td>3.14 ± 0.44</td>
<td>370 ± 28</td>
</tr>
</tbody>
</table>

* a Data are expressed as the mean of triplicate ± SD.
scavenging activities. Similar to the results obtained for radical scavenging assays, oak, clove, cinnamon, and pine extracts showed very strong ferric ion reducing activities (15.92, 7.00, 6.48, and 6.45 mmol Fe$^{2+}$/g respectively), as well as commercial pine extract (7.33 mmol Fe$^{2+}$/g). In this study, ambrette (Abelmoschus moschatus) and chamomile (Matricaria recutita) extracts possessed the lowest ferric reducing capacities (0.08 and 0.12 mmol Fe$^{2+}$/g, respectively).

**Total Phenolic Content.** There was a wide range of phenolic concentrations in the aqueous plant extracts analyzed, as shown in Table 2. The values varied from 6.86 to 397.03 mg GAE per g of sample as measured by the Folin–Ciocalteu method, which represents a variation of approximately 200-fold. Four extracts showed a very high phenolic content (> 300 mg GAE/g): oak, pine, and cinnamon aqueous extracts with, respectively, 397.03, 360.76, and 309.23 mg GAE/g of sample, and commercial pine extract with 363.02 mg GAE/g of sample. Clove and mate extracts also showed a high phenolic content (about 200 mg GAE/g) of 212.85 and 202.60 mg GAE/g of sample, respectively. Among the selected plants, juniper and ambrette extracts showed a very low phenolic content (6.86 and 14.84 mg GAE/g, respectively).

**Correlation between Assays.** To correlate the results obtained with the different methods, a regression analysis was performed (correlation coefficient ($R$), Table 3). Significant correlations were found between the various methods used to determine the antioxidant potential, especially between ABTS and FRAP assays ($R = 0.946$, Figure 1), and DPPH and ABTS assays ($R = 0.906$, Figure 2). The lowest correlations were found between the ORAC assay and others ($R = 0.618$ and $R = 0.744$ with FRAP and SOD assays, respectively).

Results of antioxidant capacities were also correlated to phenolic compound concentration determined by the Folin–Ciocalteu method. Results obtained with DPPH and ABTS assays can be related significantly with results obtained with the Folin–Ciocalteu method ($R = 0.939$ and $R = 0.966$, Figure 3). Likewise, a strong correlation was found between the ferric reducing potential, determined by the FRAP assay, and total phenolic content ($R = 0.906$, Figure 4). The lowest correlations were found with ORAC and SOD assays ($R = 0.831$ and $R = 0.845$, respectively).

![Figure 1. Correlation between ABTS and FRAP assays. Correlation coefficient $R = 0.946$.](image-url)
DISCUSSION

Antioxidant capacities of plant extracts not only depend on extract composition but also on the conditions of the test used. There are numerous published methods measuring total antioxidant capacity in vitro, which can be classified into two types: assays based on hydrogen atom transfer (HAT) and assays based on electron transfer (ET). HAT-based assays, like the ORAC assay, apply a competitive reaction scheme, in which antioxidant and substrate compete for thermally generated peroxyl radicals. ET-based assays measure the capacity of an antioxidant to reduce an oxidant, which changes color when reduced. The degree of color change is correlated with the sample’s antioxidant concentration. ET-based assays include the total phenols assay by Folin–Ciocalteu reagent, DPPH and ABTS radical scavenging capacity assays, the SOD assay, and the FRAP assay (26). No single method is sufficient; more than one type of antioxidant capacity measurement needs to be performed to take into account the various modes of action of antioxidants (26, 27).

In this study, we determined the free radical scavenging capacities of the selected plant extracts using DPPH, ABTS, and ORAC assays, and their ferric reducing capacities using the FRAP assay. DPPH, ABTS, and FRAP assays have been widely used to determine the antioxidant capacities of plant extracts as they require relatively standard equipment and deliver fast and reproducible results. Indeed, an interlaboratory comparison of six methods for measuring antioxidant potential published recently showed that DPPH and ABTS assays are the easiest to implement and yield the most reproducible results (28). The ABTS assay is particularly interesting in plant extracts because the wavelength absorption at 734 nm eliminates color interference (14). The ORAC assay requires expensive equipment and is longer to perform, but is to date the only method that takes free radical action to completion and uses the AUC technique for quantitation. It thus combines both inhibition percentage and the length of inhibition time of the free radical action by antioxidants in a single quantity (27). Moreover, this assay is considered to be more significant as it uses a biologically relevant radical source (16). The SOD assay is used much less to assess the antioxidant potential of plant extracts. Similar to the ORAC assay, the SOD assay uses a biologically relevant radical source. Moreover, this assay is easy to implement, such as the DPPH, ABTS, and FRAP assays.

The DPPH, ABTS, FRAP, ORAC, and SOD assays gave comparable results for the antioxidant activity measured in aqueous extracts of 30 selected plant extracts. The highest correlations were found between DPPH, ABTS, and FRAP assays, especially between ABTS and FRAP assays, a result previously reported by Thaipong et al. (19). The lowest correlations were found between the ORAC assay and others. Unlike the others, the ORAC assay takes into account the kinetic action of antioxidants, which might explain the discrepancy between the results obtained with the ORAC assay and those obtained with the other assays.

Significant correlations were also found between DPPH, ABTS, and FRAP assays and total phenolic content determined by the Folin–Ciocalteu method. These results indicate a relationship between phenolic compound concentration in plant extracts and their free radical scavenging and ferric reducing capacities. Therefore, the presence of phenolic compounds in plant extracts contributes significantly to their antioxidant potential. This result is in agreement with previous reports that ferric reducing potential can be related to phenolic content (13, 18).

Antioxidant properties of phenolic compounds are directly linked to their structure. Indeed, phenolics are composed of one (or more) aromatic rings bearing one or more hydroxyl groups and are therefore potentially able to quench free radicals by forming resonance-stabilized phenoxyl radicals (29, 30).

Among the 30 selected plants analyzed, oak, pine, cinnamon, clove, and mate possessed the highest antioxidant properties. Oak is an important potential source of natural antioxidants. The antioxidant properties of wines grown in oak barrels have been reported in several studies (23), but the antioxidant...
properties of plant extracts are much less documented. Here, we found that oak wood aqueous extract possessed very strong antioxidant activities, associated with a very high total phenolic content greater than that of some well-known antioxidant-rich plant extracts and antioxidant-used commercial plant extracts. Phenolic compounds have already been characterized in soluble fractions of oak heartwood, and identified as ellagitannins, such as vescalagin and castalagin, and phenolic acids such as gallic acid and ellagic acid (31). The pine and cinnamon extracts analyzed in this study possessed very strong antioxidant properties. These properties have been previously demonstrated in organic or aqueous extracts, in different species and with various assays (32–34). Pine bark and cinnamon bark phenolic components have been identified as flavan-3-ols such as catechin, epicatechin and procyanidins, and phenolic acids (35, 34, 36). Clove and mate extracts also demonstrated strong antioxidant properties and relatively high total phenolic content, in agreement with previous studies (33, 34, 37, 38). Some phenolic compounds have been characterized from clove buds, for example, phenolic volatile compounds such as eugenol, and phenolic acids such as gallic and caffeic acids (34, 39). Mate leaf major phenolic compounds have been identified as chlorogenic acids (40). In this study, we have also identified a promising source of natural antioxidant compounds from plants poorly studied, such as cistus, cabreuva, poplar, and benzoin, which have presented moderate antioxidant capacities.

This investigation further supports the view that some plants are promising sources of natural antioxidants. Antioxidant properties and total phenolic content differed significantly among the 30 selected plant extracts. Among these plant extracts, oak, pine, cinnamon, mate, and clove extracts showed very strong antioxidant properties and high total phenolic content. A significant correlation between antioxidant properties and total phenolic content was found, indicating that phenolic compounds are the major contributor to the antioxidant properties of these plant extracts. We have thus identified some promising antioxidant plant extracts. Additional studies are needed to characterize the active compounds and biological activities of these active plant extracts so that they may be included in nutraceutical formulations.

ACKNOWLEDGMENT

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LITERATURE CITED

(31) Nottier, M. F.; Vivas, N.; Vivas De Gualjac, N.; Absalon, C.; Vitry, C.; Fouquet, E. Global fractionation of oak earwood extractable polymers (lignins, polysaccharides and ellagitannins)


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