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Chemical composition of lignin and lipids from tagasaste (*Chamaecytisus proliferus* spp. *palmensis*)

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ABSTRACT

The chemical characterization of trimming residues of tagasaste (*Chamaecytisus proliferus* spp. *palmensis*), a hardy leguminous shrub that has been recently explored for pulp and paper production, was performed with especial emphasis in the composition of lignin and lipophilic extractives. Tagasaste was characterized by a high content of holocellulose (81%) and α -cellulose (41%), while having a relatively low lignin content of 18.9%. The analysis of lignin was performed “in situ” by pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) and showed a composition with a guaiacyl:syringyl (G:S) molar proportion of 38:62 (S/G molar ratio of 1.6) and the absence of *p*-hydroxyphenyl (H) units. The high S/G ratio, together with its low lignin content makes tagasaste an adequate raw material for pulping. On the other hand, the relatively high acetone extractive content (1.4%) was mostly due to polar compounds and only 0.2% corresponded to lipophilic compounds. The lipophilic compounds, analyzed by GC and GC/MS, were mainly composed of fatty acids, including α -hydroxyfatty acids, and steroid compounds, such as free and conjugated (esters and glycosides) sterols.

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1. Introduction

Tagasaste (*Chamaecytisus proliferus* spp. *palmensis*), also known as “tree lucerne”, is a hardy leguminous and fast-growing shrub of the *Fabaceae* (Genisteae) family. It is indigenous of the Canary Islands (Spain) but is now being cultivated in Australia, New Zealand and other countries (Francisco-Ortega et al., 1991). The shrub is being mainly exploited for high-protein fodder to maintain livestock (Borens and Poppi, 1990; Ventura et al., 2002) and also as N-fixing crops to improve soil fertility (Kindu et al., 2006). In order to encourage the formation of bushes with multiple stems, the shrub must be grazed with regularity, which leads to a high accumulation of trimming residues. These residues are nowadays considered as agricultural waste since they cannot be converted to valuable products.

As attempts to reduce the adverse environmental impact and to use this renewable biomass, they have been recently explored as an alternative raw material for pulp production (Díaz et al., 2004; López et al., 2004; Jiménez et al., 2006, 2007; García et al., in press). Tagasaste has been found to be an excellent raw material for paper pulp production, similar to eucalypt wood, with high holocellulose and α -cellulose contents, and low lignin and extractives content, giving high yields (Díaz et al., 2004; López et al., 2004; Jiménez et al., 2006). However, despite all this previous work, a detailed chemical composition of tagasaste trimming residues has not been addressed so far, which is of high importance for optimizing the use of this raw material for paper pulp production.

The content and chemical structure of woody components, in particular the lignin content and its composition in terms of its *p*-hydroxyphenyl (H), guaiacyl (G) and syringyl (S) moieties

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are important parameters in pulp production in view of delignification rates, chemical consumption and pulp yields. The higher reactivity of the S lignin with respect to the G lignin in alkaline systems is known (Chang and Sarkanen, 1973; Tsutsumi et al., 1995) and, therefore, the lignin S/G ratio in hardwoods affects the pulping efficiency. It has already been shown for eucalypt woods that higher S/G ratios imply higher delignification rates, less alkali consumption and, therefore, higher pulp yield (González-Vila et al., 1999; del Río et al., 2005).

On the other hand, the composition of extractives, especially the lipophilic compounds, is also important for pulp and paper production. The different classes of lipids have different behavior during cooking and bleaching. The lipids can be classified into two principal groups, namely fatty acids and neutral components, the latter including waxes, long chain *n*-fatty alcohols, alkanes and steroids and triterpenoids. And the behavior of the fatty acids in an aqueous environment is quite different from that of the neutrals. In alkaline pulping, the acids dissociate and can dissolve in water to quite a high extent, forming fatty acid soaps. The neutrals, however, have a very low solubility in water and survive the cooking process and remain in the pulp being at the origin of the so-called pitch deposits, which are responsible of reduced product quality and higher operating costs due to production stops for cleaning the equipment (Hillis and Sumimoto, 1989; Back and Allen, 2000). The increasing trend in recirculating water in pulp mills to accomplish environmental demands is aggravating these problems.

Therefore, the main objective of this work is to perform a thorough chemical characterization of tagasaste trimming residues, with especial emphasis in the chemical composition of lignin and lipophilic extractives. In this work, the lignin composition of tagasaste was characterized “*in situ*” using analytical pyrolysis coupled to gas chromatography/mass spectrometry (Py-GC/MS), a powerful analytical tool for the rapid analysis of complex polymer mixtures including lignocellulosic materials (Ralph and Hatfield, 1991; Faix et al., 1990; del Río et al., 2001, 2005) that can give information on the lignin composition in terms of the H, G and S moieties. On the other hand, the chemical characterization of the lipophilic extractives was performed by GC and GC/MS by using high-temperature short- and medium-length capillary columns, respectively. This method enables the elution and analysis of intact high molecular weight lipids (Gutiérrez et al., 1998). The knowledge of the chemical composition of the main components of tagasaste trimming residues will be useful for a better utilization of this agricultural waste.

2. Experimental

2.1. Samples

Tagasaste trimming residues were supplied by University of Huelva, Spain. The dried samples were milled using a knife mill. For the isolation of lipids, the milled samples were extracted with acetone in a Soxhlet apparatus for 8 h. The acetone extracts were evaporated to dryness and resuspended in chloroform for chromatographic analysis of the lipophilic

fraction. Two replicates were used for each sample, and all samples were subjected to GC and GC/MS analyses. For Klason lignin content estimation, the samples extracted with acetone were subsequently extracted with hot water (3 h at 100 °C) to remove the water-soluble material. Holocellulose was isolated from the pre-extracted fibers by delignification for 4 h using the acid chlorite method (Browning, 1967). The α -cellulose content was determined by removing the hemicelluloses from the holocellulose by alkali extraction (Browning, 1967). Klason lignin was estimated as the residue after sulfuric acid hydrolysis of the pre-extracted material according to TAPPI rule T222 om-88 (TAPPI, 1993). The acid-soluble lignin was determined, after filtering off the insoluble lignin, by spectrophotometric determination at 205 nm wavelength. Ash content was estimated as the residue after 6 h at 575 °C.

2.2. Solid phase extraction (SPE) fractionation

For a better characterization of the different homologous series, the lipid extracts were fractionated by a SPE procedure using aminopropyl-phase cartridges (500 mg) from Waters (Division of Millipore), as already described (Gutiérrez et al., 1998). Briefly, the dried chloroform extracts were taken up in a minimal volume (<0.5 ml) of hexane:chloroform (4:1) and loaded into the cartridge column previously conditioned with hexane (4 ml). The cartridge was loaded and eluted by gravity. The column was first eluted with 8 ml of hexane and subsequently with 6 ml of hexane:chloroform (5:1), then with 10 ml of chloroform and finally with 10 ml of diethyl ether:acetic acid (98:2). Each isolated fraction was dried under nitrogen and analyzed by GC and GC/MS.

2.3. GC and GC/MS analyses

The GC analyses of the extracts were performed in an Agilent 6890N GC system using a short-fused silica capillary column (DB-5HT, 5 m $\times$ 0.25 mm I.D., 0.1 μ m film thickness). The temperature program was started at 100 °C with a 1-min hold and then raised to a final temperature of 350 °C at 15 °C/min, and held for 3 min. The injector and flame-ionization detector temperatures were set at 300 and 350 °C, respectively. Helium was used as the carrier gas at a rate of 5 ml/min, and the injection was performed in splitless mode. Peaks were quantified by area, and a mixture of standards (octadecane, palmitic acid, sitosterol and cholesteryl oleate) was used to elaborate calibration curves.

The GC/MS analyses were performed with a Varian model Star 3400 GC equipped with an ion trap detector (Varian Saturn 2000) using a medium-length (12 m) capillary column of the same characteristics described above. The oven was heated from 120 (1 min) to 380 °C at 10 °C/min and held for 5 min. The transfer line was kept at 300 °C. The injector was temperature-programmed from 120 (0.1 min) to 380 °C at a rate of 200 °C/min and held until the end of the analysis. Helium was used as the carrier gas at a rate of 2 ml/min. Trimethylsilyldiazomethane methylation and bis(trimethylsilyl)trifluoroacetamide (BSTFA) silylation, in the presence of pyridine, were used to produce the appropriate derivatives, when required. Compounds were identified by comparing their mass spectra with mass spectra

in Wiley and NIST libraries, by mass fragmentography, and when possible, by comparison with authentic standards.

2.4. Py-GC/MS

The pyrolysis of tagasaste (1mg) was performed in a micro-furnace pyrolyzer (model 2020, Frontier Laboratories Ltd.) directly connected to a GC/MS system Agilent 6890 equipped with a fused silica capillary column HP 5MS (30 m $\times$ 0.25 mm $\times$ 0.25 μ m I.D.). The detector consisted of an Agilent 5973 mass selective detector. The pyrolysis was performed at 500 °C. The final temperature was achieved at a rate of 20 °C/min. The GC/MS conditions were as follows: oven temperature was held at 50 °C for 1 min and then increased up to 100 °C at 30 °C/min, from 100 to 300 °C at 10 °C/min and isothermal at 300 °C for 10 min using a heating rate of 20 °C/min in the scan modus. The carrier gas used was helium with a controlled flow of 1 ml/min. The compounds were identified by comparing the mass spectra obtained with those of the Wiley and NIST computer libraries and that reported in the literature (Faix et al., 1990; Ralph and Hatfield, 1991). Relative peak molar areas were calculated for carbohydrate and lignin pyrolysis products. The summed molar areas of the relevant peaks were normalized to 100%, and the data for two repetitive pyrolysis experiments were averaged.

3. Results and discussion

Tagasaste was characterized by a high content of holocellulose (81%) and α -cellulose (41%), and a lignin content of 18.9% (Klason lignin, 16.6%; acid-soluble lignin: 2.3%). Similar values have been reported by other authors (Díaz et al., 2004). This low lignin content is similar to that found in eucalypt wood (Rencoret et al., 2007), a widely raw material for pulp and papermaking, and together with the high holocellulose and α -cellulose contents makes tagasaste an interesting raw material for pulp and paper production, as already advanced by other authors (Díaz et al., 2004; López et al., 2004; Jiménez et al., 2006, 2007; García et al., in press). On the other hand, the acetone extractives accounted for 1.4% but the chloroform-soluble lipids accounted for only 0.2%, which is a value lower than that found in most lignocellulosic materials (Back and Allen, 2000). However, while the content of the main organic fractions is an important parameter in wood processing for pulp and papermaking, the chemical composition of these organic fractions, in particular the lignin composition in terms of the relative proportions of the S- and G-units, and the lipid composition, in terms of the presence of saponifiable or unsaponifiable components, strongly influences the pulping and bleaching behavior of a raw material.

3.1. Lignin composition

The lignin composition of tagasaste was characterized *in situ* by Py-GC/MS. The pyrogram of tagasaste sample is shown in Fig. 1 and the identities and relative molar abundances of the released compounds are listed in Table 1

. Py-GC/MS of tagasaste wood trimming residues released compounds arising from carbohydrates (67%) and lignin-

Fig. 1 – Py-GC/MS of tagasaste wood. The identities of the peaks are shown in Table 1.

derived phenols (34%). The lignin-derived phenols arise from guaiacyl (G) and syringyl (S) lignin units whereas no traces of *p*-hydroxyphenyl (H) units were found in tagasaste. The main lignin-derived compounds identified were 4-vinylsyringol (38), syringol (24), 4-methylsyringol (29), 4-ethylsyringol (35) and 4-vinylguaiacol (23). Syringaldehyde (41), syringylacetone (47) and *trans*-sinapaldehyde (49) were also identified. Relative peak molar areas were calculated for carbohydrate, and lignin G- and S-type degradation products. The Py-GC/MS data showed a lignin composition in tagasaste with a predominance of the S units (S/G molar ratio of 1.6), typical of hardwoods. The predominance of S-lignin units in tagasaste makes this material advantageous for delignification due to the higher reactivity of the S-lignin in alkaline systems (Chang and Sarkanen, 1973; Tsutsumi et al., 1995; González-Vila et al., 1999) and its lower condensation degree. The G units have a free C-5 position available for carbon–carbon inter-unit bonds, which make them fairly resistant to lignin depolymerization in pulping, while the S lignin is relatively unbranched and has a lower condensation degree and, therefore, is easier to

Fig. 2 – GC/MS of the lipophilic extracts from tagasaste wood. Key labels are: F_n: fatty acids; (1) α -tocopherol; (2) campesterol; (3) stigmasterol; (4) sitosterol; (5) stigmasterol; (6) 7-ketocampesterol; (7) 7-ketostigmasterol; (8) 7-ketositosterol.

Table 1 – Identification and relative molar abundance of the compounds released by Py-GC/MS of tagasaste

No.	Compounds	Origin	Mass fragments	MW	%
1	Acetic acid	C	45/60	60	39.4
2	(3H) Furan-3-one	C	55/84	84	0.7
3	1,3-Hydroxydihydro-2-(3H)-furanone	C	58/102	102	3.1
4	(3H) Furan-3-one	C	55/84	84	1.0
5	2-Furaldehyde	C	67/95/96	96	3.8
6	2-(Hydroxymethyl)-furan	C	43/70/81/98	98	0.5
7	Cyclopent-1-ene-3,4-dione	C	54/68/96	96	0.6
8	(5H) Furan-2-one	C	55/84	84	2.9
9	2,3-Dihydro-5-methylfuran-2-one	C	55/69/98	98	3.1
10	5-Methyl-2-furfuraldehyde	C	53/109/110	110	0.4
11	4-Hydroxy-5,6-dihydro-(2H)-pyran-2-one	C	58/85/114	114	2.6
12	3-Hydroxy-2-methyl-2-cyclopenten-1-one	C	55/85/112	112	0.6
13	2-Hydroxy-3-methyl-2-cyclopenten-1-one	C	55/85/112	112	0.3
14	Dihydroxypyran-1-one	C	56/84/114	114	0.8
15	Guaiacol	LG	81/109/124	124	1.9
16	Dimethyldihydropyranone	C	55/70/83/111/126	126	0.3
17	4-Methylguaiacol	LG	95/123/138	138	1.2
18	Catechol	C	64/81/92/110	110	1.1
19	5-Hydroxymethyl-2-tetrahydrofuraldehyde-3-one	C	57/69/85/98/99	138	0.4
20	5-Hydroxymethyl-2-furaldehyde	C	69/97/109/126	126	0.3
21	Methoxycatechol	L	60/97/125/140	140	0.9
22	4-Ethylguaiacol	LG	122/137/152	152	0.4
23	4-Vinylguaiacol	LG	107/135/150	150	2.1
24	Syringol	LS	111/139/154	154	3.6
25	Eugenol	LG	131/149/164	164	0.4
26	4-Propylguaiacol	LG	122/136/166	166	0.1
27	Vanillin	LG	109/151/152	152	0.7
28	cis-Isoeugenol	LG	131/149/164	164	0.4
29	4-Methylsyringol	LS	125/153/168	168	1.8
30	trans-Isoeugenol	LG	131/149/164	164	1.2
31	Homovanillin	LG	122/137/166	166	0.2
32	4-Propinylguaiacol	LG	77/91/119/147/162	162	1.0
33	4-Propinylguaiacol isomer	LG	77/91/119/147/162	162	1.3
34	Acetovanillone	LG	123/151/166	166	0.2
35	4-Ethylsyringol	LS	167/182	182	1.5
36	Guaiacylacetone	LG	122/137/180	180	0.7
37	Levoglucosane	C	60/98	162	4.8
38	4-Vinylsyringol	LS	137/165/180	180	4.2
39	4-Allylsyringol	LS	167/179/194	194	0.7
40	cis-4-Propenylsyringol	LS	167/179/194	194	0.5
41	Syringaldehyde	LS	167/181/182	182	1.2
42	4-Propynylsyringol	LS	106/131/177/192	192	1.0
43	4-Propynylsyringol isomer	LS	106/131/177/192	192	0.8
44	trans-4-Propenylsyringol	LS	167/179/194	194	2.5
45	Acetosyringone	LS	153/181/196	196	0.6
46	trans-Coniferaldehyde	LG	107/135/147/178	178	0.8
47	Syringylacetone	LS	123/167/210	210	0.5
48	Propiosyringone	LS	151/181/210	210	0.3
49	trans-Sinapaldehyde	LS	137/165/180/208	208	1.3
%G					38
%S					62
S/G					1.6

C: cellulose; LG: lignin guaiacyl; LS: lignin syringyl.

delignify. The high S/G ratio, together with its low lignin content, explains the excellent performances of tagasaste during alkaline pulping.

3.2. Lipid composition

The lipid composition in tagasaste was analyzed by gas chromatography (GC) and gas chromatography/mass spectrometry

(GC/MS), using short- and medium-length high-temperature capillary columns, respectively (Gutiérrez et al., 1998), which enable the elution and analysis of intact high molecular weight lipids such as waxes, sterol esters, and triglycerides. The GC/MS chromatogram of the lipids from tagasaste is shown in Fig. 2. The identities and abundances of the main lipid classes identified are summarized in Table 2. The structures of the main lipophilic compounds identified in

Table 2 – Composition and abundance (mg/kg) of lipophilic extractives in tagasaste trimming residues

Compounds	Mass fragments	MW	Abundance
n-Alkanes			8.8
n-Eicosane	57/71/85/282	282	0.1
n-Heneicosane	57/71/85/296	296	0.2
n-Docosane	57/71/85/310	310	0.1
n-Tricosane	57/71/85/324	324	0.3
n-Tetracosane	57/71/85/338	338	0.2
n-Pentacosane	57/71/85/352	352	0.5
n-Hexacosane	57/71/85/366	366	0.3
n-Heptacosane	57/71/85/380	380	0.5
n-Octacosane	57/71/85/394	394	0.3
n-Nonacosane	57/71/85/408	408	1.2
n-Triacontane	57/71/85/422	422	0.2
n-Hentriacontane	57/71/85/436	436	4.8
n-Tritriacontane	57/71/85/464	464	0.1
Fatty acids			141.4
n-Tetradecanoic acid	60/73/228	228	1.1
n-Pentadecanoic acid	60/73/242	242	1.0
9-Hexadecenoic acid	55/69/236/254	254	2.2
n-Hexadecanoic acid	60/73/129/256	256	55.4
n-Heptadecanoic acid	60/73/129/270	270	2.9
9-Octadecenoic acid	55/69/264	282	29.4
n-Octadecanoic acid	60/73/129/284	284	10.7
n-Nonadecanoic acid	60/73/129/298	298	1.4
n-Eicosanoic acid	60/73/129/312	312	7.4
n-Heneicosanoic acid	60/73/129/327	327	1.1
n-Docosanoic acid	60/73/129/340	340	5.4
n-Tricosanoic acid	60/73/129/354	354	6.0
n-Tetracosanoic acid	60/73/129/368	368	10.3
n-Pentacosanoic acid	60/73/129/382	382	2.6
n-Hexacosanoic acid	60/73/129/396	396	4.5
α-Hydroxy fatty acids^a			51.8
2-Hydroxyoctadecanoic acid	73/327/371	386	0.6
2-Hydroxyeicosanoic acid	73/355/399	414	0.9
2-Hydroxydocosanoic acid	73/383/427	442	22.1
2-Hydroxytetracosanoic acid	73/411/455	470	26.3
2-Hydroxyhexacosanoic acid	73/439/483	498	1.9
Steroid hydrocarbons			30.1
Ergostatriene	135/143/380	380	5.6
Ergostadiene	81/147/367/382	382	3.4
Stigmasta-3,5,22-triene	135/143/394	394	11.7
Stigmasta-3,5-diene	81/147/381/396	396	9.4
Sterols			113.1
Campesterol	55/145/213/382/400	400	14.0
Stigmasterol	55/83/255/394/412	412	35.7
Sitosterol	145/213/396/414	414	30.7
Stigmastanol	215/416	416	2.9
7-ketocampesterol	382/397/414	414	10.1
7-ketostigmasterol	286/426	426	9.0
7-ketositosterol	396/413/428	428	10.7
α-Tocopherol	165/205/430	430	2.1
Steroid ketones			30.5
Stigmasta-7,22-dien-3-one	55/269/298/367/410	410	7.1
Stigmasta-3,5-dien-7-one	174/269/410	410	14.1
Stigmast-4-en-3-one	124/229/412	412	4.5
Stigmastadienone isomer	57/136/174/269/410	410	2.0
Stigmastane-3,6-dione	245/287/428	428	2.8
Sterol glycosides^b			13.2
Campesterol 3β-D-glucopyranoside	204/217/361/383	850	1.9
Stigmasterol 3β-D-glucopyranoside	204/217/361/413	880	4.3

Table 2 (Continued)

Compounds	Mass fragments	MW	Abundance
Sitosterol 3 β -D-glucopyranoside	204/217/361/397	864	7.0
Sterol esters			28.3
Campesterol esters		n.d	2.3
Stigmasterol esters		n.d	9.2
Sitosterol esters		n.d	16.8
Monoglycerides ^b			8.1
1-Monopalmitin	73/103/129/147/371/459	474	4.2
1-Monostearin	73/103/129/147/399/487	502	3.9

^a As methyl esters and TMS ethers.
^b As TMS ethers.

Fig. 3 – Structures of the main lipophilic compounds present in tagasaste. I: hexadecanoic acid; II: 9-hexadecenoic acid; III: 2-hydroxyhexacosanoic acid; IV: stigmasterol; V: campesterol; VI: sitosterol; VII: stigmasteranol; VIII: sitosteryl 3 β -D-glucopyranoside; IX: stigmasta-3,5-dien-7-one; X: stigmasta-3,5,22-triene; XI: *n*-hentriacontane; XII: 1-monopalmitin.

the tagasaste extracts are shown in Fig. 3. The main lipids identified in tagasaste were series of fatty acids, including α -hydroxy acids, and steroid compounds, including steroid hydrocarbons, steroid ketones, sterols, sterol esters and sterol glycosides. Other compounds, such as series of alkanes and monoglycerides were also found in minor amounts.

The series of free fatty acids (141.4 mg/kg) were present in the range from *n*-tetradecanoic (C_{14}) to *n*-hexacosanoic (C_{26}) acids, with a strong even-over-odd carbon atom predominance. Hexadecanoic (palmitic) acid (I, $C_{16:0}$) and octadecanoic (stearic) acid ($C_{18:0}$) were the most abundant fatty acids followed by *n*-tetracosanoic (C_{24}) acid. Unsaturated fatty acids were also present, 9-octadecenoic (oleic) acid (II, $C_{18:1}$) being especially abundant. Fatty acids also included a series of α -hydroxyfatty acids (51.8 mg/kg) that was present in the range from 2-hydroxyoctadecanoic acid (C_{18}) to 2-hydroxyhexacosanoic acid (C_{26}) with maximum at C_{24} (III), and the presence of exclusively the even carbon atom number homologs.

Steroid compounds were the second most important lipid class found among the tagasaste extractives and included steroid hydrocarbons, steroid ketones and sterols (in free and conjugated form). Sterols, in free and conjugated (esters and glycosides) form were the most important steroids identified, free sterols being present in important amounts (113.1 mg/kg). Stigmasterol (IV) was the most abundant among the free sterols with the presence of important amounts of campesterol (V) and sitosterol (VI) and minor amounts of stigmasterol (VII) as well as the presence of the oxidized 7-ketocampesterol, 7-ketostigmasterol and 7-ketostigmasterol. Lower amounts of sterols could also be found in ester form (28.3 mg/kg), with a predominance of sitosterol esters. Sterol glycosides, such as campesterol, stigmasterol and sitosterol 3 β -D-glucopyranosides (VIII) were also identified in lower amounts (13.2 mg/kg), the latter being the most predominant. The identification of sterol glycosides was accomplished, after BSTFA derivatization of the lipid extract, by comparison with the mass spectra and relative retention times of authentic standards (Gutiérrez and del Río, 2001). It is important to point out the low content of free and conjugated (esters and glycosides) sterols, in comparison to that found in eucalypt wood (Rencoret et al., 2007), since these are the main compounds responsible for pitch deposition during Kraft cooking of hardwoods, such as eucalypt wood (del Río et al., 1998, 2000; Silvestre et al., 1999; Gutiérrez and del Río, 2001). On the other hand, steroid ketones were also found in important amounts (30.5 mg/kg), being mainly constituted by stigmasterol-7,22-dien-3-one, stigmasterol-3,5-dien-7-one (IX), stigmasterol-4-en-3-one and stigmasterol-3,6-dione. Different steroid hydrocarbons (di- and triunsaturated) were also identified, although in low amounts (30.1 mg/kg), stigmasterol-3,5,22-triene (X) being the most predominant.

Finally, a series of *n*-alkanes ranging from *n*-eicosane (C_{20}) to *n*-tritriacontane (C_{33}) with *n*-hentriacontane (XI, C_{31}) being the most prominent, was found in low amounts (8.8 mg/kg). And minor amounts of monoglycerides (8.1 mg/kg), such as 1-monopalmitin (XI) and 1-monostearin, were also present among tagasaste extractives.

4. Conclusions

Tagasaste is characterized by a high content of holocellulose and α -cellulose and a relatively low lignin content. Moreover, the chemical composition of tagasaste lignin indicates a predominance of S-lignin units over the G-lignin ones (S/G molar ratio of 1.6) and the absence of H-lignin units. The total acetone extractives accounted for 1.4% but the content on lipophilic compounds is very low (only 0.2%). The main lipids identified in tagasaste were series of fatty acids, including α -hydroxyfatty acids, and steroid compounds, including steroid hydrocarbons, steroid ketones, sterols, sterol esters and sterol glycosides.

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