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# ω-ETHYL, ω-ETHENYL AND ω-ETHYNYL-α-ALKYLIDENE-γ-LACTONES FROM *CLINOSTEMON MAHUBA**

JUAN C. MARTINEZ V.,† MASSAYOSHI YOSHIDA and OTTO R. GOTTLIEB

Instituto de Química, Universidade de São Paulo, 05508 São Paulo, Brazil

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**Key Word Index**—*Clinostemon mahuba*; Lauraceae; mahuba lactones; α-alkylidene-β-hydroxy-γ-methylene-γ-lactones; α-alkylidene-β-hydroxy-γ-methyl-γ-lactones.

**Abstract**—The trunk wood of *Clinostemon mahuba* contains eight (3*R*)-2-alkylidene-3-hydroxy-4-methylenebutanolides, seven (3*R*,4*S*)-2-alkylidene-3-hydroxy-4-methylbutanolides and seven (3*S*,4*S*)-2-alkylidene-3-hydroxy-4-methylbutanolides distinguished by the alkylidene side chains with respect to their *E*- or *Z*-geometry, ethenyl, ethynyl or ethyl terminals and lengths ($C_{16}$ or $C_{18}$).

## INTRODUCTION

'Mahuba' or 'mauba', a tree from the estuary of the Amazon, was described in 1919 as *Acrodiclidium mahuba* A. Samp. Its reclassification in 1928 into a monotypic genus as *Clinostemon mahuba* (A. Samp.) Kuhlm. et A. Samp. [2] was not respected in a revision of the Lauraceae published in 1938 where it appeared under the designation *Licaria mahuba* (A. Samp.) Kosterm. [3] Our preliminary communication on the trunk wood constituents of 'mahuba' thus had to refer to the species by this binominal [4]. Meanwhile, however, it was shown that morphologically and anatomically 'mahuba' is more closely related to *Mezilaurus* (subtribe Beilschmiediineae [5]) than to *Licaria* (subtribe Anibineae [5]) and suggested that the original generic status as *Clinostemon mahuba* be revalidated [6]. The removal of 'mahuba' from the Anibineae is consistent with chemical evidence, viz. absence of propenylphenol and allylphenol derivatives. The majority of the examined species of this subtribe (including all chemically analysed *Licaria* spp.) and of several species of the related Cinnamomineae contain such derivatives [7, 8].

## RESULTS

While characteristics of mahuba seed fat have been reported [9], the trunk wood has not been analysed previously. It contains 22 novel representatives of the γ-lactone types **1** and **2** previously isolated from two Japanese Lauraceae, *Lindera obtusiloba* Blume (**1i–1l**) [10, 11] and *Litsea japonica* (Thunb.) Jus. (**2o–2t**) [12]. While six mahubenolides (**1a, 1b, 2a, 2b, 2h, 2i**) (side chain of type X), six mahubynolides (**1c, 1d, 2c, 2d, 2j, 2k**) (side chain of type Y) and three mahubanolides (**1h, 2f, 2m**) (side chain of type Z) were obtained in a pure state, the existence of seven additional mahubanolides (**1e, 1f, 1g, 2e, 2g, 2l, 2n**) was inferred by $^1$H NMR and mass spectral examination of mixtures. Isolation and structure elucidation of the compounds belonging to series **1** had to be performed speedily, since the pure compounds decompose spontaneously in a few days.

UV, IR and $^1$H NMR spectra reported for the obtusilactones and the litsenolides (Tables 1–4) were compatible with the corresponding spectra of the mahuba lactones belonging to series **1** ($\nu_{max}^{film}$ 1780 cm$^{-1}$) and **2** ($\nu_{max}^{CHCl_3}$ 1755 cm$^{-1}$) respectively. As in the case of the previously reported compounds [10–12], the $^1$H NMR spectra were helpful in the characterization of not only the side chain terminals [$\delta$: $=CH_2$ 4.7–5.2 (**1a, 1b, 2a, 2b, 2h, 2i**), ≡CH 1.93 (**1c, 1d, 2c, 2d, 2j, 2k**), —Me 0.88 (**1e, 1h, 2e, 2f, 2l, 2m**) and the exocyclic methylene] $\delta$ 4.7 and 4.9 (**1a–1d, 1h**) or methyl [$\delta$ 1.35 (**2a–2d, 2f**), 1.46 (**2h–2k, 2m**)] and hydrogen [$\delta$ 4.53 (**2b, 2d, 2f, 2i, 2k, 2m**), 4.36 ± 0.01 (**2a, 2e, 2h, 2j**)] at the γ-carbons, but also of the geometry of the trisubstituted double bonds at the α-carbons of the lactones [$\delta$: Z-H 6.63 ± 0.05 (**1a, 1c, 2a, 2c, 2h, 2j**), E-H 6.99 ± 0.03 (**1b, 1d, 1h, 2b, 2d, 2f, 2i, 2k, 2m**)].

The *threo* or *erythro* relationship of the β,γ-substituents in the dihydromahuba lactones of series A and B respectively was ascertained by the LIS $^1$H NMR technique, Eu(fod)$_3$ complexes with the hydroxyl at C-β causing a greater shift of the signals due to *cis* rather than to *trans* entities, viz. $\Delta\delta_{H-\gamma}$ 100 vs 5.4 and $\Delta\delta_{Me-\gamma}$ 4.8 vs 2.9. Hydrogenation (Pd–C, $C_6H_6$) of the $C_{21}$-compounds of the *threo* (A) and *erythro* (B) series gave, respectively, **3a** and **3b**. Both must sustain the 3-hydroxyls and 2-alkyls in a *trans* relation, since the parent molecules are expected to approach the catalyst from their hydroxylated side [12]. The compounds, although different, gave by successive acetylation ($Ac_2O$–pyridine) and elimination of HOAc ($Al_2O_3$, $C_5H_{12}$) the same endocyclic α,β-unsaturated γ-lactone **4**. This is dextrorotatory, $[\alpha]_D$ + 27°, in opposition to the laevorotatory **5**, $[\alpha]_D$ −29.8°, of known

* Part LXI in the series "The Chemistry of Brazilian Lauraceae". For Part LX see ref. [1]. Taken from part of the Doctorate Thesis submitted by J.C.M.V. to Universidade de São Paulo (1979).

† Departamento de Química, Universidad Nacional de Colombia, Bogotá, Colombia.

Table 1. Natural γ-lactones of type **1**

| | Reference | C-β | Config. OH | $R^1$ | $R^2$ | *n* | mp | $[\alpha]_D$ | Yield |
|---|---|---|---|---|---|---|---|---|---|
| **1a** Mahubenolide | | *R* | α | H | X | 13 | oil | +6.2° | 1.1 |
| **1b** Isomahubenolide | | *R* | α | X | H | 13 | oil | +22.0° | 11.6 |
| **1c** Mahubynolide | | *R* | α | H | Y | 13 | oil | +8.0° | 0.7 |
| **1d** Isomahubynolide | | *R* | α | Y | H | 13 | oil | +23.1° | 3.5 |
| **1e** Mahubanolide | | | | H | Z | 13 | | | <0.1 |
| **1f** Isomahubanolide | | | | Z | H | 13 | | | <0.1 |
| **1g** Mahubanolide-23 | | | | H | Z | 15 | | | <0.1 |
| **1h** Isomahubanolide-23 | | *R* | α | Z | H | 15 | oil | +18.9° | 2.1 |
| **1i** Obtusilactone | [10] | | | H | X | 9 | oil | −53° | |
| **1j** Isoobtusilactone | [11] | | | X | H | 9 | oil | −56° | |
| **1k** Obtusilactone A | [11] | | | H | Z | 11 | oil | −46° | |
| **1l** Isoobtusilactone A | [11] | | | Z | H | 11 | oil | −54° | |

$[\alpha]_D$—All measurements at 24 ± 2°; for solvents see text. Yield—In pure compound ‰ of trunk wood. **1f, 2e, 2g, 2l, 2n**—Detected by $^1$H NMR and MS in less pure samples of **1h, 2a, 2f, 2h** and **2m**, respectively. **1e, 1g**—Obtained as mixture; detected by $^1$H NMR and MS. **1g, 1h, 2g, 2n**—$C_{23}$-compounds; the figure 23 included in their designation distinguishes them from all other reported $C_{21}$-mahuba lactones.

absolute stereochemistry [12]. The absolute configurations of the dihydromahubenolides and dihydromahubynolides of both series are thus as shown in Table 2.

Among these compounds, isodihydromahubenolide B (**2i**) proved important for the determination of the absolute configuration of the mahuba lactones of series **1**. Indeed, hydrogenation (Pd–$CaCO_3$, $C_6H_6$) of both, isomahubenolide (**1b**) and isomahubynolide (**1d**), gave isomahubanolide (**1f**) as the principal product, accompanied by **6** for which $^1$H NMR indicated the *erythro* relationship of the substituents at C-β,γ. Its optical

Table 2. Natural γ-lactones of type **2***

| | Reference | C-β,γ | Config. Me | Config. OH | $R^1$ | $R^2$ | *n* | mp | $[\alpha]_D$ | Yield |
|---|---|---|---|---|---|---|---|---|---|---|
| **2a** Dihydromahubenolide A | | *R,S* | β | α | H | X | 13 | 48–50° | +8.5° | 0.6 |
| **2b** Isodihydromahubenolide A | | *R,S* | β | α | X | H | 13 | 45–46° | +37.1° | 3.3 |
| **2c** Dihydromahubynolide A | | *R,S* | β | α | H | Y | 13 | 61–63° | +9.0° | 0.6 |
| **2d** Isodihydromahubynolide A | | *R,S* | β | α | Y | H | 13 | 64–65° | +42.4° | 4.6 |
| **2e** Dihydromahubanolide A | | | | | H | Z | 13 | | | <0.1 |
| **2f** Isodihydromahubanolide A | | *R,S* | β | α | Z | H | 13 | 49–50° | +36.6° | 0.6 |
| **2g** Isodihydromahubanolide-23 A | | | | | | | 15 | | | <0.1 |
| **2h** Dihydromahubenolide B | | *S,S* | β | β | H | X | 13 | 46–47° | −35.1° | 0.5 |
| **2i** Isodihydromahubenolide B | | *S,S* | β | β | X | H | 13 | 66–67° | −96.5° | 1.9 |
| **2j** Dihydromahubynolide B | | *S,S* | β | β | H | Y | 13 | 55–56° | −32.6° | 0.2 |
| **2k** Isodihydromahubynolide B | | *S,S* | β | β | Y | H | 13 | 79–80° | −90.2° | 1.1 |
| **2l** Dihydromahubanolide B | | | | | H | Z | 13 | | | <0.1 |
| **2m** Isodihydromahubanolide B | | *S,S* | β | β | Z | H | 13 | 70–71° | −93.3° | 0.4 |
| **2n** Isodihydromahubanolide-23 B | | | | | | | 15 | | | <0.1 |
| **2o** Litsenolide $A_1$ | [12] | *S,R* | α | β | H | X | 9 | oil | −2.4° | |
| **2p** Litsenolide $A_2$ | [12] | *S,R* | α | β | X | H | 9 | oil | −40.4° | |
| **2q** Litsenolide $B_1$ | [12] | *S,R* | α | β | H | Y | 9 | 40–41° | −5.9° | |
| **2r** Litsenolide $B_2$ | [12] | *S,R* | α | β | Y | H | 9 | 42–43° | −44.9° | |
| **2s** Litsenolide $C_1$ | [12] | *S,R* | α | β | H | Z | 11 | 60–62° | −9.4° | |
| **2t** Litsenolide $C_2$ | [12] | *S,R* | α | β | Z | H | 11 | 44–45° | −45.2° | |

* See footnote to Table 1.

Table 3. $^1$H NMR data of mahuba lactones of series **1***

| | **1a** | **1b** | **1c** | **1d** | **1h** | Multiplicity | *J* (Hz) |
|---|---|---|---|---|---|---|---|
| OH | — | 3.70 | — | 3.20 | 2.95 | *br.s* | — |
| H-3 | 5.10 | 5.25 | 5.10 | 5.25 | 5.25 | *m* | — |
| H-5 | 4.67 | 4.70 | 4.69 | 4.72 | 4.70 | *dd* | 2.5, 1.5 |
| H-5 | 4.87 | 4.90 | 4.90 | 4.92 | 4.92 | *dd* | 2.5, 1.5 |
| H-6 | 6.68 | 7.03 | 6.67 | 7.04 | 7.03 | *dt* | 8.0, 2.0 |
| 2H-7 | 2.77 | 2.46 | 2.78 | 2.48 | 2.48 | *q* | 8.0 |
| $(CH_2)_n$† | 1.30 | 1.27 | 1.30 | 1.30 | 1.27 | *s* | — |
| 2H-19 | 2.10 | 2.05 | 2.18 | 2.18 | — | *m* | — |
| H-20 | 5.85 | 5.83 | — | — | — | *ddt* | 16.0, 10.0, 6.5 |
| 2H-21 | 5 | 5 | — | — | — | *m* | — |
| H-21 | — | — | 1.93 | 1.93 | — | *t* | 2.2 |
| 3H-23 | — | — | — | — | 0.88 | *t* | 6.0 |

* Chemical shifts in ppm from internal TMS for $CDCl_3$ solutions; coupling constants in Hz; obtained on a 60 MHz instrument.
† $n$ = 11 (**1a–1d**), 14 (**1h**).

rotation, $[\alpha]_D$ +77°, revealed **6** to be enantiomeric with the analogous hydrogenation product of isodihydromahubenolide B (**2i**), $[\alpha]_D$ −93°. This defines the absolute configuration of the mahubenolides and mahubynolides (Table 1). In contrast to the mahuba lactones, the obtusilactones are all laevorotatory. If these data, obtained in MeOH and $CHCl_3$, while all other $[\alpha]_D$ values cited were obtained in dioxane, are considered, the *S*-configuration prevails in the obtusilactones.

With respect to the carbon skeleton, the mahuba lactones are seen to differ from the obtusilactones and the litsenolides solely by the length of the side chain. Independent evidence for this fact was adduced by defunctionalization of the fully hydrogenated derivatives **3a** and **3b** to 4-methyleicosane. Reduction ($LiAlH_4$, THF), first of these lactones and then of the mesylates of the resulting triols, gave the hydrocarbon. Its identity was established by synthesis involving initially Grignard reaction between 1-*n*-hexadecyl magnesium bromide and 2-pentanone, followed by dehydration (TsOH, PhMe) of the resulting alcohol and hydrogenation (Pd–C, PhMe) of the olefin mixture.

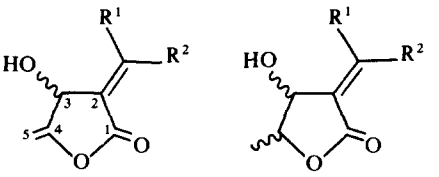
## DISCUSSION

From the biogenetic point of view, the entire group of compounds may be considered to be derived from $C_{14}$-(**1i, 2j, 2o–2r**), $C_{16}$-(**1k, 1l, 2s, 2t**), $C_{18}$-(**1a–1f, 2a–2f, 2h–2m**) or $C_{20}$-(**1g, 1h, 2g, 2n**) polyketide chains and pyruvyl-CoA, as has been postulated for the obtusilactones [10]

Table 4. $^1$H NMR data of mahuba lactones of series **2***

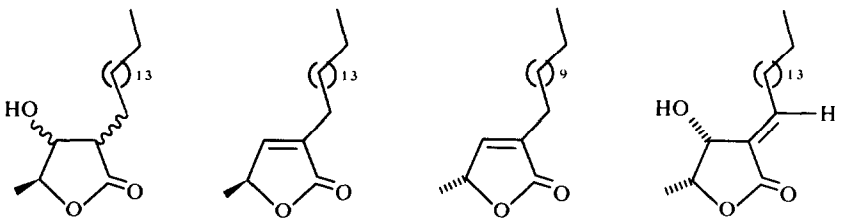
| | **2a** | **2b** | **2c** | **2d** | **2f** | **2h** | **2i** | **2j** | **2k** | **2m** | Multiplicity | *J* (Hz) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OH | — | 3.73 | – | 3.26 | 3.30 | — | 3.00 | — | — | — | *br.s* | — |
| H-3 | 4.38 | 4.56 | 4.36 | 4.56 | 4.56 | 4.63 | 4.83 | 4.66 | 4.83 | 4.83 | *m* | — |
| H-4 | 4.38 | 4.53 | 4.37 | 4.53 | 4.53 | 4.35 | 4.53 | 4.37 | 4.55 | 4.55 | *dq* | 6.5, 5.0†, 4.0‡, 2.5§ |
| 3H-5 | 1.38 | 1.33 | 1.38 | 1.33 | 1.33 | 1.47 | 1.45 | 1.47 | 1.45 | 1.45 | *d* | 6.5 |
| H-6 | 6.58 | 6.96 | 6.58 | 6.96 | 6.98 | 6.60 | 6.93 | 6.58 | 6.94 | 6.94 | *dt* | 7.8, 1.5 |
| 2H-7 | 2.76 | 2.42 | 2.76 | 2.44 | 2.44 | 2.76 | 2.43 | 2.77 | 2.43 | 2.43 | *q* | 7.8 |
| $(CH_2)_n$‖ | 1.28 | 1.27 | 1.30 | 1.30 | 1.27 | 1.30 | 1.30 | 1.30 | 1.30 | 1.27 | *s* | — |
| 2H-19 | 2.03 | 2.05 | 2.20 | 2.18 | — | 2.05 | 2.05 | 2.20 | 2.20 | — | *m* | — |
| H-20 | 5.88 | 5.88 | — | — | — | 5.88 | 5.88 | — | — | — | *ddt* | 16.0, 10.0, 6.5 |
| 2H-21 | 5 | 5 | — | — | — | 5 | 5 | — | — | — | *m* | — |
| H-21 | — | — | 1.93 | 1.93 | — | — | — | 1.93 | 1.93 | — | *t* | 2.2 |
| 3H-21 | — | — | — | — | 0.88 | — | — | — | — | 0.88 | *t* | 6.0 |

* Chemical shifts in ppm from internal TMS for $CDCl_3$ solutions; coupling constants in Hz; obtained on a 60 MHz instrument.
† **2h–2k, 2m.**
‡ **2a, 2c.**
§ **2b, 2d, 2f.**
‖ $n$ = 11 (**2a–2d, 2h–2k**), 12 (**2f, 2m**).



1 2

X = $(CH_2)_nCH{=}CH_2$
Y = $(CH_2)_nC{\equiv}CH$
Z = $(CH_2)_nCH_2{-}CH_3$



**3a** 2*R*,3*R* 4 5 6
**3b** 2*S*,3*S*

and the litsenolides [12]. In this case, the $\omega$-ethenyl and $\omega$-ethynyl groups must be generated either by direct dehydrogenation or by concomitant loss of an acetic acid unit. The latter mechanism would be consistent with the finding that in *Lindera obtusiloba*, *Litsea japonica* and *Clinostemon mahuba* $C_n$-compounds with ethenyl and ethynyl terminals were found to co-occur with $C_{n+2}$-compounds with ethyl terminals [13]. If, however, as has been proposed [14], decarboxylation accompanies the formation of $\omega$-ethenyl and $\omega$-ethynyl groups, the biosynthesis of the lactones should involve $C_{18}$-(**1i, 2j, 2o–2r**), $C_{20}$-(**1k, 1l, 2s, 2t**), $C_{22}$-(**1a–1f, 2a–2f, 2h–2m**) or $C_{24}$-(**1g, 1h, 2g, 2n**) polyketide chains, the ramification being generated through a Favorsky-type rearrangement. Proposed earlier in connection with a similar problem [15], the suggestion that Favorsky rearrangements of polyketide precursors may occur in nature has recently been renewed [16].

Obtusilactone (**1i**), the principal $\gamma$-lactone of *Lindera obtusiloba*, was shown to possess cytotoxic activity [10]. It thus seems desirable to assay also the mahuba lactones for biological properties.

## EXPERIMENTAL

*Isolation of constituents.* Botanical material was collected in the vicinity of Belém, Pará State, and identified by João Murça Pires. Air-dried, powdered trunk wood of *C. mahuba* (A. Samp.) Kuhlm. et A. Samp. (0.5 kg) was extracted with $C_6H_6$. The solvent was evapd and the residue (15 g) submitted to dry column chromatography (450 g Si gel deactivated with 10% $H_2O$, $C_6H_6$–EtOAc, 7:3). The column was divided into 18 equal portions which were eluted separately with $Me_2CO$. Portions 1 + 2 gave a fatty oil (2.3 g) and portions 16 + 18 gave polar material (3.6 g) which were not further examined. Portions 3–9 gave a viscous oil (3 g) which was separated by prep. TLC (Si gel, $C_6H_6$–EtOAc, 4:1) into fraction A ($R_f$ 0.59, 140 mg), fraction B ($R_f$ 0.68, 1.12 g) and di-(2-ethylhexyl)-phthalate ($R_f$ 0.84, 1.6 g). Portions 10–15 gave a solid (3 g) which was separated with MeOH into insoluble sitosterol (1.8 g) and a soluble fraction C (1.1 g).

Fraction A was separated by prep. TLC (Si gel, hexane–$Me_2CO$, 4:1) into **1c** ($R_f$ 0.35) and **1a** ($R_f$ 0.44). Fraction B was separated by prep. TLC (Si gel, hexane–$Me_2CO$ 4:1) into **1d** ($R_f$ 0.32) and a mixture ($R_f$ 0.40, 860 mg) which was separated by TLC (4% $AgNO_3$ on Si gel, $C_6H_6$–EtOAc 2:1) into products D ($R_f$ 0.43, 477 mg) and E($R_f$ 0.53, 127 mg). Both were purified by TLC (Si gel, $C_6H_6$–EtOAc, 4:1), D giving **1b** ($R_f$ 0.68) and E giving **1h** ($R_f$ 0.68). Fraction C was separated by TLC (Si gel, hexane–$Me_2CO$, 4:1) into products F ($R_f$ 0.27, 480 mg) and G ($R_f$ 0.39, 550 mg). Product F was separated by repeated TLC (Si gel, $C_6H_6$–EtOAc, 3:1) into mixtures H ($R_f$ 0.62, 350 mg) and I 0.67, 95 mg). Repeated TLC (Si gel, $C_6H_6$–EtOAc, 19:1) effected the separation of mixture H into **2d** ($R_f$ 0.48) and **2c** ($R_f$ 0.58), and of mixture I into **2k** ($R_f$ 0.48) and **2j** ($R_f$ 0.58). Product G was separated by repeated TLC (Si gel, $C_6H_6$–EtOAc, 3:1) into mixtures J ($R_f$ 0.62, 320 mg) and K ($R_f$ 0.67, 190 mg). Repeated TLC (Si gel, $C_6H_6$–EtOAc, 19:1) effected the separation of **5** into a further mixture L ($R_f$ 0.48, 257 mg) and **2a** ($R_f$ 0.58) and of mixture K into a further mixture M ($R_f$ 0.48, 146 mg) and **2h** ($R_f$ 0.58). TLC (4% $AgNO_3$ on Si gel, $C_6H_6$–EtOAc, 2:1) effected the separation of L into **2b** ($R_f$ 0.37) and **2f** ($R_f$ 0.48) and of M into **2i** ($R_f$ 0.37) and **2m** ($R_f$ 0.48).

(3R,2Z)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylenebutanolide* (**1a**). (Found: $M^+$ 334.2496. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 224 (ε 9950). IR $\nu_{max}^{film}$ $cm^{-1}$: 3450, 1780, 1680, 1640, 913, 724. MS *m/e* (rel. int.): 334 (2), 316 (1), 306 (2), 291 (10), 263 (1), 140 (7), 97 (15), 95 (20), 83 (23), 81 (23), 71 (33), 70 (100), 69 (52), 57 (45), 55 (83), 43 (53), 41 (100).

(3R,2E)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylenebutanolide* (**1b**). (Found: $M^+$ 334.2500. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 221 (ε 12760). IR $\nu_{max}^{film}$ $cm^{-1}$: 3450, 1780, 1680, 1640, 913, 724. MS *m/e* (rel. int.): 334 (3), 316 (2), 306 (4), 291 (22), 263 (3), 140 (19), 97 (43), 95 (50), 83 (61), 81 (64), 71 (31), 70 (100), 69 (58), 57 (91), 55 (58), 43 (81), 41 (77).

(3R,2Z)-2-*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylenebutanolide* (**1c**). (Found: $M^+$ 332.2339. $C_{21}H_{32}O_3$ requires: M. 332.2351). UV $\lambda_{max}^{MeOH}$ nm: 223 (ε 11 000). IR $\nu_{max}^{film}$ $cm^{-1}$: 3480, 3300, 2120, 1780, 1680, 724. MS *m/e* (rel. int.): 332 (2), 314 (2), 304 (3), 289 (4), 261 (3), 140 (14), 97 (18), 95 (30), 83 (28), 81 (40), 71 (10), 70 (100), 69 (32), 57 (16), 55 (69), 43 (50), 41 (100).

(3R,2E)-2-(*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylenebutanolide* (**1d**). (Found: $M^+$ 332.2362. $C_{21}H_{32}O_3$ requires: M 332.2351). UV $\lambda_{max}^{MeOH}$ nm: 221 (ε 13 500). IR $\nu_{max}^{film}$ $cm^{-1}$: 3480, 3300, 2120, 1780, 1680, 724. MS *m/e* (rel. int.): 332 (2), 314 (1), 304 (3), 289 (3), 261 (3), 140 (10), 97 (18), 95 (35), 83 (25), 81 (45), 71 (12), 70 (100), 69 (35), 57 (13), 55 (72), 43 (37), 41 (100).

(3R,2E)-2-*Octadecanylidene*-3-*hydroxy*-4-*methylenebutanolide* (**1h**). (Found: $M^+$ 364.2999. $C_{23}H_{40}O_3$ requires: M 364.2977). UV $\lambda_{max}^{MeOH}$ nm: 221 (ε 12 890). IR $\nu_{max}^{film}$ $cm^{-1}$: 3450, 1780, 1680, 727. MS *m/e* (rel. int.): 364 (1), 346 (1), 336 (1), 335 (3), 321 (4), 320 (14), 292 (35), 140 (16), 97 (18), 95 (16), 83 (22), 81 (16), 70 (100), 69 (26), 57 (26), 55 (39), 43 (57), 41 (60).

(3R,4S,2Z)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2a**). (Found: $M^+$ 336.2612. $C_{21}H_{36}O_3$ requires: M 336.2664). UV $\lambda_{max}^{MeOH}$ nm: 220 (ε 10 250). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3450, 1745, 1680, 1640, 910, 724; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 336 (5), 318 (2), 308 (7), 292 (6), 142 (15), 140 (17), 97 (17), 95 (32), 83 (27), 81 (35), 71 (18), 70 (100), 69 (36), 57 (50), 55 (45), 43 (66), 41 (60).

(3R,4S,2E)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2b**). (Found: $M^+$ 336.2620. $C_{21}H_{36}O_3$ requires: M 336.2664). UV $\lambda_{max}^{MeOH}$ nm: 217 (ε 13 150). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3450, 1745, 1680, 1640, 910, 724; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 336 (12), 318 (3), 308 (9), 292 (7), 142 (20), 140 (30), 97 (20), 95 (30), 83 (24), 81 (28), 71 (14), 70 (100), 69 (32), 57 (40), 55 (60), 43 (54), 41 (68).

(3R,4S,2Z)-2-(*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2c**). (Found: $M^+$ 334.2568. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 220 (ε 10 310). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3500, 3300, 2120, 1740, 1680, 727; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 334 (3), 316 (1), 306 (1), 290 (3), 142 (12), 140 (5), 97 (6), 95 (25), 83 (15), 81 (40), 71 (10), 70 (100), 69 (30), 57 (22), 55 (30), 43 (60), 41 (70).

(3R,4S,2E)-2-(*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2d**). (Found: $M^+$ 334.2480. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 216 (ε 13.690). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3400, 3300, 2120, 1730, 1670, 724; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 334 (3), 316 (2), 306 (1), 290 (7), 142 (14), 140 (17), 97 (20), 95 (43), 83 (27), 81 (55), 71 (14), 70 (100), 69 (33), 57 (38), 55 (72), 43 (61), 41 (83).

(3R,4S,2E)-2-*Hexadecanylidene*-3-*hydroxy*-4-*methylbutanolide* (**2f**). (Found: $M^+$ 338.2890. $C_{21}H_{38}O_3$ requires: M 338.2901). UV $\lambda_{max}^{MeOH}$ nm: 217 (ε 13 150). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3400, 1740, 1680, 727; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 338 (1), 320 (1), 310 (3), 294 (1), 142 (15), 140 (8), 97 (10), 95 (5), 83 (15), 81 (11), 71 (10), 70 (100), 69 (18), 57 (30), 55 (40), 43 (72), 41 (84).

(3S,4S,2Z)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2h**). (Found: $M^+$ 336.2648. $C_{21}H_{36}O_3$ requires: M 336.2664). UV $\lambda_{max}^{MeOH}$ nm: 220 (ε 10 550). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3500, 1740, 1680, 1640, 917, 724; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 336 (5), 318 (3), 308 (3), 292 (4), 142 (15), 140 (12), 97 (20), 95 (50), 83 (47), 81 (30), 71 (20), 70 (100), 69 (30), 57 (80), 55 (40), 43 (62), 41 (55).

(3S,4S,2E)-2-(*Hexadec*-15-*enylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2i**). (Found: $M^+$ 336.2748. $C_{21}H_{36}O_3$ requires: M 336.2664). UV $\lambda_{max}^{MeOH}$ nm: 217 (ε 13 440). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3420, 1740, 1690, 1667, 920, 735; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 336 (7), 318 (5), 308 (6), 292 (5), 142 (18), 140 (3), 97 (23), 95 (40), 83 (34), 81 (44), 71 (18), 70 (100), 69 (40), 57 (50), 55 (78), 43 (68), 41 (87).

(3S,4S,2Z)-2-(*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2j**). (Found: $M^+$ 334.2597. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 220, (ε 10 550). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3500, 3300, 2120, 1740, 1675, 724; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 334 (4), 316 (3), 306 (3), 290 (4), 142 (13), 140 (10), 97 (12), 95 (26), 83 (20), 81 (50), 71 (22), 70 (100), 69 (28), 57 (60), 55 (52), 43 (75), 41 (70).

(3S,4S,3E)-2-(*Hexadec*-15-*ynylidene*)-3-*hydroxy*-4-*methylbutanolide* (**2k**). (Found: $M^+$ 334.2505. $C_{21}H_{34}O_3$ requires: M 334.2508). UV $\lambda_{max}^{MeOH}$ nm: 217 (ε 12 910). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3420, 3300, 2120, 1740, 1690, 735; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int): 334 (6), 316 (3), 306 (3), 290 (7), 142 (23), 140 (23), 97 (25), 95 (51), 83 (34), 81 (68), 71 (20), 70 (100), 69 (45), 57 (65), 55 (76), 43 (74), 41 (100).

(3S,4S,2E)-2-*Hexadecanylidene*-3-*hydroxy*-4-*methylbutanolide* (**2m**). (Found: $M^+$ 338.2910. $C_{21}H_{38}O_3$ requires: M 338.2901). UV $\lambda_{max}^{MeOH}$ nm: 217 (ε 14 740). IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3450, 1740, 1690, 735; $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1754. MS *m/e* (rel. int.): 338 (3), 320 (1), 310 (4), 294 (2), 142 (19), 140 (31), 97 (13), 95 (11), 83 (17), 81 (14), 71 (9), 70 (100), 69 (24), 57 (39), 55 (52), 43 (82), 41 (90).

*Selective hydrogenations.* The mahuba lactone (50 mg) in $C_6H_6$ (5 ml) was added to a pre-hydrogenated suspension of 5% Pd–$CaCO_3$ (50 mg) in $C_6H_6$ (5 ml) and hydrogenated at room temp. and pres. to the absorption of 1 or 2 mol of $H_2$/mol of substrate. The soln was filtered and evapd. The residue was purified by prep. TLC (Si gel, $C_6H_6$–EtOAc, 4:1). Thus, by absorption of *ca* 1 mol of $H_2$/mol, **1b** gave **1f** ($R_f$ 0.65, 35 mg) and **6** ($R_f$ 0.45, 8 mg); **2b** gave **2f** ($R_f$ 0.43, 46 mg); **2i** gave **2m** ($R_f$ 0.45, 48 mg). By absorption of *ca* 2 mol of $H_2$/mol, **1d** gave **1f** ($R_f$ 0.65, 33 mg) and **6** ($R_f$ 0.45, 10 mg); **2d** gave **2f** ($R_f$ 0.43, 47 mg); **2k** gave **2m** ($R_f$ 0.45, 44 mg). **6**, $[\alpha]_D^{24}$ +77.1 (dioxane), and **2m**, $[\alpha]_D^{24}$ −93.3° (dioxane), gave identical spectral data.

*Complete hydrogenations* were performed in the same way over 5% Pd–C catalyst to satn with $H_2$. **1b** gave a mixture containing **3a** or one of its diastereomers as principal constituent ($R_f$ 040, 22 mg), **4** ($R_f$ 0.64, 3 mg) and a compound ($R_f$ 0.15, 16 mg) which was not examined further. **1d** gave the same products. **2d** gave **3a** ($R_f$ 0.47, 41 mg). **2f** gave **3a** ($R_f$ 0.47, 6 mg) and another compound ($R_f$ 0.27, 1 mg) which was not examined further. **2m** gave **3b** ($R_f$ 0.57, 8 mg) and another compound ($R_f$ 0.33, 3 mg) which was not examined further. **2k** gave **3b** ($R_f$ 0.57, 41 mg).

(2R,3R,4S)-2-*Hexadecanyl*-3-*hydroxy*-4-*methylbutanolide* (**3a**). Mp 95–96°; $[\alpha]_D^{24}$ −9.6° (dioxane). IR $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 3600, 3400, 1770. $^1H$ NMR (60 MHz, $CDCl_3$): δ 0.88 (*t*, *J* = 7 Hz, 3H-21), 1.27 (*br. s*, $(CH_2)_{15}$), 1.45 (*d*, *J* = 6 Hz, 3H-5), 2.60 (*m*, H-2), 2.80 (*br. s*, OH), 3.83 (*dd*, *J* = 8, 7 Hz, H-3), 4.23 (*dq*, *J* = 7, 6 Hz, H-4). MS *m/e* (rel. int.): 340 (11) $M^+$, 322 (23), 129 (40), 116 (60), 99 (21), 97 (17), 85 (8), 83 (17), 71 (20), 69 (23), 57 (63), 55 (56), 43 (100), 41 (90). Acetate, mp 55–56°. IR $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1770, 1740. $^1H$ NMR (60 MHz, $CDCl_3$): δ 0.88 (*t*, *J* = 7 Hz, 3H-21), 1.27 (*br. s*, $(CH_2)_{15}$), 1.48 (*d*, *J* = 6.5 Hz, 3H-5), 2.10 (*s*, OAc), 2.66 (*m*, H-2), 4.37 (*dq*, *J* = 4.5, 6.5 Hz, H-4), 4.93 (*dd*, *J* = 4.5, 6 Hz, H-3). MS *m/e* (rel. int.): 382 (1) $M^+$, 322 (3), 171 (8), 158 (43), 99 (36), 97 (8), 85 (6), 83 (10), 71 (11), 69 (15), 57 (26), 55 (30), 43 (100), 41 (39).

(2S,3S,4S)-2-*Hexadecanyl*-3-*hydroxy*-4-*methylbutanolide* (**3b**). Mp 88–90°; $[\alpha]_D^{24}$ −37.7° (dioxane). IR $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 3600, 3400, 1770. $^1H$ NMR (60 MHz, $CDCl_3$): δ 0.88 (*t*, *J* = 7 Hz, 3H-21) 1.27 (*br. s*, $(CH_2)_{15}$), 1.45 (*d*, *J* = 6 Hz, 3H-5) 2.56 (*m*, H-2), 4.2–4.7 (*m*, H-3, H-4, OH). MS *m/e* rel. int.): 340 (18) $M^+$, 322 (6), 129 (42), 116 (100), 99 (30), 97 (10), 85 (22), 83 (11), 71 (13), 69 (20), 57 (85), 55 (39), 43 (78), 41 (67). Acetate mp 62–64°. IR $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1770, 1745. $^1H$ NMR (60 MHz, $CDCl_3$): δ 0.88 (*t*,

$J$ = 7 Hz, 3H-21), 1.27 (*br, s*, $(CH_2)_{15}$), 1.42 (*d*, $J$ = 6.5 Hz, 3H-5), 2.13 (*s*, OAc), 2.70 (*m*, H-2), 4.60 (*dq*, $J$ = 3.5, 6.5 Hz, H-4), 5.62 (*dd*, $J$ = 3.5, 5 Hz, H-3). MS *m/e* (rel. int.) 382 (1) $M^+$, 322 (5), 171 (8), 158 (47), 99 (31), 97 (7), 85 (18), 83 (9), 71 (9), 69 (13), 57 (29), 55 (28), 43 (100), 41 (41).

*Elimination of* HOAc *from acetates of* **3a** *and* **3b**. The compounds (33 mg) were percolated through a Brockman $Al_2O_3$ (activity II/III, 5 g) column. Pentane–$Me_2CO$ (1:1) eluted in both cases pure (4*S*)-2-hexadecanyl-4-methylbut-2-enolide (**4**, 25 mg), mp 60–61°; $[\alpha]_D^{24}$ +27.1° (dioxane). UV $\lambda_{max}^{MeOH}$ nm: 208 ($\varepsilon$ 13 455). IR $\nu_{max}^{CHCl_3}$ $cm^{-1}$: 1750, 1653. $^1H$ NMR (60 MHz, $CDCl_3$): $\delta$ 0.88 (*t*, $J$ = 7 Hz, 3H-21), 1.27 (*br. s*, $(CH_2)_{14}$), 1.40 (*d*, $J$ = 7 Hz, 3H-5), 2.23 (*m*, 2H-6), 5.0 (*dq*, $J$ = 1.5, 7 Hz, H-4), 7.0 (*q*, $J$ = 1.5 Hz, H-3). MS *m/e* (rel. int.): 322 (77), 293 (1), 278 (5), 112 (70), 111 (25), 99 (5), 97 (20), 95 (26), 85 (7), 83 (22), 81 (30), 71 (17), 69 (41), 67 (46), 57 (60), 55 (85), 53 (23), 43 (100), 41 (97), 39 (43).

*Defunctionalization of* **3a** *and* **3b**. The compounds (200 mg) in THF (15 ml) were added dropwise to a suspension of $LiAlH_4$ (100 mg) in THF (10 ml). The mixture was stirred at room temp. for 3 hr. $H_2O$ (10 ml) was added dropwise. The ppt. was filtered, washed, dried and purified by prep. TLC (Si gel, $CHCl_3$–MeOH (19:1) to 2,3-dihydroxy-4-hydroxymethyl-*n*-eicosane (150 mg), mp 69–70°. IR $\nu_{max}^{KBr}$ $cm^{-1}$: 3450. $^1H$ NMR (60 MHz, $CDCl_3$): $\delta$ 0.88 (*t*, $J$ = 7 Hz, 3H-21), 1.27 (*br. s*, $(CH_2)_{15}$, 3H-1), 3.20 (*br. s*, 3 OH), 3.5–4.0 (*m*, 2 CHOH, $CH_2OH$). MS *m/e* (rel. int.): 345 (0.2), 344 (0.2), 327 (3), 313 (1), 309 (1), 308 (2), 300 (16), 299 (65), 282 (6), 281 (4), 264 (13), 139 (3), 137 (6), 125 (8), 123 (16), 111 (22), 109 (27), 99 (6), 97 (43), 95 (37), 85 (22), 83 (53), 81 (37), 71 (48), 69 (48), 67 (27), 57 (100), 55 (71), 43 (97), 41 (94). This triol (150 mg) in dry pyridine (20 ml) at 0° was treated with $MeSO_2Cl$ (3 ml). After 36 hr at room temp., the mixture was added to $H_2O$ (100 ml) and extracted with $Et_2O$ (4 × 50 ml). The $Et_2O$ solns were combined, concd, washed with M HCl, aq. $NaHCO_3$, $H_2O$, dried and evapd. The residue (oil, 140 mg) in dry $Et_2O$ (20 ml) was added dropwise to a suspension of $LiAlH_4$ (200 mg) in dry $Et_2O$ (30 ml). The mixture was stirred at room temp. (24 hr). $H_2O$ (20 ml) was added dropwise, followed by 10 M aq. NaOH (30 ml). The $Et_2O$ layer was separated. The aq. layer was extracted with $Et_2O$. The combined $Et_2O$ solns were concd, washed with $H_2O$, dried and evapd. The residue (52 mg) in pentane was filtered through Si gel giving 4-methyleicosane, $n_D^{22}$ = 1.4405. IR $\nu_{max}^{film}$ $cm^{-1}$: 2940, 1460, 1380, 725. $^1H$ NMR (60 MHz, $CCl_4$): $\delta$ 0.88 (*t*, 3 Me), 1.28 (*s*, 35H); MS *m/e* (rel. int.): 296 (0.4), 281 (2), 267 (1), 253 (6), 239 (0.5), 225 (2), 211 (1), 197 (1), 183 (2), 169 (2), 155 (2), 141 (3), 127 (3), 113 (5), 99 (8), 85 (29), 71 (62), 57 (73), 43 (100).

*Synthesis of* 4-*methyleicosane*, employing standard techniques [17] for the Grignard condensation of *n*-hexadecyl bromide with 2-pentanone, the TsOH dehydration of the resulting 4-methyleicosan-4-ol, followed by the catalytic hydrogenation of the olefin mixture, gave a product identical in all respects to the alkane obtained by defunctionalization of the mahuba lactones.

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