

High Value-Added Biomolecules from Beach Waste of Marine Origin-Screening for Potential Candidates among Seagrass of the Cymodoceaceae Family

Micheline Grignon, Bernadette Rezzonico

▶ **To cite this version:**

Micheline Grignon, Bernadette Rezzonico. High Value-Added Biomolecules from Beach Waste of Marine Origin-Screening for Potential Candidates among Seagrass of the Cymodoceaceae Family. The Open Bioactive Compounds, 2017, 5 (1), pp.83-94. ⟨10.2174/1874847301705010083⟩. ⟨hal-04611200⟩

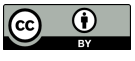
HAL Id: hal-04611200

https://hal.science/hal-04611200v1

Submitted on 13 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Send Orders for Reprints to reprints@benthamscience.ae

The Open Bioactive Compounds Journal, 2017, *5*, 83-94

BENTHAM OPEN

CrossMark

The Open Bioactive Compounds Journal

Content list available at: www.benthamopen.com/TOBCJ/

DOI: 10.2174/1874847301705010083



RESEARCH ARTICLE

High Value-Added Biomolecules from Beach Waste of Marine Origin-Screening for Potential Candidates among Seagrass of the Cymodoceaceae Family

Micheline Grignon-Dubois* and Bernadette Rezzonico

Université Bordeaux, EPOC, UMR 5805, F 33600, Pessac, France

Received: June 29, 2017 Revised: November 29, 2017 Accepted: December 15, 2017

Abstract:

Background:

Detrital leaves from seagrass of the Cymodoceaceae family were assayed for biologically active molecules that have commercial as well as societal benefits.

Objective:

We focused on L-chiro-inositol, a very rare natural occurring cyclitol, and chicoric acid, a polyphenolic compound, in which both applications were found in the nutraceutical segment.

Method:

Six species of seagrass belonging to the genera *Syringodium, Cymodocea* and *Halodule* were collected from their native habitat. The L-chiro-inositol content of the crude aqueous extracts prepared from different batches of *Cymodocea nodosa* flotsam was measured by quantitative ^{1}H-NMR spectroscopy. High concentrations were found with values ranging from 22.2 to 35.0 mg.g^{-1} plant dw. The presence of L-chiro-inositol in the tropical species *C. rotundata*, *C. serrulata*, *Syringodium isoetifolium*, and *Halodule pinifolia* was also characterized by qualitative NMR. The chicoric acid content of crude aqueous methanolic extracts prepared from *C. rotundata*, *C. serrulata*, *S. isoetifolium*, and *Halodule pinifolia* was determined by quantitative HPLC-DAD. The values found ranged from 0.39 to 6.15 mg.g^{-1} dry weight. Chicoric acid was unambiguously identified as the major phenolic in *S. isoetifolium*, and *Halodule pinifolia,* while it was found in mixture with flavonol derivatives in *C. rotundata* and *C. serrulata*. Flavonol derivatives are also of interest for their bioactivity.

Result:

Considering the demonstrated therapeutic applications of L-chiro-inositol and chicoric acid, their high value on the nutraceutical market, and their rare occurrence in the plant kingdom, their presence in *Syringodium, Cymodocea* and *Halodule* detrital leaves makes this abundant biomass of interest for dietary and pharmaceutical applications.

Conclusion:

These results show that there is a real potential for harvesting beachcast Cymodoceacea.

Keywords: L-Chiro-Inositol, Chicoric Acid, Cymodoceaceae Family, *Cymodocea*, *Syringodium*, *Halodule*, Quantitative NMR and HPLC.

* Address correspondence to this author at the Université Bordeaux, UMR 5805, EPOC, Bat B18; F33600 Pesac, France, Tel: +33-5-40002290; E-mails: micheline.grignon@u-bordeaux.fr, m.grignon@laposte.net

1. INTRODUCTION

During the last decade, the global nutraceutical market for medicinal herbs has grown at an unprecedented rate, as consumers focus on health maintenance using natural products and health-enhancing foods. As a result, plant secondary metabolites have become economically important in the field of food additives, nutraceuticals and drugs. This is the case of chiro-inositol and chicoric acid.

Inositols constitute an important class of biologically active compounds [1 - 4]. Only five are known to occur in plants in variable amounts. Chiro-inositol exits in two enantiomeric forms, *i.e.* D-chiro-inositol (DCI) and L-chiro-inositol (LCI). They both exhibit a positive effect on glucose metabolism [3], but are very rare in nature, especially LCI, whose distribution in higher plants is very limited. LCI has been identified, for instance, in *Amyema miquelii* [5], Chrysantemum [6], *Cremanthodium ellisii* [7], *Euphorbia resinifera* [8], and *Euphorbia pilulifera* [9]. More recently, LCI has been found in *Ageratina petiolaris*, a plant traditionally used in Mexico for the treatment of diabetes [10].

Chicoric acid (CA; Fig. (**1**)) is a rare and valuable natural product of special interest owing to its large spectrum of biological properties including antioxidant activities, anti-obesity effects, anti-HIV, and others [11]. These properties explain its success on the nutraceutical market [12, 13]. CA is the main phenolic compound in *Echinacea purpurea*, but it does not occur in appreciable amounts in other species such as *E. pallida* and *E. angustifolia* [14]. The identification of any novel sources of CA is of economic interest.

Marine biodiversity offers potential resources for a wide variety of non-drug nutritional natural products. Several species of seaweeds are used as human food or as raw material for the production of nutraceuticals and cosmeceuticals [15]. Compared to algae, seagrasses remain less exploited despite they offer promising opportunities to find valuable phytochemicals [16, 17].

Fifty-nine seagrass species are recognised worldwide, distributed in four families [18]. The Cymodoceaceae family (Manatee Grasses) encompasses the greatest variety with 15 species in five genera.

The bioactivity so far reported for seagrass metabolites has been recently reviewed [19]. Examples include cytotoxicity, antioxidant-, antimicrobial-, antiviral-, or anti-inflammatory activity. The ability of Zosterin (a pectin isolated from *Zostera asiatica*) to decrease toxicity of antitumor drugs and to purge heavy metals from human organisms [20, 21] led to marketed seagrass-derived food and drugs in Russia [see as examples: 22-24]. For our part, we have demonstrated that *Z. marina* and *Z. noltei* detrital leaves can compete with *Rosmarinus officinalis* for the production of rosmarinic acid, which is marketed as a nutraceutical [17].

Seagrass beds generate considerable standing biomass, which could be exploited as raw material. In places dependent on tourism, local governments are under great public pressure to remove seagrass detritus from beaches and shorelines used for recreational purposes. In most cases, the collected biomass is disposed of in waste disposal sites.

The increasing demand for alternative medicine, and the harvesting and collection pressures for the medicinal plants of interest point up the need for alternative resources. Using dead seagrass biomass as a source of phytochemicals offers some particular advantages:

1. Physical events (storm, waves, currents, *etc*…), and natural seasonal leaf drop result in massive deposit of leaf litter along shorelines. As they originate from large areas of seagrass bed, and sometimes even from different meadows, they offer a more representative metabolite content than isolated samples from a single meadow.
2. Seagrasses are much more resistant to decomposition than are freshwater angiosperms or algae. The rate of decomposition of seagrass detritus is generally low (< 1% of dry wt/day) compared with other sources of detritus.
3. We have previously shown that significant concentrations of cyclitol and/or phenolic compounds remain in the detrital leaves of species of Zosteraceae and Cymodoceaceae [16, 17, 25 - 27].
4. In contrast to terrestrial plants, vegetative reproduction is more important in seagrasses than pollination. This limits the plant-to-plant variation and consequent genetic inconsistencies in the type and level of phytochemicals produced by terrestrial plants.
5. Heretofore, there has been no market for Cymodoceaceae flotsam, so that the cost of the same is simply that of harvesting.

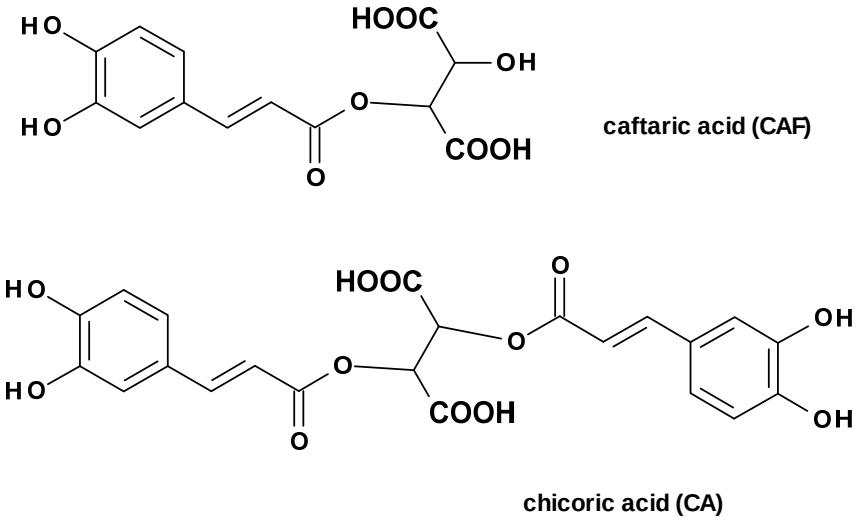


Fig. (1). Chemical structure of caftaric- and chicoric acid.

Some members of the Cymodoceaceae family have been reported to accumulate cyclitols, including myo- and L-chiro-inositol. However, LCI had not been isolated and its stereochemical assignment was only based on a hypothetical biosynthesis pathway [28].

We have recently reported the isolation of LCI and CA from the dead biomass of the tropical seagrass *Syringodium filiforme* [25, 26], and CA from the temperate *Cymodocea nodosa* [27]. Considering the economic potential of these two substances within the pharmaceutical, cosmetic, and food industries, it appears of interest to evaluate the potential of other tropical members of Cymodoceaceae.

The aim of this study was to examine the phytochemical content of detrital leaves, with a view toward exploiting the flotsam. This work reports the quantitative determination of LCI in the temperate *C. nodosa*, and the first quantitative characterization of polyphenols in *C. rotundata*, *C. serrulata*, *S. isoetifolium*, and *Halodule pinifolia,* which are found throughout the Indian and Pacific Oceans [29]. In addition, these tropical species were screened for the possible presence of LCI.

2. MATERIAL AND METHODS

2.1. General

All the solvents used were HPLC grade. Trifluoroacetic acid (TFA), anhydrous pyridine, trimethylchlorosilane (TMCS), and hexamethyldisilazane (HMDS) were purchased from Aldrich Chemical Company (Saint-Louis, Missouri, USA), and analytical-grade water from Sodipro Company (Echirolles, France). NMR spectra were recorded on a Bruker AVANCE 400 MHz (Billerica, MA, USA). All the NMR solvents (DMSO, D_2O, or CD_3OD) and trimethylsilyl d-4-propionic acid (TMSP) used as internal standards for the qNMR experiments were purchased from Euriso-Top (Gif-sur-Yvette, France). Ultraviolet (UV) spectra were recorded on a V-630 UV-VIS Jasco spectrophotometer (Easton, USA) in HPLC grade water. Rotatory power was measured on a Perkin Elmer 241 polarimeter. Authentic sample of caftaric- and chicoric acid (also known as cichoric acid and dicaffeoyltartaric acid) was given by Eburon Organics (B-2310 Rijkevorsel, Belgium). All the other standards were purchased from Extrasynthèse (Genay, France). Chlorogenic acid (Extrasynthèse) was used for the HPLC quantification of CA and caftaric acid (CAF).

2.2. Plant Material

The following species were studied: *Cymodocea nodosa* (Ucria) Ascherson, *Cymodocea rotundata*, Ehrenberg & Hemprich. Ex Ascherson, *Cymodocea serrulata* (R. Brown) Ascherson & Magnus, *Halodule pinifolia* (Miki) den Hartog, and *Syringodium isoetifolium* (Ascherson) Dandy (Table **1**). The temperate seagrass *C. nodosa* was sampled in Canary Island and throughout the Mediterranean Sea, while the tropical species were collected along the coast of Palk Bay, India (Table **1**). Identification of the species was based on morphology and microscopic leaf anatomy of both living tissue and fresh green detrital leaves, and on comparison with identification keys reported in literature [see as

examples: 30-32].

Whatever the species and the sampling site, green freshly detached leaves were collected in the intertidal zone and from large accumulations of detritus along shorelines (Table **1**). After collection, the samples were thoroughly rinsed in seawater and then quickly washed in freshwater to remove sand and salt. Associated debris and algae were removed when present, then plant material was air-dried at room temperature in the dark. When shoreline accumulation contain several seagrass species, each of them were separated before drying.

Table 1. Collection data.

Genus	Species	Common Name	Geographical Range	Sampling Site	Collection Date
Syringodium **Kützing**	*S. filiforme* Kützing Synonyms: *Cymodocea filiformis* *Cymodocea manatorum* *Phucagrostis manatorum*	manatee grass	Western tropical Atlantic from Florida (USA) to Venezuela, including the Gulf of Mexico and the Caribbean Sea, as well as Bermuda. ,	Guadeloupe, French West Indies	July to October 2007
	S. isoetifolium (Ascherson) Dandy	noodle seagrass	Indo-Pacific region, including Fiji and Samoa.	Palk Bay, Tamil Nadu, India	October to December 2012
Cymodocea **König**	*C. nodosa* Ucria (Ascherson)	little Neptune grass.	Mediterranean Sea and Atlantic Ocean (Portugal, Mauritania, Senegal, Canary, Madeira and Cape Verde Islands)	Canary island, Spain Cadiz, Spain Alfacs Bay, Spain Monastir, Tunisia, Zeytineli, Turkey	14/07/2007 10/05/2008 21/05/2008 18/07/2008 28/07/2008
	C. rotundata Ehrenberg & Hemprich ex Ascherson		Indo-Pacific	Palk Bay, Tamil Nadu, India	October to December 2012
	C. serrulata (R. Brown) Ascherson & Magnus		Indo-Pacific	Palk Bay, Tamil Nadu, India	October to December 2012
Halodule **Endlinger**	*H. pinifolia* (Miki) den Hartog		Asian Pacific and eastern Indian Oceans	Palk Bay, Tamil Nadu, India	October to December 2012

2.3. Extraction of Seagrasses and Determination of their Composition

2.3.1. Typical Procedure for Extraction of LCI

Dried ground leaves (5 g) were extracted at room temperature with water (40 mL, 24 h). The process was twice repeated, and then the extracts were pooled, lyophilized, and analyzed by NMR.

2.3.2. Isolation and Identification of LCI

A pure sample of LCI (72 mg) was isolated from a crude aqueous extract of *C. nodosa* (12 g), following the silylation-desilylation process we have previously developed [25]. The purity was confirmed by ^{1}H NMR and the rotatory power was measured on a Perkin Elmer 241 polarimeter at 25°C ($[\alpha]_D^{25}$ = - 67.8, c = 0.5, H_2O).

2.3.3. Determination of the LCI Concentrations by ^{1}H NMR

Samples were prepared with 3.00 mg of dried crude extract, 0.4 mL of D_2O and 100 µL of a D_2O solution of TMSP (internal standard), and transferred to a 5 mm NMR tube. The internal standard solution was prepared by dissolving TMSP of known purity in 5 mL of D_2O. One dimensional ^{1}H NMR spectra were acquired with an AVANCE DPX 400 MHz spectrometer (Bruker) in the conditions previously described [25]. For quantitative analysis, manual integrations of the concerned peaks were achieved. LCI was quantified by integrating the area of the d (2 H) at 3.95 ppm and the internal reference signal (s, 9 H) at 0.0 ppm. The amount of the internal standard was calculated to give peaks of similar intensities for both analyte and standard. This similarity helps minimising the error in measurements.

The amount of LCI for each extract was calculated from the resultant analyte to standard peak ratio according to the following equation:

$$\text{Amount of LCI (extract)} = \frac{MW_{LCI}}{MW_{IS}} \times \frac{W_{IS}}{W_{extract}} \times \frac{I_{LCI}}{I_{IS}} \times \frac{N_{IS}}{N_{LCI}} \times P_{IS}$$

Where:

LCI and IS refer to L-chiro inositol and the internal standard respectively, *MW* are the respective molecular weights, *W* the amount of substance used, *I* the integrated peak area, *N* the number of atoms that gives rise to the measured NMR signals (N_{IS} = 9, N_{LCI} = 2), P_{IS} the percentage purity of the internal standard (98%).

The amount of LCI in the plant is obtained according to the equation:

Amount in the plant = Amount of LCI (extract) x extraction yield.

Data are expressed in milligrams per gram ($mg.g^{-1}$ of dry matter of leave tissue, mean ± standard deviation (SD) of three determinations).

2.3.4. Typical Procedure for Extraction of Phenolics

Dried ground leaves (10 g) were extracted at room temperature with aqueous methanol (50:50; 120 mL, 24 h). The process was repeated, and then the extracts were pooled, evaporated to dryness, and analyzed by NMR, HPLC and LC-MS.

2.3.5. HPLC Analysis

Separation and quantification of phenolics in the crude extracts were performed as previously described [27] using the binary gradient 0.1% (v/v) TFA in water (A) and methanol (B). External standard calibration with chlorogenic acid dissolved in methanol/water (70:30) with the aid of sonication was established on six data points, covering the concentration range 0.0619-0.00619 $mg.mL^{-1}$. Linear regression on the HPLC analyses gave R2 values of 0.9995. Chromatographic peaks were checked for peak purity, and identification was achieved by comparing retention times and UV spectra with those of standards. Quantitative determinations were carried out by peak area measurements at 328 nm, using the calibration curve of chlorogenic acid at the same wavelength and the correction factors, which take into account the differences in the responses of the HPLC detector to CA, CAF, and chlorogenic acid. These factors have been determined by the Institute for Nutraceutical Advancement (INA) in the frame of the INA Methods Validation Program (INA Method 106.000 2000) [33]. The data presented in Table **2** are the average from three experiments, calculated using the following equation and correction factors:

% W/W individual phenol compound = (C × F × 100)/Cs

Where:

C is the concentration of the tested phenolic compound ($mg.mL^{-1}$) in the analyzed extract, calculated as chlorogenic acid from peak areas and linear regression;

F is the correction factor of phenolic response against chlorogenic acid (F = 0.888 for CAF and 0.695 for CA);

and Cs is the concentration of the sample ($mg.mL^{-1}$) diluted in deionized water for analysis.

Data are expressed in milligrams per gram of dry matter of plant material ($mg.g^{-1}$ dw; mean ± standard deviation (SD) of three determinations.

2.3.6. LC-MS Analysis

LC-MS was performed using an HP1100 (Hewlett-Packard, Palo-Alto, CA, USA) equipped with an Agilent MSD 1946B simple quad mass spectrometer and HP Chemstation software. Positive mode ESI spectra of the column eluate were recorded in the range of m/z 100–1000 a.m.u. Absorbance was measured at 280 and 320 nm. Compounds were separated using an MN Nucleodur C18 column (Macherey-Nagel, Düren, Germany): 125 mm × 2 mm i.d., 3 µm particle size. The analytes were eluted at a flow rate of 0.3 mL min^{-1} using the binary gradient (v/v) formic acid in water (pH 2.55, A) and methanol (B). The following linear gradient was used: 15% B to 100% B (15 min). Separation of the analytes was carried out at 50°C. The injection volume was 2 µL. For MS analysis, compounds were detected using the following conditions: nebulizing gas pressure, 60 psi; drying gas flow rate, 12 $mL.min^{-1}$; drying gas temperature, 350°C; capillary voltage, 4000 V; temperature source, 350°C. Data were acquired in full scan mode (m/z 100-1000) at a fragmentor voltage of 70 V.

3. RESULTS AND DISCUSSION

3.1. Quantitative Determination of the LCI Content in *C. nodosa*

Quantitative analyses of mixtures of sugars are generally carried out using chromatographic techniques such as HPLC and GC. However, these methods are time consuming and suffer numerous limitations due to the preliminary chemical derivatizations necessary for carbohydrate detection. These problems can be circumvented by using quantitative ^{1}H NMR spectroscopy. This fast, non-destructive technique with minimal sample preparation has been proved useful for quantification of individual components in crude extracts without the need for fractionation or isolation procedures [25, 34 - 37].

The LCI content of the crude aqueous extracts prepared from different batches of *C. nodosa* flotsam collected in the Canary Islands and throughout the Mediterranean Sea was measured by quantitative ^{1}H-NMR spectroscopy as previously described [25, 37]. The presence of three proton signal at δ 3.50 (dd), 3.67 (multiplet) and 3.95 (d), and three carbon signals at δ 70.48, 71.70 and 72.79, allow identification of the major product to free chiro-inositol [38, 39].

The doublet of LCI at 3.95 ppm, and the singlet (9 H) at 0.0 ppm of the TMSP chosen as internal standard were used for all calculations. The values found ranged from 22.2 to 35.0 mg.g^{-1} plant dw (Table **2**). These values are in the same order as those found in *S. filiforme* [25]. The chiro-inositol contained in *C. nodosa* was isolated from the crude extract to measure its rotatory power. The purification step was achieved by sequential silylation-desilylation with HMDS/TMCS in pyridine, then hydrolysis of the silylated chiro-inositol with TFA in CH_2Cl_2 led to a white precipitate of chiro-inositol (see Materials and Methods for details). Its purity was confirmed by ^{1}H NMR (Fig. **2**), and the observed levorotation ($[\alpha]_D^{25} = -67.8$, c = 0.5 (literature data: $[\alpha]_D^{20} = -70$, c = 0.55 in H_2O [40])) allowed to unambiguously identify the chiro-inositol contained in *Cymodocea* to LCI.

To the best of our knowledge, there are few published quantifications of LCI in plants. Epifano *et al* [41]. found 0.8 mg.g^{-1} of LCI in *Phagnalon sordidum* while Ichimura *et al* [6] found concentrations ranging from 0.2 to 1.9 mg.g^{-1} (fresh weight) in various organs of the ornamental plant Chrysanthemum. In a sample of living *S. filiforme* leaves from Jamaica, Drew [28] estimated the LCI content at 50 mg.g^{-1} but mentioned that his method of quantification could led to values in excess of 100% e.d.wt. Considering the demonstrated hypoglycaemic action of LCI, the high concentrations found in our study (23-25 mg.g^{-1} plant dw) offer promise for the exploitation of *C. nodosa* flotsam as a new cheap source for nutraceutical or therapeutic applications.

The presence of LCI in the tropical species *C. rotundata, C. serrulata, S. isoetifolium,* and *Halodule pinifolia* collected in Palk Bay (India), was also characterized by qualitative NMR. LCI appeared to be present in variable amount in all the samples.

Few authors have studied the biological properties of LCI, while it is well documented in the case of DCI. DCI has found applications as drugs [42]. It has a positive effect on glucose metabolism and can be used for the treatment of symptomatic insulin-resistant type II diabetes without known toxic or deleterious side effects [43] or as a preventive and treatment agent for cataracts [44]. DCI increases the action of insulin in patients with polycystic ovary syndrome (PCOS), which is the most common cause of anovulatory infertility in the US [45, 46]. Comparison of the respective effects of LCI and DCI on diabetic rats have shown that the stereoisomerism differences between the D and L- forms did not affect the hypoglycaemic action of chiro-inositol [47].

Usefulness of DCI as a nutritional supplement in the treatment or prevention of oxidative stress and related deseases has been claimed [48], which resulted in extensive cultivation of *Fagopyrum sagittatum* Gilib (common name: buckwheat) for the production of DCI-based herbal remedies. The concentrations of LCI found in the leaves of *S. filiforme* (23-25 mg.g^{-1}) and *C. nodosa* (22-35 mg.g^{-1}) are greater than the concentration of total DCI in buckwheat (14 mg.g^{-1} in farinetta) [49]. The ability of LCI to mimic DCI action, especially management of diabetes, opens promising opportunities for the exploitation of *Cymodoceaceae* beach cast.

3.2. Quantitative Determination of the CA Content in Tropical Seagrasses.

High performance liquid chromatography (HPLC) combined with diode array detection (DAD) was used for both qualitative and quantitative analyses of the crude extract composition. The identification of products in a sample was performed by matching both their HPLC retention time (R_t) and 220-400 nm on-line UVspectra with those of standards. Chromatograms were systematically recorded at 280, 328, and 350 nm, which allowed a clear distinction between C6,

C6-C3, and C6-C3-C6 backbone type of phenolic metabolites. HPLC analysis using a C18 column and methanol: aqueous trifluoroacetic acid (0.1 M) as the mobile phase allowed separation of the major and minor phenolics in one chromatographic run. Individual phenolic compounds were identified by comparing the absorption spectra of the unknown metabolite with that of authentic standards.

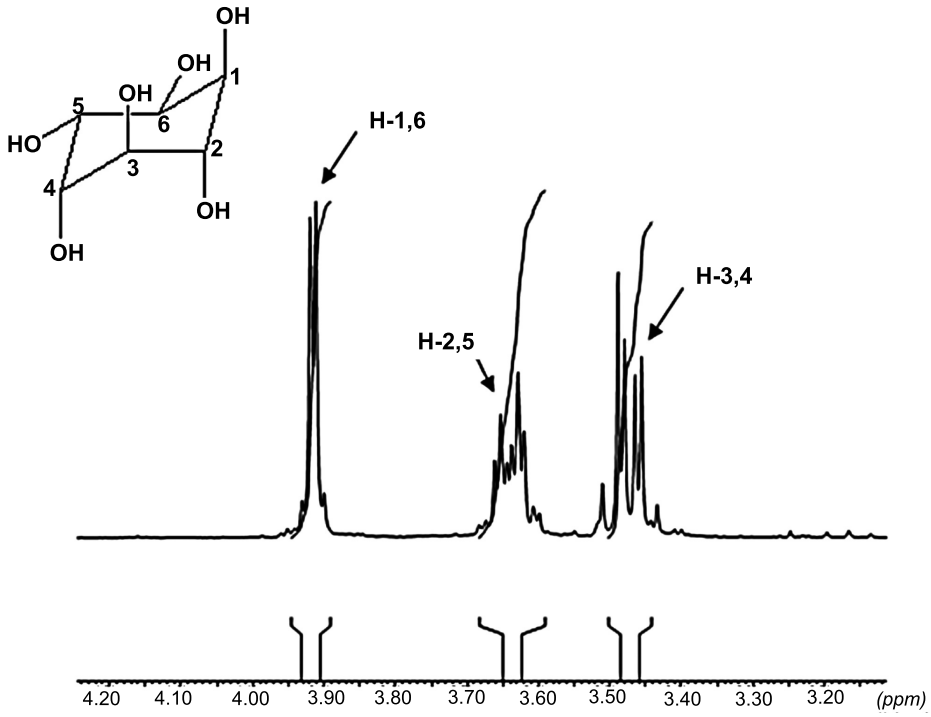


Fig. (2). ^{1}H NMR spectum (in D_2O) of pure free chiro-inositol isolated from *Cymodocea*.

Examination of Fig. (**3**) shows that *S. filiforme, S. isoetifolium, Halodule pinifolia* and *C. nodosa* share a very similar phenolic profile largely dominated by a compound eluted at R_t ~ 36.9 min with a typical caffeate UV spectra in good agreement with CA (λ_{max} 330 nm). The identity of CA was confirmed by comparison of the retention time, on line UV and UV-vis spectra, NMR and LC-MS data (ESIMS m/z: 497 $[M+23]^+$; main product ion at *m*/*z* = 163), with those of a commercial standard. All these analytical techniques led to perfectly overlaid results. A minor phenolic eluted at R_t ~ 21.7 min (λ_{max} 328 nm, ESIMS m/z: 335 $[M+23]^+$; main product ion at *m*/*z* = 163) was identified as caftaric acid (CAF, Figs. **1** and **3**). This substance often co-occurs with CA in others plants and could originate from partial hydrolysis of CA. The concentrations of CA found for *S. isoetifolium* and *Halodule pinifolia* (4.06 and 6.15 $mg.g^{-1}$, Table **2**) are similar to those previously found in *S. filiforme*. In contrast, *C. serrulata* and *C. rotundata* exhibit a complex mixture of phenolics, among which CA is still present but less abundant, while a mixture of flavonols was eluted between 39 and 45 min. Their on-line absorbance and spectral shape were characteristic of 3-O-glycosyl flavonols (Fig. **4**). On the basis of LC-MS and comparison to standard, some were tentatively assigned to: peak 2: rutin, MW 610; peaks 8 and 10, Kaempferol glucoside isomers, MW 448; peak 11, Kaempferol pentoside, MW 418. A peak at 21.5 min (λ_{max} 255 nm) was observed in the two species and identified to p-hydroxy benzoic acid. All the other peaks eluted from 2.0 to 20 min exhibit a spectral shape with λ_{max} ranging from 250 to 280 nm characteristic of aromatic C6 skeleton.

CA is of special interest due to its rarity in the plant kingdom and its biological properties. It has been reported to possess multifunctional effects, namely immunostimulating, anti-hyaluronidase and antioxidant activities, the ability to promote phagocyte activity in *vitro* and in *vivo*., the ability to inhibit HIV-1 integrase and replication [50, 51], and a protective effect on the free radical-induced degradation of collagen [52]. CA has been found to be one of the most potent HIV-1 integrase inhibitor [11]. Rutin and flavonols are also of interest. Epidemiological studies suggest that a high dietary intake of flavonols is associated with reduced risk of vascular disease and improvement in a number of parameters associated with this pathology [53]. Rutin and kaempferol have a variety of biological benefits including antiallergic, anti-inflammatory, antimicrobial, antiproliferative, antidiabetic, and anticarcinogenic properties [54 - 56].

Making direct comparisons between our results and the CA amounts reported in the literature for terrestrial plants appears difficult. Indeed, how the calculations have been done is not always clear, some of the results are expressed on a fresh weight basis, and concentrations were often obtained without taking into account the difference in the responses of the HPLC detector to CA and the standards used for quantification. Using the method developed by the Institute for Nutraceutical Advancement for the *Echinaceae* [33] solves these problems, and the data obtained represent the real amounts of CA in the dry plant.

Table 2. LCI and CA content values. Data are expressed in milligrams per gram (mg.g^{-1} of dry matter of leave tissue, mean ± standard deviation (SD) of three determinations).

Species	Sampling Site	LCI Content	CA Content
S. filiforme	**Guadeloupe, French West Indies**	**23-25**[a]	**0.94–5.26** [b]
S. isoetifolium	Palk Bay, India	Present, nd	4.06
C. nodosa	Canary Island, Spain Cadiz, Spain Alfacs Bay, Spain Monastir, Tunisia, Zeytineli, Turkey	35.0 ± 0.3 32.9 ± 0.6 22.2 ± 0.1 31.6 ± 0.6 25.0± 0.2	**27.44± 0.42**[c] **17.94±0.21** **18.52±0.25** **17.66±0.24** **12.11±0.22**
C. rotundata	Palk Bay, India	Present, nd	0.39
C. serrulata	Palk Bay, India	Present, nd	0.96
Halodule pinifolia	Palk Bay, India	Present, nd	6.15

Values from our previous works are given in bold character [a] [24]; [b] [25]; [c] [26]; nd: non quantified

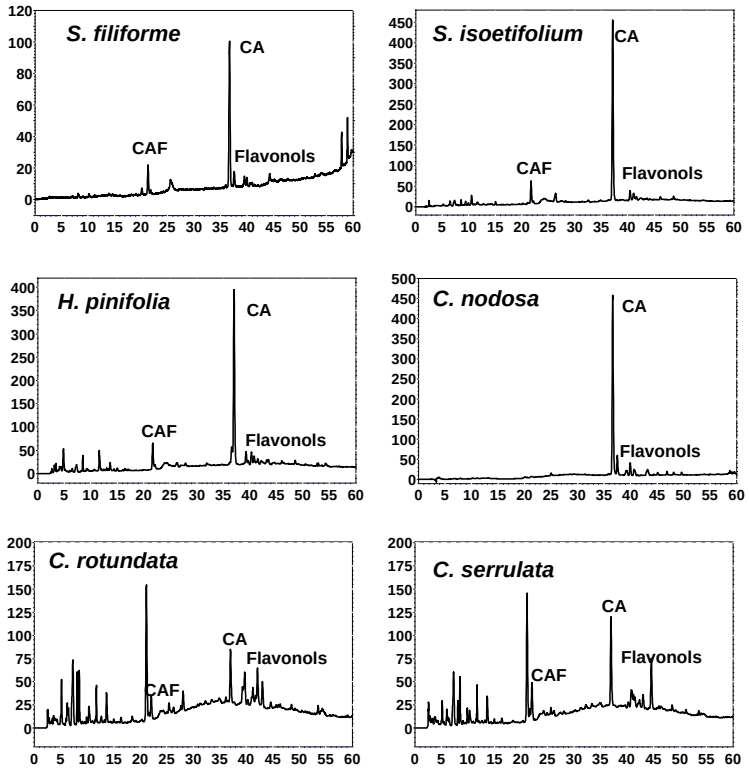


Fig. (3). HPLC profiles of crude extracts obtained from the six Cymodoceaceae species: traces at 280 nm, abscissa in min, ordinate in mAU. Retention times (min), assignment: 21.7 CAF; 36.9 CA; 38.5-45.0 mixture of flavonols.

Noticeable was the fact that CA and LCI were found in all the species. Although other members of Cymodoceaceae should be analyzed, these results already suggest that CA and LCI could be used as taxonomic markers for Cymodoceaceae. Among the four families of seagrasses, the Cymodoceaceae encompasses the highest variety with 15 species in five genera. Except for the six species presented in this work, the full characterization of the phenolic content of the nine others still needs to be established. Considering the high value properties of both LCI and CA, it appears of interest to investigate these other members of Cymodoceaceae growing in tropical seas.

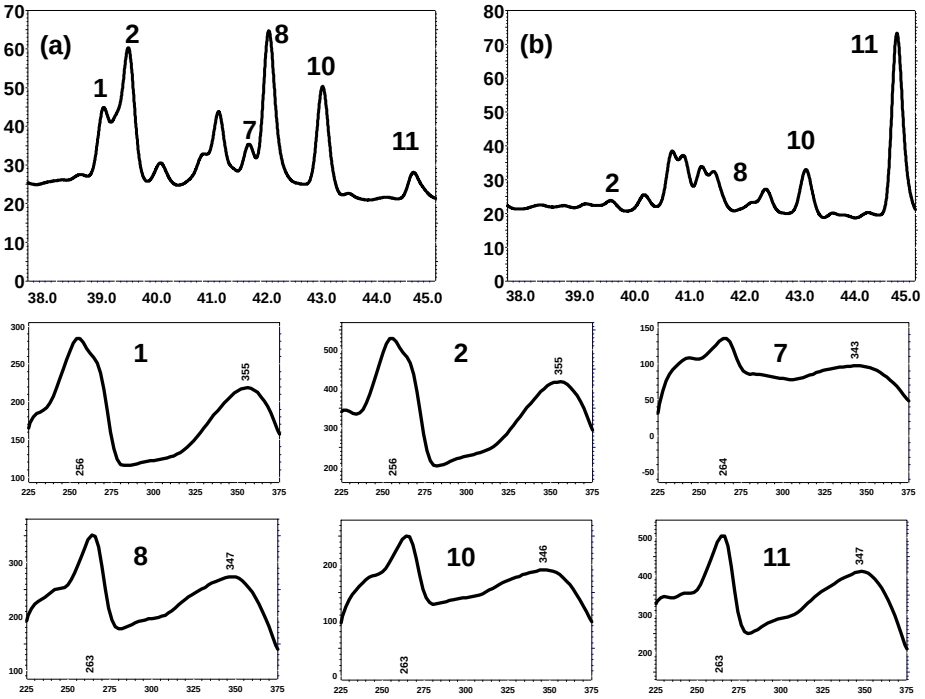


Fig. (4). Close-ups of the *Cymodocea* HPLC traces (280 nm, min, mAU) showing the flavonal compounds and their respective on-line UV spectum. (a) *C. rotundata*; (b) *C. serrulata*. Retention times (min), assignment: (1) 39.3, rutin derivative; (2) 39,7, rutin (8) 42.2 and (10) 43.1, kaempferol glucoside isomers; (11) 44.7, kaempferol pentoside.

CONCLUDING REMARKS

Considering the demonstrated therapeutic applications of L-chiro-inositol [3, 4, 48], and chicoric acid [12, 13], their high value on the nutraceutical market, and their rare occurrence in the plant kingdom, their presence in *Syringodium, Cymodocea* and *Halodule* detrital leaves makes this abundant biomass of interest for dietary and pharmaceutical applications. These results show that there is a real potential for harvesting beachcast Cymodoceacea.

Seagrass meadows form one of the most widespread and productive coastal systems in the world. Huge amounts of leaves are shed and washed ashore, often building important banks of seagrass litter. Recovery of chiro-inositol or chicoric acid from beach waste material could promote opportunities for the economic development of tropical coastal areas. In the West the demand for herbal drugs has reached a new high in recent years. In India, the total market for nutraceuticals is also growing trying to incorporate traditional herbal ingredients into the nutraceutical portfolio. Indian seagrasses were traditionnaly used for thousands of years for a variety of applications from food to medicine and the engagement of the Tamil Nadu community in collecting and sorting seagrasses has been recently reported [57]. All these features could justify significant exploitation of this abundant renewable resource. Harvesting seagrass litter on areas where it is a nuisance to other economic activities, could be of benefit to all.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

We are grateful to Eburon Organics (B-2310 Rijkevorsel, Belgium) for providing the authentic samples of CA and CAF, and to the Service Central d'Analyse (SCA), CNRS, F69360 Solaize, for recording the LC-MS spectra. We also thank the European SUDOE program for financial support. We would like to thank Saurabh Bansal, Eduardo Portillo Hahnefeld, and everyone who kindly volunteered on the spot to help us harvest our sea grass samples in various locations.

REFERENCES

[1] Einat H, Clenet F, Shaldubina A, Belmaker RH, Bourin M. The antidepressant activity of inositol in the forced swim test involves 5-HT(2) receptors. Behav Brain Res 2001; 118(1): 77-83.
[http://dx.doi.org/10.1016/S0166-4328(00)00314-4] [PMID: 11163636]

[2] Somasundar P, Riggs DR, Jackson BJ, Cunningham C, Vona-Davis L, McFadden DW. Inositol hexaphosphate (IP6): A novel treatment for pancreatic cancer. J Surg Res 2005; 126(2): 199-203.
[http://dx.doi.org/10.1016/j.jss.2005.01.022] [PMID: 15919420]

[3] Ostlund RE Jr, McGill JB, Herskowitz I, Kipnis DM, Santiago JV, Sherman WR. D-chiro-inositol metabolism in diabetes mellitus. Proc Natl Acad Sci USA 1993; 90(21): 9988-92.
[http://dx.doi.org/10.1073/pnas.90.21.9988] [PMID: 8234346]

[4] Kawa JM, Taylor CG, Przybylski R. Buckwheat concentrate reduces serum glucose in streptozotocin-diabetic rats. J Agric Food Chem 2003; 51(25): 7287-91.
[http://dx.doi.org/10.1021/jf0302153] [PMID: 14640572]

[5] Hensens OD, Lewis KG, Mulquiney CE. Some extractives from mistletoe. Aust J Chem 1971; 24(2): 431-4.
[http://dx.doi.org/10.1071/CH9710431]

[6] Ichimura K, Kohata K, Yamaguchi Y, Douzono M, Ikeda H, Koketsu M. Identification of L-inositol and scyllitol and their distribution in various organs in chrysanthemum. Biosci Biotechnol Biochem 2000; 64(4): 865-8.
[http://dx.doi.org/10.1271/bbb.64.865] [PMID: 10830508]

[7] Wang AX, Zhang Q, Jia ZJ. Phenylpropanosids, lignans and other constituents from *Cremanthodium ellisii.* Pharmazie 2004; 59(11): 889-92.
[PMID: 15587595]

[8] Bøe JE, Winsnes R, Nordal A, Bernatek E. New constituents of *Euphorbia resinifera* Berg. Acta Chem Scand 1969; 23(10): 3609.
[http://dx.doi.org/10.3891/acta.chem.scand.23-3609] [PMID: 5381552]

[9] el-Naggar L, Beal JL, Parks LM, Salman KN, Patil P. A note on the isolation and identification of two pharmacologically active constituents of *Euphorbia pilulifera.* Lloydia 1978; 41(1): 73-5.
[PMID: 642726]

[10] Bustos-Brito C, Andrade-Cetto A, Giraldo-Aguirre JD, Moreno-Vargas AD, Quijano L. Acute hypoglycemic effect and phytochemical composition of *Ageratina petiolaris.* J Ethnopharmacol 2016; 185: 341-6.
[http://dx.doi.org/10.1016/j.jep.2016.03.048] [PMID: 27013093]

[11] Chhipa N, Patel KM, Ganchi SP, Sen DJ. Chicoric acid and its analogues as an anti-HIV integrase agents. World J Pharm Pharm Sci 2014; 3(2): 2321-35.

[12] Liu CZ, Abbasi BH, Gao M, Murch SJ, Saxena PK. Caffeic acid derivatives production by hairy root cultures of *Echinacea purpurea.* J Agric Food Chem 2006; 54(22): 8456-60.
[http://dx.doi.org/10.1021/jf061940r] [PMID: 17061821]

[13] Wang Y, Diao Z, Li J, *et al.* Chicoric acid supplementation ameliorates cognitive impairment induced by oxidative stress *via* promotion of antioxidant defense system. RSC Advances 2017; 7(57): 36149-62.
[http://dx.doi.org/10.1039/C7RA06325C]

[14] Pellati F, Benvenuti S, Magro L, Melegari M, Soragni F. Analysis of phenolic compounds and radical scavenging activity of *Echinacea* spp. J Pharm Biomed Anal 2004; 35(2): 289-301.
[http://dx.doi.org/10.1016/S0731-7085(03)00645-9] [PMID: 15063463]

[15] Cardozo KH, Guaratini T, Barros MP, *et al.* Metabolites from algae with economical impact. Comp Biochem Physiol C Toxicol Pharmacol 2007; 146(1-2): 60-78.
[http://dx.doi.org/10.1016/j.cbpc.2006.05.007] [PMID: 16901759]

[16] Achamlale S, Rezzonico B, Grignon-Dubois M. Evaluation of *Zostera* detritus as a potential new source of zosteric acid. J Appl Phycol 2009; 21(3): 347-52.
[http://dx.doi.org/10.1007/s10811-008-9375-8]

[17] Achamlale S, Rezzonico B, Grignon-Dubois M. Rosmarinic acid from beach waste: Isolation and HPLC quantification in *Zostera* detritus from Arcachon lagoon. Food Chem 2009; 113(4): 878-83.
[http://dx.doi.org/10.1016/j.foodchem.2008.07.040]

[18] Short F, Carruthers T, Dennison W, Waycott M. Global seagrass distribution and diversity: A bioregional model. J Exp Mar Biol Ecol 2007;

350(1): 3-202.
[http://dx.doi.org/10.1016/j.jembe.2007.06.012]

[19] Zidorn C. Secondary metabolites of seagrasses (Alismatales and Potamogetonales; Alismatidae): Chemical diversity, bioactivity, and ecological function. Phytochemistry 2016; 124: 5-28.
[http://dx.doi.org/10.1016/j.phytochem.2016.02.004] [PMID: 26880288]

[20] Dolgii OD, Petrov MV, Malenok PI, Luzanov ME, Mekhonoshin AA, Pakhomov AI. Method of preparing pectin from sea algae. Russia Patent 1999. RU 2132696C1

[21] Loenko YN, Artyukov AA, Kozlovskaya EP, Miroshnichenko VA, Elyakov GB. Zosterin. Vladivostok Dal'nauka 1997; pp. 41-145.

[22] Bobylin VV, Vozhdaeva LI. Method of producing protein-pectin mass "vostok". Patent RU2129388C1 1999.

[23] Bobylin VV, Ostroumova TA. Method of producing soft cheese "Vesenniy". Patent RC2128918 1999.

[24] Gavriljuk VB, Gavriljuk BK. Preparation for preventing and treating capillary cutaneous lesions (Telangioectasias). In: Russia Patent RU2242217 2004.

[25] Nuissier G, Diaba F, Grignon-Dubois M. Bioactive agents from beach waste: *Syringodium flotsam* evaluation as a new source of L-chiro-inositol. Innov Food Sci Emerg Technol 2008; 9(3): 396-400.
[http://dx.doi.org/10.1016/j.ifset.2007.12.002]

[26] Nuissier G, Rezzonico B, Grignon-Dubois M. Chicoric acid from Syringodium filiforme. Food Chem 2010; 120(3): 783-8.
[http://dx.doi.org/10.1016/j.foodchem.2009.11.010]

[27] Grignon-Dubois M, Rezzonico B. The economic potential of beach-cast seagrass – *Cymodocea nodosa:* a promising renewable source of chicoric acid. Bot Mar 2013; 56(4): 303-11.
[http://dx.doi.org/10.1515/bot-2013-0029]

[28] Drew EA. Sugars, cyclitols and seagrass phylogeny. Aquat Bot 1983; 15(4): 387-408.
[http://dx.doi.org/10.1016/0304-3770(83)90007-4]

[29] Green EP, Short FT. World Atlas of Seagrasses. In: Association with UNEP-WCMC by the. California: University of California Press 2003.

[30] Lanyon J. Guide to the identification of seagrasses in the Great Barrier Reef region Great Barrier Reef Marine Park Authority Special Publication Series (3). Townsville: Nadicprint Services 1986; p. 544.

[31] El Shaffai A. Field Guide to Seagrasses of the Red Sea. IUCN and Courbevoie, France: Total Foundation: Gland, Switzerland 2016; p. viii+56. ISBN:978-2-8317-1414-1

[32] Kuo J, den Hartog C. Seagrass taxonomy and identification key. In: Short FT, Cole RG, Eds. Global Seagrass Research Methods. Amsterdam: Elsevier Science B.V. 2001.
[http://dx.doi.org/10.1016/B978-044450891-1/50003-7]

[33] INA. Institute for Neutraceutical Advancement (1991) Ref: Economic and Medicinal Plant Research, vol 5, 1991, pp 253-321, www.nsf.org/business/ina/echinacea.asp?program=INA. INA Phenolics in Echinacea by HPLC. http://www.nutraceuticalinstitute.com /methods/echinacea.html May, 2000.

[34] Rivero-Cruz B, Rivero-Cruz I, Rodríguez JM, Cerda-García-Rojas CM, Mata R. Qualitative and quantitative analysis of the active components of the essential oil from *Brickellia veronicaefolia* by nuclear magnetic resonance spectroscopy. J Nat Prod 2006; 69(8): 1172-6.
[http://dx.doi.org/10.1021/np060180b] [PMID: 16933870]

[35] Al-Deen TS, Hibbert DB, Hook JM, Wells RJ. An uncertainty budget for the determination of the purity of glyphosate by quantitative nuclear magnetic resonance (QNMR) spectroscopy. Accredit Qual Assur 2004; 9(1-2): 55-63.
[http://dx.doi.org/10.1007/s00769-003-0737-2]

[36] Pauli GF, Gödecke T, Jaki BU, Lankin DC. Quantitative 1H NMR. Development and potential of an analytical method: an update. J Nat Prod 2012; 75(4): 834-51.
[http://dx.doi.org/10.1021/np200993k] [PMID: 22482996]

[37] Grignon-Dubois M, Echmak C. First evaluation of the marine invasive species *Spartina anglica* as a potential renewable source of glycine betaine. J Appl Pharm Sci 2013; 3(06): 29-34.

[38] Abraham RJ, Byrne JJ, Griffiths L, Koniotou R. 1H chemical shifts in NMR: Part 22-Prediction of the ^{1}H chemical shifts of alcohols, diols and inositols in solution, a conformational and solvation investigation. Magn Reson Chem 2005; 43(8): 611-24.
[http://dx.doi.org/10.1002/mrc.1611] [PMID: 15986495]

[39] Angyal SJ, Odier L. The ^{13}C-NMR spectra of inositols and cyclohexanepentols: the validity of rules correlating chemical shifts with configuration. Carbohydr Res 1982; 100(1): 43-54.
[http://dx.doi.org/10.1016/S0008-6215(00)81024-1] [PMID: 6814758]

[40] Podeschwa M, Plettenburg O, Vom Brocke J, Black O, Adelt S, Altenbach HJ. Stereoselective synthesis of myo-, neo-, L-chiro-, D-chiro-, allo-, scyllo- and epi-inositol systems *via* conduritols prepared from p-benzoquinone. Eur J Org Chem 2003; 2003(10): 1958-72.
[http://dx.doi.org/10.1002/ejoc.200200572]

[41] Epifano F, Marcotullio MC, Menghini L. Constituents of *Phagnalon sordidum.* Chem Nat Compd 2002; 38(2): 204-5.
[http://dx.doi.org/10.1023/A:1019620905422]

[42] Iuorno MJ, Nestler JE. Insulin-lowering drugs in polycystic ovary syndrome. Obstet Gynecol Clin North Am 2001; 28(1): 153-64. [http://dx.doi.org/10.1016/S0889-8545(05)70191-1] [PMID: 11293000]

[43] Larner J, Kennington A. Pharmaceutical composition for insulin-resistant diabetics. European Patent EP 0465508B1 1992.

[44] Jun JG, Jun YJ, Kim JJ, Kim YA, Kim YJ, Lee WG. Chiro inositol or pinitol as prevention and treatment agent for cataract and composition thereof. Korea Patent KR 3029333A 2003.

[45] Nestler JE, Jakubowicz DJ, Reamer P, Gunn RD, Allan G. Ovulatory and metabolic effects of D-chiro-inositol in the polycystic ovary syndrome. N Engl J Med 1999; 340(17): 1314-20. [http://dx.doi.org/10.1056/NEJM199904293401703] [PMID: 10219066]

[46] Baillargeon JP, Diamanti-Kandarakis E, Ostlund RE Jr, Apridonidze T, Iuorno MJ, Nestler JE. Altered D-chiro-inositol urinary clearance in women with polycystic ovary syndrome. Diabetes Care 2006; 29(2): 300-5. [http://dx.doi.org/10.2337/diacare.29.02.06.dc05-1070] [PMID: 16443877]

[47] Musalmah M, Elkkairee MR, La CM, Wan Ngah WZ. Effect of latex quebrachitol and L-chiro-inositol on blood glucose levels in normal and alloxan-induced diabetic rats. Malaysian J Biochem Mol Biol 2001; 6: 7-11.

[48] Larner J. Method of treating endothelial dysfunction oxidative stress and related diseases. United States Patent US 0004096A1 2006.

[49] Steadman KJ, Burgoon MS, Schuster RL, Lewis BA, Edwardson SE, Obendorf RL. Fagopyritols, D-chiro-inositol, and other soluble carbohydrates in buckwheat seed milling fractions. J Agric Food Chem 2000; 48(7): 2843-7. [http://dx.doi.org/10.1021/jf990709t] [PMID: 10898633]

[50] Reinke RA, Lee DJ, McDougall BR, *et al.* L-chicoric acid inhibits human immunodeficiency virus type 1 integration *in vivo* and is a noncompetitive but reversible inhibitor of HIV-1 integrase *in vitro.* Virology 2004; 326(2): 203-19. [http://dx.doi.org/10.1016/j.virol.2004.06.005] [PMID: 15302207]

[51] Charvat TT, Lee DJ, Robinson WE, Chamberlin AR. Design, synthesis, and biological evaluation of chicoric acid analogs as inhibitors of HIV-1 integrase. Bioorg Med Chem 2006; 14(13): 4552-67. [http://dx.doi.org/10.1016/j.bmc.2006.02.030] [PMID: 16524737]

[52] Barrett B. Medicinal properties of *Echinacea*: A critical review. Phytomedicine 2003; 10(1): 66-86. [http://dx.doi.org/10.1078/094471103321648692] [PMID: 12622467]

[53] Graf BA, Milbury PE, Blumberg JB. Flavonols, flavones, flavanones, and human health: Epidemiological evidence. J Med Food 2005; 8(3): 281-90. [http://dx.doi.org/10.1089/jmf.2005.8.281] [PMID: 16176136]

[54] Gullon B, Lu-Chau T, Moreira MT, Lema JM, Eibes G. Rutin: A review on extraction, identification and purification methods, biological activities and approaches to enhance its bioavailability. Trends Food Sci Technol 2017; 67: 220-35. [http://dx.doi.org/10.1016/j.tifs.2017.07.008]

[55] Kashyap D, Sharma A, Tuli HS, Sak K, Punia S, Mukherjee TK. Kaempferol - A dietary anticancer molecule with multiple mechanisms of action: Recent trends and advancements. J Funct Foods 2017; 30: 203-19. [http://dx.doi.org/10.1016/j.jff.2017.01.022]

[56] Devi KP, Malar DS, Nabavi SF, *et al.* Kaempferol and inflammation: From chemistry to medicine. Pharmacol Res 2015; 99: 1-10. [http://dx.doi.org/10.1016/j.phrs.2015.05.002] [PMID: 25982933]

[57] Newmaster AF, Berg KJ, Ragupathy S, Palanisamy M, Sambandan K, Newmaster SG. Local knowledge and conservation of seagrasses in the Tamil Nadu state of India. J Ethnobiol Ethnomed 2011; 7(1): 37. [http://dx.doi.org/10.1186/1746-4269-7-37] [PMID: 22112297]

© 2017 Grignon-Dubois and Rezzonico

This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International Public License (CC-BY 4.0), a copy of which is available at: (https://creativecommons.org/licenses/by/4.0/legalcode). This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.