



## **Nutritional, Spectral and Thermal Characteristic of Lamiaceae Seeds**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. Authors PKS and SC collected and prepared the seed and soil samples for the analyses and analyzed the polyphenol, oil and starch contents. Author KSP designed the study and coordinated the analyses and paper writing. Author EKT determined the mineral content of the seeds and soils by XRF. Authors JMG and PMR collected and interpreted the FTIR spectra and thermograms. Authors KSP and PMR wrote the original draft. Author PMR took care of the Ms. revision. All the authors read and approved the final manuscript.*

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### **ABSTRACT**

**Aims:** Species of the family Lamiaceae possess a rich tradition of use for flavoring and medicinal purposes. This paper focusses on the nutritional and thermal characteristics of the seeds from eight species belonging to this family: *Gmelina arborea* Roxb. ex Sm., *Hyptis suaveolens* (L.) Poit., *Leonotis nepetifolia* (L.) R.Br., *Ocimum americanum* L., *Ocimum sanctum* L. (Rama Tulsi), *Ocimum*

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*tenuiflorum* L. (Krishna Tulsi), *Origanum vulgare* L. and *Tectona grandis* L.f.

**Methodology:** The oil, starch, total polyphenol, flavonoid and mineral contents for aforementioned seeds were determined. Fourier-transform infrared (FTIR) spectroscopy was used to assess the phytoconstituents. Thermogravimetric/derivative thermogravimetric analyses (TG/DTG) and differential scanning calorimetry (DSC) analyses were performed to analyze the decomposition patterns.

**Results:** The concentrations of oil, starch, total polyphenol, flavonoids and minerals for the seeds from the eight plants under study ranged from 11.8 to 50.4%, from 0.22 to 1.84%, from 295 to 5842 mg/kg, from 1660 to 12680 mg/kg and from 11756 to 33927 mg/kg, respectively. Unsaturated oils, polyphenols and lignin were recognized by vibrational spectroscopy. The sequence of thermal effects in the seed pyrolysis process above 100°C have been put in relation to seed protein crystallization (endotherm at 200°C), oxidation reactions and degradation of hemicellulose and other fiber components (at around 300°C), and decomposition of polyunsaturated (at 357°C) and mono-unsaturated (at 391°C) triglycerides.

**Conclusion:** Lamiaceae seeds are potential food alternatives to cereals.

**Keywords:** *Lamiaceae*; *seeds*; *fourier-transform infrared spectroscopy*; *thermal analysis*; *chemical compounds*; *mineral composition*.

## 1. INTRODUCTION

The Lamiaceae or Labiatae (Clade: Angiosperms / Eudicots / Asterids. Order: Lamiales) are a family of flowering plants comprising about 200 genera and 3,200 species, commonly with aromatic, herbage, quadrangular stems, and verticillate inflorescences. They are widely cultivated for medicinal, perfumery, culinary and ornamental purposes [1]. Members of this family are a source of strong aromatic essential oils, tannins, saponins and organic acids [2,3]. Eight Lamiaceae plants with a widespread distribution in central India, viz. *Gmelina arborea* Roxb., *Hyptis suaveolens* (L.) Poit, *Leonotis nepetifolia* (L.) R.Br., *Ocimum americanum* L., *Ocimum sanctum* L., *Ocimum tenuiflorum* L., *Origanum vulgare* L., and *Tectona grandis* L.f., are studied herein. *Gmelina arborea* (Malay bush-beech) and *T. grandis* (Bangkok teak) are large deciduous trees harvested for local use as a wood, food and medicine purposes and as a source of oils [4,5]. *Hyptis suaveolens* (pignut) is a strong-scented herb considered to be stimulant, carminative, endorific and lactagogue, which grows as a weed over large areas in barrel land in the rainy season. *Leonotis nepetifolia* (Christmas candlestick) is an annual short-lived perennial plant, often found in road, canal and riversides in the rainy season. *Ocimum americanum* L., *O. sanctum* L. (Rama Tulsi, light holy basil), *O. tenuiflorum* L. (Krishna Tulsi, dark holy basil), and *Origanum vulgare* are perennial and aromatic plants, used in treatments of various diseases [6,7]. These plants have shown promising properties as functional foods, in pain therapy and as bactericides and fungicides [8,9,

10,11,12,13]. The chemistry and uses of *G. arborea* and *H. suaveolens* seed oils have been reported [14,15], but most of the characteristics of Lamiaceae seeds from Indian origin remain undescribed. The purpose of this paper is to report the nutritional and mineral contents, and the thermal behaviour of the seeds from the eight selected species.

## 2. MATERIALS AND METHODS

### 2.1 Sample Collection

Seeds from the eight Lamiaceae plants (viz. *G. arborea* (GA), *T. grandis* (TG), *H. suaveolens* (HS), *L. nepetifolia* (LN), *O. americanum* (OA), *O. sanctum* (OS), *O. tenuiflorum* (OT) and *O. vulgare* (OV) under study were collected in the Raipur city area, India (21.25°N 81.63°E), and were authenticated by a plant taxonomist and by using a standard monograph [16]. The ripening periods of TG, HS and LN; OA, OS, OT and OV; and GA were October-November, December and May, respectively. Their leaves and fruits were collected in the relevant period together with near-surface soil samples in year, 2017.

### 2.2 Sample Preparation

The seeds were manually separated from the fruits. All samples were sun-dried for one week in a glass room, and further dried in an oven at 50°C overnight. Subsequently, they were crushed into fine powder and sieved out particles of mesh size, ≤100 µm. They were stored in the glass bottle and preserved in the refrigerator at -4°C.

## 2.3 Analyses

The pH value of the soil was determined by keeping a 5 g sample in a 100 mL conical flask with deionized water (15 mL) overnight. The pH value of the decanted solution was measured with a Hanna Instruments (Woonsocket, RI, USA) pH meter. The moisture content of the seeds was determined by drying the seeds at 105°C in an air oven for 6 h period to the analysis, and mean values were determined. All characterization results are presented on a dry weight (dw) basis.

The oil content in the seeds was determined by extraction from a 5 g powdered sample (kernel of GA and TG, and whole seed of HS, LN, OA, OS, OT and OV) in n-hexane (25 mL), as described in the literature [17]. The oil content was presented as a percentage on the basis of the dry weight (dw) of the seeds.

Analytical reagent (AR) grade sodium maleate (CAS 371-47-1) buffer, sodium acetate (CAS 127-09-3) buffer, potassium hydroxide (CAS 1310-58-3), amyglucosidase (CAS 9032-08-0), pancreatic- $\alpha$ -amylase (MDL MFCD00081319) were purchased from Sigma-Aldrich, and glucose oxidase–peroxidase was purchased from Megazyme International Ireland Ltd. The starch content of seeds was determined by the enzymatic method [18].

Analytical grade Folin-Ciocalteu reagent (MDL MFCD00132625), aluminum chloride (CAS 7446-70-0), tannic acid (CAS 1401-55-4), gallic acid (149-91-7) and quercetin (CAS 117-39-5) for the analysis of the phenols were purchased from Sigma-Aldrich. For the analysis of the total polyphenol content (TPC), 100 mg of sample (whole seed of GA, TG, HS, LN, OA, OS, OT and OV) in powder form were mixed with 5 mL of an acetone: Water mixture (70: 30, v/v), and subjected to sonication for 20 minutes at 20°C in an ultrasonic bath, according to the procedure described by Bertaud et al. [19]. The TPC of each extract was determined by use of the Folin-Ciocalteu reagent and expressed as tannic acid equivalents (TAE) [20]. The flavonoid content (Fla) was analyzed by the aluminum chloride method and expressed as quercetin equivalents (QE) [21].

A Bruker Tracer 5i portable X-ray fluorescence (pXRF) spectrometer (Serial Number 900F4473), equipped with a 4W rhodium anode and Xflash Silicon Drift Detector (SDD) with a typical resolution of 2028 channels, was employed for

the elemental analysis of the seed samples. Four standard reference materials, brown and white cowpea [*Vigna unguiculata* (L.) Walp.] seeds, cowpea and mango (*Mangifera indica* L.), leaves with reference values from ICP-OES and MS (As, Mo and Se in mg/kg) after Aqua Regia (HCl: HNO<sub>3</sub>, 4:1) digestion were used for validation of the pXRF results. A standard soil sample (NCS DC 73382 CRM) was used for as a reference for the soil analyses.

The vibrational spectrum in the 400 to 4000 cm<sup>-1</sup> range was characterized using a Thermo Scientific (Waltham, MA, USA) Nicolet iS50 FTIR spectrometer, equipped with an in-built diamond attenuated total reflection (ATR) system, with a 1 cm<sup>-1</sup> spectral resolution and by averaging 64 scans.

Thermogravimetric/derivative thermogravimetric analyses (TG/DTG) and differential scanning calorimetry (DSC) analyses were conducted with a Perkin-Elmer (Waltham, MA, USA) STA6000 simultaneous thermal analyzer by heating the samples in a slow stream of N<sub>2</sub> (20 mL/min) from room temperature up to 800°C, at a heating rate of 20°C/min. Pyris v.11 software was used for data analysis.

## 3. RESULTS AND DISCUSSION

### 3.1 Seeds Physical Characteristics

The seeds of the eight Lamiaceae under study (GA, TG, HS, LN, OA, OS, OT and OV) were colored from yellow to black and featured different shapes, viz. circular, elliptic, lanceolate, ovate and sagittate (Fig. 1 and Table 1). Apropos of seed weights, *Ocimum* seeds were the smallest, with weights ranging from 0.3 to 1.0 mg per seed, whereas LN, HS, GA and TG seeds ranged from moderate to (very) big size, featuring weights from 2.6 to 481 mg per seed. The moisture content of the seeds varied from 4.2% to 8.1% and showed a fair correlation with seed mass ( $r = 0.75$ ).

### 3.2 Oil and Starch Contents

As noted above, the oil from Lamiaceae seeds has wide medicinal uses. In the seeds from the eight species discussed herein, oil contents ranged from 11.8% to 50.4% (Table 1). Among them, GA and TG seeds were highly oily, with lipid fractions in the 41.2 to 50.4% range. Similar oil percentage in some *Ocimum*, GA and TG seeds have been reported elsewhere [22,23].

The concentration of total starch in the eight seeds ranged from 0.22% to 1.84%. Four seeds –GA, LN, OA and TG– showed low starch contents (1.24 to 1.84%), while in the other seeds it was contained at trace levels (0.22 to 0.64%). The concentration of resistant starch in the seeds ranged from 0.03% to 1.13%, with a high fraction of insoluble starch in seven of the seeds (except for GA), varying from 17% to 78%.

### 3.3 Phenolic Content

The TPC and Fla contents in the Lamiaceae seeds varied from 295 to 5842 mg/kg and from 1660 to 12680 mg/kg (in TAE and QE, respectively). These contents were noticeably lower than the TPC and Fla concentration in their leaves, which varied from 15406 to 29900 mg/kg and from 9804 to 34800 mg/kg, respectively. *O. sanctum* and *T. grandis* species were the richest in flavonoids.

### 3.4 Mineral Contents

The sum of the concentrations of the 19 elements under analysis (P, S, Cl, K, Rb, Mg,

Ca, Sr, Ba, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, Mo and Pb) in the GA, HS, LN, OA, OS, OT, OV and TG seeds was found to be 11756, 22629, 30977, 23586, 27133, 18641, 33927 and 22077 mg/kg, respectively. Their reduced concentration in the GA seeds (whole seeds, with seed coat) was noteworthy.

P, S, K, Rb, Mg, Ca, Sr, Mn, Fe, Cu and Zn were detected in all eight seeds, and were in the 2954 to 6829, 884 to 2543, 3304 to 16284, 4 to 17, 1047 to 2862, 567 to 11368, 6 to 94, 10 to 68, 86 to 1239, 7 to 49 and 11 to 120 mg/kg range, respectively (Table 1). Cobalt was identified in all seeds (except GA and LN) at traces level, 1 mg/kg. Barium was detected in HS, OA and OS seeds at low levels (ranging from 13 to 25 mg/kg). Other toxic elements, such as Ti, V, Cr, Mo and Pb, were detected in OS seeds also at low levels, in the range of 2 - 70 mg/kg. Clusters of mineral elements at high concentrations were identified for the seeds of three species: P-Mg-Ca-Mn, for LN; Rb-Sr-Ti-V-Cr-Fe-Mo-Pb, for OS; and S-Cu, for HS. The maximum K and Zn concentrations were detected in OV and GA seeds.

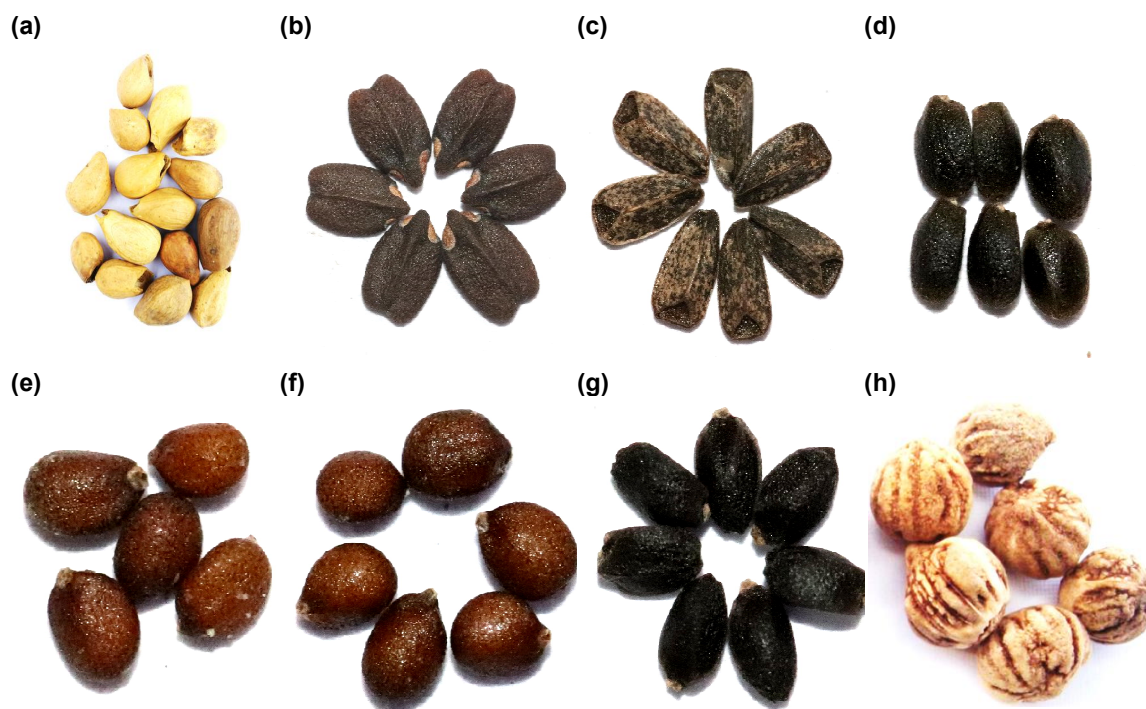


Fig. 1. Seeds from: (a) *Gmelina arborea*, (b) *Hyptis suaveolens*, (c) *Leonotis nepetifolia*, (d), *Ocimum americanum*, (e) *Ocimum sanctum*, (f) *Ocimum tenuiflorum*, (g) *Origanum vulgare*, and (h) *Tectona grandis*

Table 1. Physico-chemical characteristics of Lamiaceae seeds and leaves (in brackets)

Parameter	<i>Gmelina arborea</i>	<i>Hyptis suaveolens</i>	<i>Leonotis nepetifolia</i>	<i>Ocimum americanum</i>	<i>Ocimum sanctum</i>	<i>Ocimum tenuiflorum</i>	<i>Origanum vulgare</i>	<i>Tectona grandis</i>
Color	Light yellow	Dark brown	Salty black	black	Dark brown	Dark brown	black	Light brown
Shape	obovate	sagittate	lanceolate	Narrow ovate	Broad ovate	Broad ovate	elliptic	circular
Mass, mg	94.7	5.0	2.6	1.1	0.3	0.3	1.0	481
Moisture, %	7.5	6.4	4.2	4.9	5.2	5.5	4.2	8.1
Oil, %	50.4	17.2	30.3	13.4	12.7	11.8	14.8	41.2
Total starch, %	1.42	0.22	1.84	1.82	0.45	0.62	0.64	1.24
Resistant starch, %	0.03	0.08	0.31	1.13	0.31	0.34	0.50	0.41
Resistant/total starch, %	2.1	36	17	62	69	55	78	33
TPh, mg/kg	1447(21476)	4181(23875)	3538 (16042)	2117(15406)	295(28900)	5842(25898)	750(29900)	4904(25580)
Fla, mg/kg	2075(34800)	3025(9804)	2825(16538)	5100(9966)	15850(18900)	5350(24295)	3600(28900)	7375(21548)
P, mg/kg	4880	3634(820)	6829	4631	3983	3630	4738	2954
S, mg/kg	1507	2543(1925)	2235	1940	1678	1537	2096	884
Cl, mg/kg	ND	0 (6733)	ND	ND	ND	ND	183	ND
K, mg/kg	3304	4355 (24376)	7165	7775	6950	5544	16284	11816
Rb, mg/kg	10	6 (6)	11	9	17	14	7	4
Mg, mg/kg	1047	2070 (1979)	2862	1804	2775	1189	2339	1120
Ca, mg/kg	567	9736 (5028)	11368	7201	10186	6363	7917	5060
Sr, mg/kg	6	21 (50)	29	59	94	18	29	26
Ba, mg/kg	ND	14	ND	13	25	ND	ND	ND
Ti, mg/kg	ND	0 (114)	ND	ND	70	ND	ND	ND
V, mg/kg	ND	ND	ND	ND	2	ND	ND	ND
Cr, mg/kg	ND	ND	ND	ND	5	ND	ND	ND
Mn, mg/kg	66	44 (175)	68	10	43	21	25	34
Fe, mg/kg	219	145 (1020)	346	86	1239	255	235	160
Co, mg/kg	ND	1	ND	1	1	ND	1	1
Cu, mg/kg	30	49	36	12	13	13	30	7
Zn, mg/kg	120	11	28	45	48	57	43	11
Mo, mg/kg	ND	0 (4)	ND	ND	2	ND	ND	ND
Pb, mg/kg	ND	0 (4)	ND	ND	2	ND	ND	ND

For comparative purposes, the concentration of trace elements in the leaves of HS was tested. Their total concentrations were remarkably higher in the leaves, 42241 mg/kg, probably due to coordination with polyphenols. Elements i.e. S, Cl, K, Mg, Ca and Fe were the dominated elements in the leaves. The concentration of elements i.e. P, S, Cl, K, Rb, Mg, Ca, Sr, Ti, Cr, Mn, Fe, Mo and Pb in the dried HS leaves was found to be 820, 1925, 6733, 24376, 6, 1979, 5028, 50, 114, 11, 175, 1020, 4 and 4 mg/kg.

### 3.5 Bioaccumulation

The pH value of soil solutions ( $n = 8$ ) ranged from 7.5 to 8.9, with a mean value ( $p = 0.05$ ) of  $8.1 \pm 0.4$ . The concentrations of Cl, P, S, K, Rb, Mg, Ca, Sr, Mn, Fe, Cu and Zn elements were in the following ranges: 109-161, 118-185, 190-280, 1101-1170, 3-8, 1180-1740, 4480-7852, 40-59, 1000-1480, 13400-19700, 30-58 and 17-28 mg/kg, respectively (with mean values of  $138 \pm 13$ ,  $154 \pm 16$ ,  $243 \pm 22$ ,  $1504 \pm 137$ ,  $6 \pm 1$ ,  $1504 \pm 137$ ,  $6402 \pm 800$ ,  $51 \pm 5$ ,  $1278 \pm 117$ ,  $17055 \pm 1549$ ,  $48 \pm 6$  and  $24 \pm 3$  mg/kg, respectively). Among them, K, Mg, Ca, Mn and Fe were the main elements in the near-surface soil.

Three nutrients (P, S and K) were found to be hyperaccumulated in all seeds with respect to their mean soil values, with bioaccumulation factors in the 19 to 44, 4 to 10 and 2 to 11 range, respectively (with mean values of 29, 7 and 6, respectively). On the other hand, in HS leaves, Cl and K were the elements that were strongly hyperaccumulated (with bioaccumulation factors of 49 and 17, respectively).

### 3.6 Correlation Coefficients

The taxonomies of the eight Lamiaceae plants under study are different, and they can be grouped into three classes: (i) GA and TG; (ii) HS and LN; and (iii) OA, OS, OT and OV. The correlation coefficient values for the different parameters under analysis were computed for group (iii) and are shown in Table 2. A high correlation among S, P, K and Cl nutrients was found. Several elements (Mg, Ca, Sr, Ba, Ti, V, Cr, Mn and Fe) featured high correlations, suggesting their role as cofactor elements in the bioaccumulation of each other. Rb co-factor element showed a good correlation with heavy metals (Ti, V, Cr, Mn, Fe, Zn, Mo and Pb), while Co cofactor element had a high correlation with P, S, K, Cl, Mg, Ca and Sr. Elements i.e. Rb, Mg,

Ca, Sr, Ba, Ti, V, Cr, Mn, Fe, Mo and Pb had an excellent correlation in their accumulation pattern.

### 3.7 Vibrational Characterization

The ATR-FTIR spectra of the seeds samples under study are depicted in Fig. 2. The main bands and their assignments are summarized in Table 3 [24]. Peaks at around 3300 ( $\nu$  O-H) are characteristic absorption bands from cellulose [25]. Other prominent bands attributed to cellulose are those at  $1317\text{-}1305\text{ cm}^{-1}$  (C-H vibration),  $1159\text{-}1154\text{ cm}^{-1}$  ( $\nu$  C-O-C in bridge, asymmetric),  $1059\text{-}1057\text{ cm}^{-1}$  ( $>\text{CH-O-CH}_2$ ),  $1035\text{-}1027\text{ cm}^{-1}$  ( $\nu$  C-O),  $921\text{-}896\text{ cm}^{-1}$  ( $\nu$  C-O-C in bridge, symmetric) and  $668\text{-}665\text{ cm}^{-1}$  ( $\beta$ -glycosidic linkage). Peaks indicative of the presence of hemicellulose are those that appear at  $1644\text{-}1637\text{ cm}^{-1}$  (C=O stretching),  $1378\text{-}1377\text{ cm}^{-1}$  ( $-\text{CH}_3$  symmetric deformation) and  $1240\text{-}1236\text{ cm}^{-1}$  (C-C-O asymmetrical stretching from acetylated glucomannan). Peaks at  $2924\text{-}2922\text{ cm}^{-1}$  ( $-\text{CH}_2$  stretching) and  $2854\text{-}2853\text{ cm}^{-1}$  ( $-\text{CH}$  stretching) indicate the presence of cutine and wax. The peak that appears at  $1651\text{ cm}^{-1}$  can be attributed to C=C absorption of cellulose when it is cross-linked and dehydrated, but it may also appear when the samples are rich in unsaturated oils. This band can be put in relation with the band at  $1738\text{ cm}^{-1}$  (C=O stretching), typical of hemicellulose, but which may also be associated with the stretching vibration of the ester carbonyl functional groups of triglycerides. The presence of this band, typical of the vinyl group, could justify the quantitative presence of unsaturated oils in the seeds under study. The sharp, intense C-H wags at  $1000\text{-}997\text{ cm}^{-1}$  are also indicative of vinyl. The bands that appear in *T. grandis* sample at  $1606\text{ cm}^{-1}$  (aromatic ring stretching) and at  $896\text{ cm}^{-1}$  are typical of lignin. The bands at  $1520\text{-}1505\text{ cm}^{-1}$  (aromatic skeletal vibration) are also typical of lignin. The presence of pectin is indicated by peaks at  $1457\text{-}1455\text{ cm}^{-1}$  (associated with O-CH<sub>3</sub> stretching) for pectic ester and at  $1417\text{-}1411\text{ cm}^{-1}$  (COO<sup>-</sup> symmetric stretching vibration) for calcium pectate [26]. Bands near  $921\text{-}916\text{ cm}^{-1}$  probably correspond to  $\alpha$ -glycosidic linkage. The bands at  $1710\text{ cm}^{-1}$  (conjugated C=O),  $1436\text{ cm}^{-1}$  (CH<sub>2</sub> scissoring, known as the marker of crystallinity) and  $814\text{ cm}^{-1}$  (aromatic C-H out-of-plane bending or to C-O-C deformation) are not assigned to a particular plant fraction or component. The band at  $721\text{ cm}^{-1}$  (due to O-C=O in-plane deformation or a CH<sub>2</sub> rocking deformation) is attributed to phenolic components.

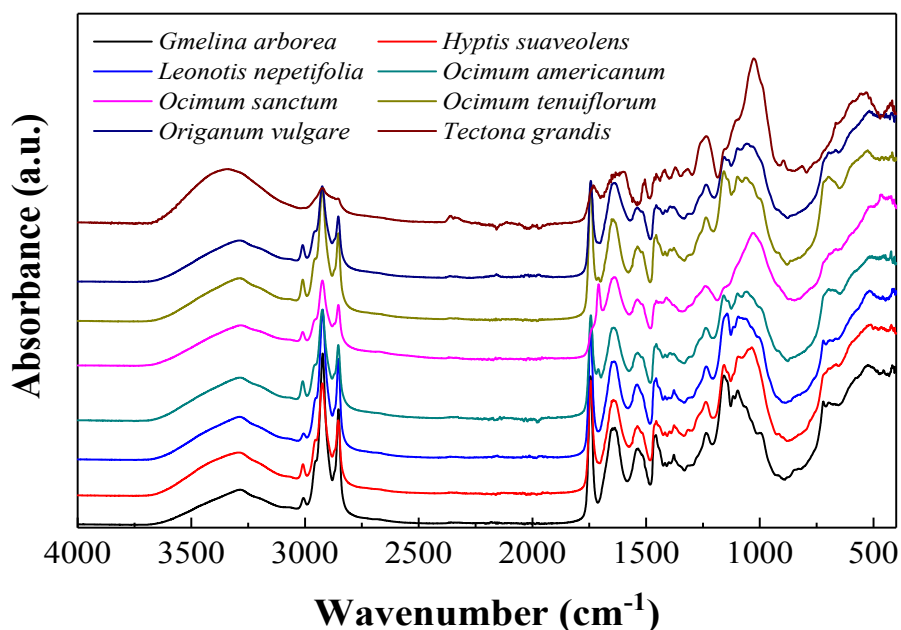
**Table 2. Correlation coefficients of chemical variables for the four *Ocimum* seeds under study**

	<b>P</b>	<b>S</b>	<b>K</b>	<b>Cl</b>	<b>Rb</b>	<b>Mg</b>	<b>Ca</b>	<b>Sr</b>	<b>Ba</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Cu</b>	<b>Zn</b>	<b>Mo</b>	<b>Pb</b>
<b>P</b>	1																		
<b>S</b>	0.98	1.00																	
<b>Cl</b>	0.62	0.75	1.00																
<b>K</b>	0.75	0.85	0.98	1.00															
<b>Rb</b>	-0.85	-0.87	-0.69	-0.75	1.00														
<b>Mg</b>	0.36	0.37	0.30	0.39	0.12	1.00													
<b>Ca</b>	0.03	0.03	0.00	0.07	0.46	0.94	1.00												
<b>Sr</b>	0.02	-0.07	-0.41	-0.29	0.50	0.73	0.85	1.00											
<b>Ba</b>	-0.08	-0.19	-0.53	-0.41	0.58	0.64	0.80	0.99	1.00										
<b>Ti</b>	-0.33	-0.36	-0.33	-0.30	0.77	0.73	0.92	0.86	0.86	1.00									
<b>V</b>	-0.33	-0.36	-0.33	-0.30	0.77	0.73	0.92	0.86	0.86	1.00	1.00								
<b>Cr</b>	-0.33	-0.36	-0.33	-0.30	0.77	0.73	0.92	0.86	0.86	1.00	1.00	1.00							
<b>Mn</b>	-0.16	-0.06	0.32	0.28	0.42	0.77	0.81	0.40	0.34	0.74	0.74	0.74	1.00						
<b>Fe</b>	-0.43	-0.44	-0.34	-0.33	0.82	0.67	0.88	0.79	0.80	0.99	0.99	0.99	0.76	1.00					
<b>Co</b>	0.78	0.73	0.33	0.49	-0.33	0.81	0.63	0.63	0.53	0.33	0.33	0.33	0.28	0.22	1.00				
<b>Cu</b>	-0.73	-0.84	-0.99	-0.99	0.79	-0.28	0.05	0.40	0.52	0.41	0.41	0.41	-0.20	0.43	-0.41	1.00			
<b>Zn</b>	-0.78	-0.88	-0.97	-1.00	0.74	-0.44	-0.12	0.22	0.35	0.26	0.26	0.26	-0.30	0.29	-0.55	0.98	1.00		
<b>Mo</b>	-0.33	-0.36	-0.33	-0.30	0.77	0.73	0.92	0.86	0.86	1.00	1.00	1.00	0.74	0.99	0.33	0.41	0.26	1.00	
<b>Pb</b>	-0.33	-0.36	-0.33	-0.30	0.77	0.73	0.92	0.86	0.86	1.00	1.00	1.00	0.74	0.99	0.33	0.41	0.26	1.00	1.00

**Table 3. Main absorption bands in the ATR-FTIR spectra of seed samples from eight species of the *Lamiaceae* family and their assignments (all wavenumbers are expressed in  $\text{cm}^{-1}$ ) [24,29,30]**

<i>Gmelina arborea</i> kernel	<i>Hyptis suaveolens</i> whole seed	<i>Leonotis nepetifolia</i> whole seed	<i>Ocimum americanum</i> whole seed	<i>Ocimum sanctum</i> whole seed	<i>Ocimum tenuiflorum</i> whole seed	<i>Origanum vulgare</i> whole seed	<i>Tectona grandis</i> whole seed	Assignments
3284	3294	3289	3289	3282	3288	3289	3345	O-H stretching (cellulose)
2922	2924	2922	2924	2924	2924	2924	2923	-CH <sub>2</sub> stretching (cutine, wax and pectin)
2853	2954	2853	2854	2853	2853	2853		-CH <sub>2</sub> stretching (cutine and wax)
1745	1744	1744	1743		1743	1743	1738	C=O stretch (uronic ester groups in hemicellulose)
		1710	1709	1710				C=O stretching of aldehyde/ketone
	1651				1651		1651	C=C (cellulose) / COO <sup>-</sup> symmetric stretch
1637	1644	1640	1644	1639	1645	1640		C=O stretching (hemicellulose)
							1600	C=C-C=C (cellulose) / aromatic ring stretch (lignin)
1535	1538	1540	1537	1539	1538	1539	1538	COO <sup>-</sup> symmetric stretching
			1519		1520	1520	1505	aromatic skeletal
1457	1456	1456	1455	1455	1456	1455	1455	O-CH <sub>3</sub> stretching
				1436				CH <sub>2</sub> scissoring
	1417	1417	1417	1411	1417	1416	1417	COO <sup>-</sup> stretching / typical of pyranoside
	1397		1393			1393		CH rocking
1377	1377	1378	1378	1378	1378		1372	-CH <sub>3</sub> symmetric deformation (hemicellulose)
								stretching of C-H bending in the CH <sub>2</sub>
	1315		1305		1307	1312	1317	C-H (cellulose)
1235	1238	1236	1237	1240	1236	1236	1236	C-C-O asymm stretching, acetylated glucomannan
1158	1158	1143	1159		1158	1156	1154	C-O-C in bridge, asymmetric (cellulose)
1117								C-O (cellulose)
1096	1096	1094	1097		1097	1097	1097	C-O-C stretch in pyranose
			1057		1059	1058		>CH-O-CH <sub>2</sub> (cellulose) / -C-O-H (fructose)
	1035			1027			1027	C-O stretching (cellulose) / -C-O-H (glucose)
997					1001			C-H wags, vinyl
	916				921		896	C-O-C symmetric / glycosidic linkages (cellulose); aromatic
							814	C-H out-of-plane binding or C-O-C deformation
721		721						O-C=O in-plane def. or a CH <sub>2</sub> rocking def
698		691	695	694	699	695		<i>cis</i> C=C
	665	668		665		668	666	$\beta$ -glycosidic linkage (cellulose)
525	510	518	506		525	518		saccharide moieties

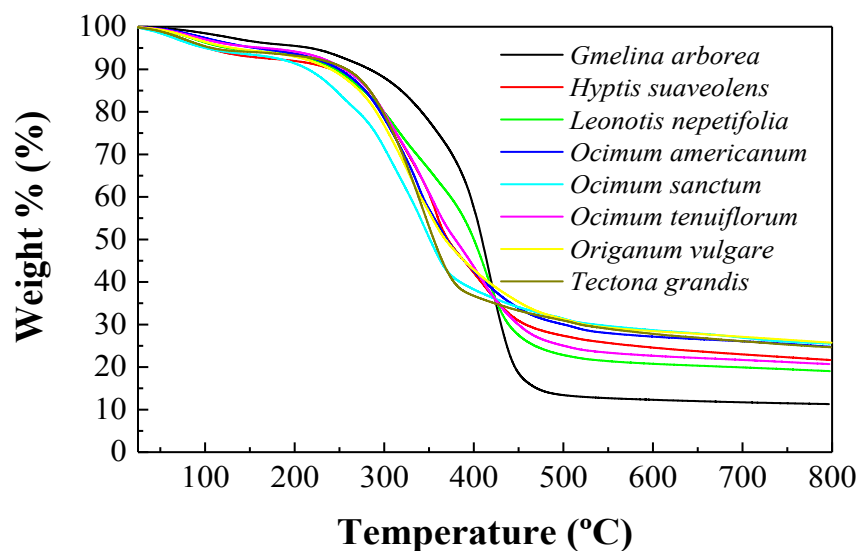




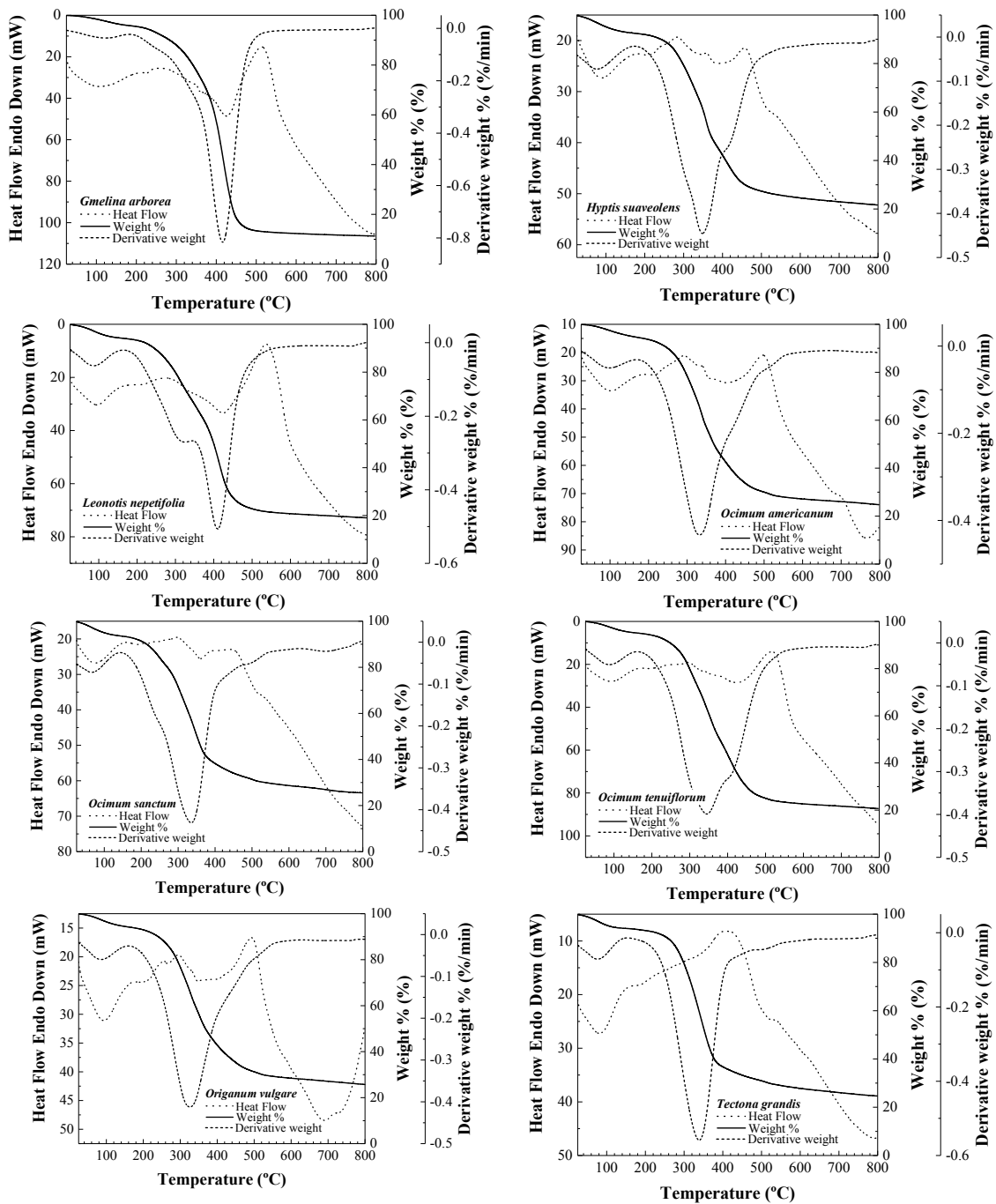
**Fig. 2.** ATR-FTIR spectra of seed samples from species of the *Lamiaceae* family. Some offset has been added to the y axis for clarity purposes

An interesting feature for the *Lamiaceae* is that they show vibrational spectra similar to those exhibited by other families of the Asterid clade (*Sapotaceae* and *Asteraceae*). Bands at  $1651\text{ cm}^{-1}$  and  $1644 - 1637\text{ cm}^{-1}$  are in good agreement with those exhibited in *Sapotaceae* for their kernel and coat fractions, respectively

[27]. The absence of the bands at  $1015\text{ cm}^{-1}$  and  $\sim 878\text{ cm}^{-1}$  (apart from that of  $795\text{ cm}^{-1}$ ) is also a common feature with the *Asteraceae* (unpublished results). The absence of bands at  $1574, 1563, 1336, 1138, 1076, 857, 778$  and  $757\text{ cm}^{-1}$  has been previously observed for *Salvia hispanica* L. [28].



**Fig. 3.** Comparison of TG curves for the seeds from eight species of the *Lamiaceae* family



**Fig. 4.** DSC (*dotted line*, y-axis on the left side of the graph), TG (*solid line*, first y-axis on the right side of the graph) and DTG (*dashed line*, second (rightmost) y-axis on the right side of the graph) curves for the seeds from eight species of the *Lamiaceae* family under study

### 3.8 Thermal Characterization

Differences in weight loss for the different seeds of the *Laminaceae* family can be observed in the TG curves depicted in Fig. 3. Additional DTG

peaks and DSC thermal effects are shown in Fig. 4. The main endotherm at around 110°C can be related both to dehydration and to gelatinization of starch (an order-disorder transition for the starch/moisture system). The small endotherm

at around 200°C indicates seed protein crystallization to  $\beta$ -crystals accompanied by the random-coil  $\rightarrow$   $\beta$ -form conformational transition. The chain of thermal events above 240°C began with those related to oxidation reactions, followed by those attributed to the degradation of hemicellulose and other fiber components (at around 300°C), and by those associated with the decomposition of the polyunsaturated (at 357°C) and mono-unsaturated (at 391°C) triglycerides. The very slow weight loss above 450°C can be attributed to remaining lignin mass loss.

#### 4. CONCLUSIONS

The nutritional potential of the seeds from eight Lamiaceae species was assessed by determining their proximate and phytochemical composition. Results indicated that the oil contents ranged from 11.8 to 50.4 mg/kg, with the highest levels for *G. arborea* and *T. grandis*. Total polyphenols varied from 295 to 5842 mg/kg (lower than in leaves) and mineral elements from 11756 to 33927 mg/kg (with concentration following the Ca>K>P>S>Mg>Fe>Zn sequence). Three main nutrients (P, S and K) were found to be hyperaccumulated in all seeds with respect to their mean soil values. Some toxic elements as Ba and Pb were found, albeit at low levels. These results suggest that the seeds of the Lamiaceae studied species can be nutritive despite the presence of some toxic components. The thermal profiles displayed by basil species (*O. americanum*, *O. tenuiflorum*, *O. sanctum*) and *O. vulgare* differed from those of *H. suaveolens*, *L. nepetifolia* and *T. grandis*, and all of them were clearly distinguishable from that of *G. arborea*. Differences should be related to lipids (tryglycerides) and lignin contents.

#### CONSENT

It is not applicable.

#### ETHICAL APPROVAL

It is not applicable.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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