Phytochemicals and Antioxidant Activities of Edible Herbs

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ABSTRACT

The contents of plant chemicals such as volatile compounds, phenolic compounds, fatty acids content and antioxidant activities from Thai edible herbs were determined. Eucalyptol was the most prominent volatile compound in Alpinia galanga (68%). The main phenolic acids (hydrocinnamic acids) in these herbs were ferulic acid, sinapic acid and syringic acid. Ferulic acid was the major hydrocinnamic acid derivative, ranging from 2 to 52 mg/g, followed by sinapic acid (16 to 24 mg/g) and syringic acid (1 to 8 mg/g). Polyunsaturated fatty acid (PUFA) was the most predominant fatty acid found in analyzed Thai herbs, followed by saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA). Four PUFAs including 18:3n-3, 18:2n-6, 18:3n-6 and 20:4n-6 was detected in the samples. Alpinia galanga had the highest omega-3 PUFA (18:3n-3) among all samples tested. Boesenbergia pandurata extract exhibited highest antioxidant activities. This research provided useful information for screening Thai edible herbs as potential sources of bioactive components for consumers and public health workers.

Keywords: Edible herbs, Phytochemicals, Volatile compounds, phenolic compounds, fatty acids, antioxidants

1. INTRODUCTION

Southeastern Asian countries especially, in Thailand, China and India have been used edible herbs as flavoring, seasoning, coloring agents and food preservatives as well as medicinal plants and folk medicines for a thousand years [1]. Edible herbs, medicinal herbs, vegetables and fruits have been known to process antioxidant properties. The antioxidant activities could be obtained from leaves, roots, rhizome, flowers, fruits, seeds and bark [2]. Herbs have also been recognized as antimicrobial, anti-inflammatory, anti-mutagenic, anti-carcinogenic potential [3]. Edible herbs always contribute in Thai dishes, especially in dietary cultures where local edible herbs are used regularly [4]. Flavor is usually the result of many volatile and nonvolatile components presented in herbs, possessing diverse chemical and physicochemical properties [5]. Whereas the nonvolatile compounds contribute mainly to the taste, the volatile ones influence both taste and aroma. A vast array of compounds may be responsible for the aroma of the food products, such as alcohols, aldehydes, esters, dicarbonyls, short to medium chain free fatty acids, methyl ketones, lactones, phenolic compounds and sulphur compounds [6]. Phenolic compounds have strong antioxidant activities associated with their ability to scavenge free radicals, break radical chain reactions and chelate metals [7]. Increased consumption of phenolic compounds has been correlated with a reduced risk of cardiovascular disease and certain cancers [8-9]. Fatty acids play a major role as an energy source, affect cellular membrane structure and improve resistance to stress [10]. Polyunsaturated fatty acids (PUFAs) were found in some vegetables including watercress, mint, parsley, spinach, Chinese cabbage, Brussels sprouts, bok choy, cobs lettuce, broccoli and Chinese broccoli [11-12]. Dietary intake of unsaturated fatty acids has been shown to reduce the risk of cardiovascular disease and possibly the incidence of some cancers and diabetes among other conditions [13]. The demand for these commodities has grown in recent years as a consequence of continually increasing consumption of ready-to-eat foods, which include edible herbs as ingredients in Thai cuisine [14]. The selected edible herbs were used in various dishes such as Thai curry and spicy soups with local style cooking in Northeastern Thailand. However, the knowledge about volatile compounds, phenolic compounds, fatty acids and antioxidant properties of edible herbs consumed in Northeastern Thailand is scared. Therefore, the aim of this research was to investigate the volatile compounds, phenolic compounds, fatty acids and antioxidant properties of edible herbs from Northeastern Thailand. The receiving results could be
useful information for consumers and public health workers.

2. MATERIAL AND METHODS

2.1 Chemicals

The compounds 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,4,6-tripiridyl-s-triazine (TPTZ), Folin-Ciocalteu’s reagent, standards of gallic, ferulic, p-phthoxybenzoic, protocatechuic, p-coumaric, caffeic, syringic, sinapic, chlorogenic and vanillic acids were purchased from Sigma–Aldrich Fine Chemicals (St. Louis, MO). The phosphoric acid, methanol and acetonitrile used in the HPLC analysis were purchased from Merck (Darmstadt, Germany). All other solvents purchased from Fisher Scientific were of the highest available purity.

2.2 Edible herbs

Edible herbs including galangal (Alpinia galanga), ginger (Zingiber officinale Rosc.), turmeric (Curcuma longa Linn.) and kaempfer (Boesenbergia pandurata) were obtained from three representative markets in the Ubon Ratchathani province during September to November, 2012. At each market, 3 kg samples were sampled from three representative outlets. Single composite samples for each representative market, were prepared by combining about 500 g of homogenized single sample of the same rhizome variety from three representative outlets and then homogenizing again to obtain a uniform single composite sample. All samples were cleaned and freeze-dried using freeze-drier (Model DuratopTM IP/Dura DryTM IP, FTS® System, Inc., Stone Ridge, NY, USA) before analysis. Analyses were conducted in triplicate (n = 3).

2.3 Determination of volatile compounds

The samples were ground and 0.2 g was put in vials. The vials were sealed with an aluminium–rubber septum (Supelco, Bellefonte, PA, USA) and analyzed by the headspace sampling technique [15]. GC-MS analysis was carried out using a GC-2010 chromatograph coupled to a GC/MS-QP2010 (Shimadzu, Japan). Samples were analyzed on a fused-silica capillary column Rtx-5Ms (5% diphenyl 95% dimethyl polysiloxane, 30 mm length, 0.25 mm internal diameter, 0.25 μm film thickness; Restek, U.S.) and Rtx-5 (5% diphenyl 95% dimethyl polysiloxane, 30 mm length, 0.25 mm internal diameter, 0.25 μm film thicknesses; Restek, U.S.). Carrier gas, helium; constant pressure, 134.2 kPa; injector temperature, 250°C; split ratio, 1:5; temperature program, 80 to 250°C at 10°C /min then held isothermal (2 min) at 250°C; ion source temperature, 200°C; transfer line temperature, 250°C; ionization energy, 70 eV; electron ionization mass spectra were acquired over the mass range 35-550 u. Identification of the components was performed by comparing the mass spectra with those on record in the Wiley G 1035 A library [16].

2.4 Determination of total phenolic content

The extracts prepared from the sample (1 g) were extracted for 2 h with 10 mL of 80% ethanol at room temperature on an orbital shaker (Heidolph NIMAX 1010, Schwabach, Germany) set at 180 rpm. The mixture was centrifuged at 1400 x g for 20 min and the supernatant was decanted into a 30 mL vial. The pellet was re-extracted under identical conditions. Supernatant was combined and used for total phenolics contents. Total phenolics content was determined using Folin–Ciocalteu reagent as followed by Abu-Bakar et al. [17] as adapted from Velioglu et al., [18]. Briefly, 300 μL of extract was mixed with 2.25 mL of Folin–Ciocalteu reagent (previously diluted 10-fold with distilled water) and allowed to stand at room temperature for 5 min; 2.25 mL of sodium carbonate (60 g/L) solution was added to the mixture. After 90 min at room temperature, absorbance was measured at 725 nm using spectrophotometer (Model RF-1500, Shimadzu Co., Kyoto, Japan). Results were expressed as mg gallic acid equivalents in 1 g of dried sample (mg GAE/g).

2.5 Identification and quantification of phenolic compounds

2.5.1 Extraction of herbal phenolics

The phenolic compounds in the herb samples were extracted using a modification of the procedure described by Bengoechea et al. [19] as adapted from Uzelac et al. [20]. Each sample (5 g) was weighed with 50 mL of methanol/HCl (100:1; v/v) which contained 2% tertbutylhydroquinone in inert atmosphere (N2) during 12 h at 35°C in the dark. The extract was then centrifuged at 4000 rpm/min using a refrigerated centrifuge (Beckman Coulter, Avanti J-E Centrifuge, Palo Alto, CA, USA), and the supernatant was evaporated to dryness under reduced pressure (35–40°C). The residue was redissolved in 25 mL of water/ethanol (80:20, v/v) and extracted four times with 25 mL of ethyl acetate. The organic fractions were combined, dried for 30–40 min with anhydrous sodium sulfate, filtered through the Whatman-40 filter, and evaporated to dryness under vacuum (35–40°C). The residue was redissolved in 5 mL of methanol/ water (50:50, v/v) and filtered through a 0.45 μm filter before injection (20 μL) into the HPLC apertures. Samples were analyzed in triplicate.

2.5.2 HPLC-DAD system for analysis of phenolic compounds

RP-HPLC system for analysis of phenolic compounds was performed using Shimadzu LC-20AC pumps, SPD-M20A with diode array detector and chromatographic separations were performed on a LUNA C-18 column (4.6 x 250 mm i.d., 5 μm). The composition of solvents and the gradient elution conditions used were described previously by Bengoechea et al. [19] Schieber et al. [21] and Butsat et al. [22] with some modifications. The mobile phase consisted of purified water with acetic acid (pH 2.74) (solvent A) and acetonitrile (solvent B) at a flow rate
of 0.8 mL/min. Gradient elution was performed as follows: from 0 to 5 min, linear gradient from 5 to 9% solvent B; from 5 to 15 min, 9% solvent B; from 15 to 22 min, linear gradient from 9 to 11% solvent B; from 22 to 38 min, linear gradient from 11 to 18% solvent B; from 38 to 43 min, from 18 to 23% solvent B; from 43 to 44 min, from 23 to 90% solvent B; from 44 to 45 min, linear gradient from 90 to 80% solvent B; from 45 to 55 min, isocratic at 80% solvent B; from 55 to 60 min, linear gradient from 80 to 5% solvent B and a re-equilibration period of 5 min with 5% solvent B used between individual runs. Operating conditions were as follows: column temperature, 38°C, injection volume, 20 µL, and UV-diode array detection at 280 nm (hydroxybenzoic acids), 320 nm (hydroxyacinamic acids) and 370 nm (flavonols) at a flow-rate of 0.8 mL/min. Spectra were recorded from 200 to 600 nm. Phenolic compounds in the samples were identified by comparing their relative retention times and UV spectra with those of authentic compounds and were detected using an external standard method. Standards namely: gallic, ferulic, p-hydroxybenzoic, protocatechuic, p-coumaric, caffeic, syringic, sinapic, chlorogenic and vanillic acids were purchased from Sigma-Aldrich Fine Chemicals (St. Louis, MO).

2.6 Determination of fatty acids content

2.6.1 Lipid extraction

Lipids were extracted according to the method of Bligh and Dyer [23]. Approximately 5 g of well-ground samples was extracted with 50 mL of chloroform-methanol (2:1, v/v) containing 10 mg/L of butylated hydroxytoluene and 0.1 mg/mL of nanodecanoic acid (C19:0, Sigma) as an internal standard. Then, the samples were stored in a fume hood overnight. Each sample was filtered and transferred into a separate funnel and added with 15 mL of 0.9% sodium chloride. The samples were shaken well to allow the phases to separate; the lower phase was then evaporated and transferred into a 10 mL volumetric flask.

2.6.2 Fatty acids content determination

Fatty acid methyl esters (FAMEs) of the total lipid extract were prepared by transesterification in H2SO4 (0.9 mol/L in methanol). Before injection into the gas chromatography, the FAMEs were filtered by Sep-pak silica column (Alltech Associates, Inc., Deerfield, IL). Samples (1 mL) were analyzed quantitatively using a Shimadzu model GC-2014 system (Shimadzu, Tokyo, Japan) fitted with flame ionization detection eluted with H2 at 30 ± 1 mL/min, with a split ratio of 1:17. A fused silica capillary column (30 m x 0.25 mm, 25 μm film thickness; DB-Wax, USA) was used. The injector and detector were maintained at 250°C. Nitrogen was used as a carrier gas and temperature programming was from 150°C (hold 5 min) to 230°C at 15°C /min, then to 170°C (hold 10 min) at 10°C /min, then to 200°C (hold 3 min) at 5°C /min and then to 230°C (hold 2 min) at 15°C /min. Fatty acids were identified by comparison with standard mixtures of FAME (nanodecanoic acid) running the same method of Yang et al. [24]. The emergent peaks were identified by comparing their retention time with internal standard fatty acid nanodecanoic acid (C19:0). Fatty acid contents were calculated as the following formulas [25].

Fatty acid content = (area under each peak/area of internal standard)×100×10/g sample

2.7 Antioxidant activities determination

2.7.1 DPPH free radical scavenging activity

The hydrogen atom or electron-donation ability of the corresponding extracts and some pure compounds was measured from the bleaching of a purple-colored methanol solution of DPPH [26]. The antioxidant activity of the extracts, on the basis of the scavenging activity of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical, was determined by the method described by Braca et al. [27]. Ethanolic extract (0.1 mL) was added to 3 mL of a 0.001 M DPPH in methanol. The absorbance at 517 nm was determined after 30 min, and the percent inhibition of activity was calculated as [(A0−Ao)/Ao]×100 (Ao = absorbance without extract; A0 = absorbance with extract).

2.7.2 Ferric reducing antioxidant power (FRAP)

The total reducing capacity was determined using the FRAP assay [28]. The FRAP reagent was initially prepared consisting of 300 mM acetate buffer, pH 3.6, 10 mM iron reagent (TPTZ) solution in 40 mM HCl, and 20 mM FeCl3·6H2O solution. The fresh working solution was warmed at 37°C before using. The extract (100 μL) was allowed to react with 1.9 mL of the FRAP solution. After incubation for 4 min, the absorbance was read at 593 nm using a spectrophotometer. The results were calculated by standard curves prepared with known concentrations of FeSO4, and were expressed as μmol FeSO4/g.

2.8 Statistical analysis

The experiments were run in triplicate determinations. Data were subjected to analysis of variance (ANOVA) and mean comparison was carried out using Duncan’s multiple range test (DMRT) [29]. Statistical analyses were performed using the Statistical Package for Social Science (SPSS 11.0 for windows, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1 Volatile compounds

The extraction of the volatile compounds from Thai edible herbs was carried out following the headspace sampling and analysis by means of coupled GC-MS method. Fifteen volatile compounds were identified in the rhizome of all samples. There were significant differences among different varieties tested. Eucalyptol was the most prominent volatile compound in Alpinia galanga (68%) (Table1). Isoserine was found to be a volatile in Curcuma longa.
Linn. (34%) and Alpinia galanga (10%) (Table 1). However, paeonol, (E)-carveol, (E,E)-2,4-octadienial, methyl salicylate, myrtanol and eugenol acetate were the major volatile compounds in Paeoniae Radix (Paenia albiflora Pallas var. trichocarpa Bunge) [30]. The different types of volatile compounds in different herb species might be resulted in the various tastes and flavor of those herbs [31]. Volatile compounds are responsible for plant flavor [32]. Herbs have been used for providing humans with tastes in foods. In addition to taste, their beneficial health effects have also been widely attracted by food scientists.

### Table 1 Volatile compounds (% area) of edible herbs

<table>
<thead>
<tr>
<th>Edible herbs</th>
<th>Volatile compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpinia galangal</td>
<td>Eucalyptol (68.80%), Isoserine (10.33%), Caryophyllene (8.02%), 4-Carvomenthenol (6.88%), Alpha-humulene (5.97%)</td>
</tr>
<tr>
<td>Boesenbergia pandurata (Roxb.) Schltro</td>
<td>Alpha-tumerone (41.85%), Alpha-phellandrene (26.98%), Zingiberene (16.06%), Camphene (15.11%)</td>
</tr>
<tr>
<td>Curcuma longa Linn.</td>
<td>Isoserine (34.38%), 1-heptadecene (22.91%), Carotol (12.65%), Alpha-phellandrene (10.85%)</td>
</tr>
<tr>
<td>Zingiber officinale Roscoe</td>
<td>Zingiberene (26.84%), Eucalyptol (26.07%), Camphene (18.19%), Betas-sesquiphellandrene (12.09%), Citral (8.55%), Hexaldehyde (8.27%)</td>
</tr>
</tbody>
</table>

### Table 2 Phenolic acids of edible herbs

<table>
<thead>
<tr>
<th>Edible herbs</th>
<th>Hydrobenzoic acids (mg/g DW)</th>
<th>Hydrocinamic acids (mg/g DW)</th>
<th>Total phenolic acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpinia galangal (Linn.)</td>
<td>GA</td>
<td>PCCA</td>
<td>p-HO</td>
</tr>
<tr>
<td></td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Boesenbery pandurata (Roxb.) Schltro</td>
<td>ND</td>
<td>ND</td>
<td>3.35±0.34</td>
</tr>
<tr>
<td>Curcuma Longa Linn.</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Zingiber officinale Roscoe</td>
<td>ND</td>
<td>ND</td>
<td>1.79±0.19</td>
</tr>
</tbody>
</table>

Table 2 Phenolic acids of edible herbs.

<table>
<thead>
<tr>
<th>ND= not detectable</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA= Gallic acid; PCCA=Protocatechuc acid; p-HO=p-hydroxy benzoic acid; ChA= Chorogenic acid; VA= Vanillic acid; CFA= Caffeic acid; SyA=Syringic acid; p-CA= p-Coumaric acid; FA=Ferulic acid; SNA=Sinapic acid.</td>
</tr>
<tr>
<td>*Means ± SD (n=3). Different superscripts in the same row indicate the significant differences (p &lt; 0.05).</td>
</tr>
</tbody>
</table>

### 3.2 Total phenolic content (TPC)

Ethanol extracts obtained from the samples were evaluated for the presence of phenolic compounds. The samples were evaluated using the Folin-Ciocalteu assay, which was suggested as a fast and reliable method to quantify phenolics in foods [34]. TPC was determined in comparison with standard gallic acid and the results expressed in terms of mg gallic acid equivalent (GAE)/g DW. The levels of TPC in the evaluated edible herbs varied from 3 mg GAE/g DW in Zingiber officinale Roscoe Wall to 12 mg GAE/g DW in Boesenbergia pandurata (Roxb.) Schltro (Fig. 1). The highest value of TPC was found in Boesenbergia pandurata (Roxb.) Schltro. (12 mg GAE/g DW), followed by Alpinia galangal (8 mg GAE/g DW) compared to other samples. However, high phenolic content was found in villous amomum, Fructus amomi (83.47 mg GAE/g) [35]. The different phenolic content in various herb species might be different from cultivars. Phenolic compounds are the main bioactive compounds in fruits and vegetables [36]. Maqsood et al. [37] reported that phenolic compounds have been received considerable attention, due to their potential antioxidant activities, which potentially have beneficial implications in human health.

![Figure 1](image-url)
3.3 Identification of phenolic acids

RP-HPLC analysis was used to identify the phenolic compounds of the extracts, by comparison with standard compounds. Phenolic acids are hydroxylated derivatives of hydrobenzoic acid and hydrocinnamic acid, which often occur in plants as esters, glycosides and bound complexes [38]. In the analyzed samples, it was possible to identify 10 phenolic acids including gallic acid, protocatechuic acid, p-hydroxy benzoic acid, chlorogenic acid, vanillic acid, caffeic acid, syringic acid, p-coumaric acid, ferulic acid and sinapic acid. The distribution of phenolic acids in all samples is presented in Table 2. The highest concentrations of total phenolic acids were found in Boesenbergia pandurata (Roxb.) Schltr. (100 mg/g DW), followed by Zingiber officinale Roscoe. (41 mg/g DW), Curcuma Longa Linn. (26 mg/g DW) and Alpinia galanga (Linn.) (24 mg/g DW). The main phenolic acids (hydrocinnamic acids) in these samples were ferulic acid, sinapic acid and syringic acid. Ferulic acid was the major hydrocinnamic acid derivative, ranging from 2 to 52 mg/g DW, followed by sinapic acid (16 to 24 mg/g DW) and syringic acid (1 to 8 mg/g DW). The highest content of ferulic acid, sinapic acid and syringic acid was found in Boesenbergia pandurata (Roxb.) Schltr. (Table 2).

High levels of ferulic acid are found in herbs, vegetables, fruits, cereals, and coffee [39]. Ferulic acid is an abundant dietary antioxidant which may offer beneficial effects against cancer, cardiovascular disease and diabetes [39]. The hydroxybenzoic acid, gallic acid, vanillic acid and p-hydroxy benzoic acid occurred in low quantities (Table 2). Natural antioxidants are important ingredients that facilitate the control of the oxidative deterioration of foods [40]. Herbs extracts containing high amounts of total and individual phenolics, were found to exhibit antioxidant activities [41]. Phenolic compounds found in plants have been reported to have a strong antioxidant activity [41-43]. The antioxidant potential of phenolic compounds is dependent on the number and arrangement of the hydroxyl groups as well as the presence of electron donating substituent in the ring structure [42].

3.4 Fatty acid content

Polyunsaturated fatty acid (PUFA) was the most predominant fatty acid found in analyzed samples, followed by saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) (Table 3). The content of PUFAs in samples ranged from 547 mg/100 g in Zingiber officinale Roscoe. to 2792 mg/100 g in Curcuma longa Linn. (Table 3). Consumption of PUFAs, especially n-3 PUFA is increasing because of beneficial effects on reducing the risk of diabetes by reduction of glucose intolerance and lowering blood pressure [44]. Linoleic acid (C18:2n-6) content ranged from 167 mg/100 g in Zingiber officinale Roscoe. to 785 mg/100 g in Curcuma longa Linn. (Table 3). Curcuma longa Linn. contained the highest GLA (18:3n-6) (1972 mg/100 g). In addition, arachidonic acid (AA, 20:4n-6) was found only in Boesenbergia pandurata (Roxb.) (151 mg/100 g). Essential fatty acids are related to human health [45-46]. Plants oil provide rich sources of triglycerides containing n-6 PUFAs mainly LA [47]. Additionally, green vegetables (watercress, mint, parsley, spinach, Chinese cabbage, Brussels sprouts, bok choy, cobs lettuce, broccoli, Chinese broccoli, baby bok choy) are known to contain a relatively high proportion of omega-3 PUFAs, primarily in the form of α-linolenic acid (ALA) [11]. Vegetables contribute polyunsaturated fatty acids (PUFAs) of the n-3 variety, mainly ALA [12]. ALA was found in plants, animals, zooplankton, phytoplankton and marine species. The most predominant n-3 polyunsaturated fatty acid (PUFA) in terrestrial plants is ALA [48]. LA and ALA are essential fatty acids for human because they cannot be synthesized by human. The two most important metabolically active polyunsaturated fatty acids are the parent fatty acids LA and ALA [46, 48-49]. LA is only fatty acid to appreciably lower plasma/serum total and low-density lipoprotein (LDL) cholesterol levels when substituted

### Table 3 Fatty Acid Contents (mg/100 g) of Edible Herbs

<table>
<thead>
<tr>
<th>Edible herbs</th>
<th>C14:0</th>
<th>C15:0</th>
<th>C16:0</th>
<th>C18:0</th>
<th>SFA</th>
<th>C16:1</th>
<th>C18:1</th>
<th>MUFA</th>
<th>C18:2 n-6</th>
<th>C18:3 n-6</th>
<th>C18:3 n-9</th>
<th>C20:4 n-6</th>
<th>C21:5 n-9</th>
<th>C20:5 n-3</th>
<th>C20:5 n-6</th>
<th>C20:5 n-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpinia galanga (Linn.)</td>
<td>22.13</td>
<td>ND</td>
<td>154.58</td>
<td>24.63</td>
<td>ND</td>
<td>201.34</td>
<td>ND</td>
<td>80.06</td>
<td>80.06</td>
<td>200.51</td>
<td>573.62</td>
<td>58.85</td>
<td>ND</td>
<td>832.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swartz.</td>
<td>±4.10*</td>
<td>±8.41</td>
<td>±8.27</td>
<td>±0.19</td>
<td>±0.08</td>
<td>±0.08</td>
<td>±0.49</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.05</td>
<td></td>
</tr>
<tr>
<td>Boesenbergia pandurata (Roxb.) Schltr.</td>
<td>ND</td>
<td>ND</td>
<td>1218.77</td>
<td>394.02</td>
<td>ND</td>
<td>1612.79</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>600.06</td>
<td>1382.10</td>
<td>145.48</td>
<td>150.96</td>
<td>2278.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curcuma Longa Linn.</td>
<td>ND</td>
<td>ND</td>
<td>187.46</td>
<td>77.54</td>
<td>265.00</td>
<td>ND</td>
<td>87.54</td>
<td>ND</td>
<td>785.37</td>
<td>1972.39</td>
<td>314.54</td>
<td>ND</td>
<td>2792.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zingiber officinale</td>
<td>ND</td>
<td>±9.21</td>
<td>±9.75</td>
<td>±0.51</td>
<td>±0.31</td>
<td>±0.31</td>
<td>±0.53</td>
<td>±1.03</td>
<td>±0.12</td>
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<td></td>
<td></td>
<td></td>
<td>±1.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roscoe.</td>
<td>±1.86</td>
<td>±8.03</td>
<td>±0.06</td>
<td>±0.06</td>
<td>±0.05</td>
<td>±0.05</td>
<td>±0.06</td>
<td>±1.51</td>
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<td></td>
<td></td>
<td></td>
<td>±1.46</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ND= not detectable

SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid

*Means ± SD (n=3)
for carbohydrate in the diet. Gamma linoleic acid (18:3n-6) has also been shown to support the treatment of rheumatoid arthritis, diabetic neuropathy, atopic eczema, cancer, asthma, osteoporosis and possibly coronary heart disease (CHD) [50]. AA is the precursor of prostaglandin E2 (PGE2) [51-52]. Dietary n-6 fatty acids also have been shown to possess effective tumoricidal properties, when taken according to their recommended daily intake, against prostate and breast cancers as well as malignant gliomas pancreas tumors and lymphocytic leukaemia [53-54]. The content of total saturated fatty acids (SFAs) in samples ranged from 101 mg/100 g in Zingiber officinale Roscoe. to 1,613 mg/100 g in Boesenbergia pandurata (Roxb.) (Table 3). The main SFA in samples were palmitic acid (16:0) and stearic acid (18:0). Kelley et al. [55] reported that diet enriched in palmitic acid (16:0) resulted in an increased ex vivo collagen and adenosine diphosphate (ADP) induced whole blood platelet aggregation. Li et al. [56] also reported that diet rich in SFA may influence Thromboxane A2 (TXA2) formation via effect on tissue proportion of AA. Palmitoleic acid (16:1) and oleic acid (18:1) were detected in the samples. The content of total MUFA ranged from 57 mg/100g in Zingiber officinale Roscoe. to 87 mg/100g in Curcuma longa Linn. (Table 3). Consumption of MUFA has the beneficial effect on reducing the risk of diabetes [57].

3.5 Antioxidant activities of edible herbs

3.5.1 DPPH radical scavenging activity

The DPPH radical is widely used to evaluate the radical scavenging activity of antioxidant compounds. The ability to act as donor of hydrogen atoms in the transformation of the DPPH radical to its reduced form was investigated for different edible herb extracts. The antioxidant activities of Thai edible herbs are shown in Table 4. The results showed that the DPPH radical scavenging activity of edible herbs ranged from 78% to 86% (Table 4). It was observed that Curcuma longa Linn. having high inhibition activity was a very potent radical scavenger. High DPPH radical scavenging activity of some edible herbs extract (kemum (82.6%), ginger (79.0%) and turmeric (64.6%)) were also reported [57]. The varied radical scavenging activity of the herbs extracts might be depended on the amount of total phenolic content in each sample (Fig. 1). Several flavonoids and polyphenols have been isolated from plant extracts with potent DPPH radical scavenging activities [44]. Marwah et al. [58] reported that DPPH radical scavenging activity of plants depends upon species.

3.5.2 Ferric reducing antioxidant power (FRAP)

The FRAP assay is a method of measuring the ability of antioxidants to reduce Fe³⁺ to Fe²⁺ [28]. The formation of blue color from Fe³⁺-TPTZ complex (Fe³⁺ tripyridyltriazine) increases the absorbance at 593 nm. The FRAP values of the extracts of edible herbs are shown in Table 4. The FRAP value of different edible herbs extracts indicated that the Boesenbergia pandurata extract had the greatest reducing power, followed by Alpinia galangal, Curcuma longa and Zingiber officinale (Table 4). High antioxidant activity determined by using FRAP method was also found in Chinese edible spices [32]. The Boesenbergia pandurata extract gave high FRAP values; these might be due to their higher ferulic and total phenolic acids contents (Table 2). Phenolic acids was positively associated with the FRAP [37]. Polyphenolic compounds found in edible plants have been reported to have multiple biological effects, including antioxidant activity [38].

<table>
<thead>
<tr>
<th>Edible herbs</th>
<th>Antioxidant activity</th>
<th>DPPH (% inhibition)</th>
<th>FRAP (µmol FeSO₄/100 g sample )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpinia galangal</td>
<td></td>
<td>85.29±0.18ᵇ</td>
<td>563.09±2.46ᵇ</td>
</tr>
<tr>
<td>Boesenbergia pandurata (Roxb.) Schltro</td>
<td></td>
<td>86.42±0.32ᵃ</td>
<td>606.39±2.25ᵃ</td>
</tr>
<tr>
<td>Curcuma longa Linn.</td>
<td></td>
<td>82.57±0.94ᵇ</td>
<td>472.06±1.46ᵇ</td>
</tr>
<tr>
<td>Zingiber officinale Roscoe.</td>
<td></td>
<td>78.26±0.74ᵈ</td>
<td>421.24±1.78ᵈ</td>
</tr>
</tbody>
</table>

*Means ± SD (n=3).

Different superscripts in the same column indicate the significant differences (p < 0.05).

4. CONCLUSION

The study shows that there are differences in phytochemicals and antioxidant properties of edible herbs consumed in Thailand. Eucalyptol was the most prominent volatile compound in Alpinia galangal. The main phenolics (hydrocinnamic acids) in those herbs were ferulic acid, sinapic acid and syringic acid. Linoleic acid (LA, 18:2n-6), alpha-linolenic acid (ALA, 18:3n-3), gamma-linoleic acid (GLA, 18:3n-6), and arachidonic acid (AA, 20:4n-6) were detected in the samples. Boesenbergia pandurata extract exhibited highest antioxidant activities. There were significant differences among different varieties tested. This research generated useful information for consumers and researchers to utilize herbs as sources of bioactive compounds.
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