

A SCALABLE METHOD FOR THE ISOLATION OF ANTI-HIV AGENTS FROM THE TROPICAL PLANT *Calophyllum*

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CROSS-REFERENCE

This application is a continuation-in-part of U.S. Patent Serial No. 60/068,251, filed December 19, 1997.

10 FIELD OF THE INVENTION

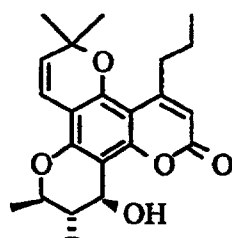
The present invention relates to an improved method for isolating purified costatolide and soulattrolide from the trunkbark latex of *Calophyllum* plants.

15 BACKGROUND OF THE INVENTION

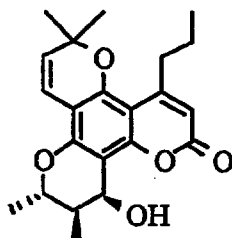
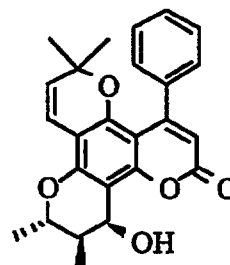
A series of polycyclic coumarins were isolated,¹ through the natural products screening program at the National Cancer Institute, from several tropical plants of the genus *Calophyllum* in Sarawak, Malaysia. These natural products, including (+)-calanolide A (1, NSC 650886),¹⁻⁴ (-)-calanolide B (costatolide) (2, NSC 661122),^{1,5} and soulattrolide (3),⁶ were identified as HIV-1- specific nonnucleoside reverse transcriptase inhibitors (NNRTIs)^{1,2,7-9} with unique drug-resistance profiles.¹⁰⁻¹³ (+)-Calanolide A (1), the most potent compound in the series, was selected for further development and is currently in clinical trials to evaluate its safety and pharmacokinetics of single and multiple doses in normal healthy volunteers.¹⁸

25 After oral administration, (+)-calanolide A (1) was generally well tolerated and no patterns indicative of a safety concern were observed.¹⁸ Plasma concentrations of (+)-calanolide A (1) in humans were higher than anticipated from animal data and it appeared that therapeutic levels can be achieved in humans.¹⁸ Because of our ongoing interest in developing (+)-calanolide A (1) and related compounds, we were

30 interested in developing other (+)-calanolide, A analogues, such as costatolide (2) as a possible alternative to calanolide A(1).



(+) - Calanolide A (1)

Costatolide (2)
or
(-) - Calanolide B

Soulattrolide (3)

Unlike (+)-calanolide A (1), which is extremely limited from natural sources, with the best yields obtained thus far being approximately 1 mg/g extract,⁶ costatolide (2) is rich in the latex of *Calophyllum teysmannii*, a very abundant plant species.⁶ A yield of 48% costatolide (2) was isolated from the latex extractables by repetitive chromatographies including preparative HPLC.⁶ Since latex harvests could, in theory, be sustained over an extended period of time and would not be destructive to the plant, sufficient supplies of costatolide (2) could be obtained from natural sources for preclinical and clinical development, and possible commercialization,¹⁴ providing that a scalable isolation method could be developed which is superior to the synthetic approaches^{2,15} and earlier isolation approaches^{6,19} in terms of overall yield, cost effectiveness, and environmental implications. For instance, U.S. Patent No. 5,591,770 describes the isolation of costatolide and soulattrolide in small quantities by HPLC, a tedious and high cost method which is not suitable for industrial production of costatolide and soulattrolide.

SUMMARY OF THE INVENTION

The present invention relates to an improved efficient and scalable method for the isolation of costatolide (2) from the trunkbark latex of *Calophyllum* plants such as *C. teysmannii*. The method can also be applied to extracting and isolating a second major component of the latex, soulattrolide (3), another HIV-1 NNRTI.

According to the method of the invention, the latex was initially treated with a non-polar solvent, e.g., hexane, to extract preferably non-costatolide materials, leaving behind a solid residue of crude costatolide. The resulting crude costatolide was then recrystallized from a aprotic polar solvent, e.g., acetone, repeatedly to

produce a final costatolide product that was 96% pure. If desired, additional costatolide as well as soulattrolide can be recovered from the mother liquors and purified via recrystallization. The method of the invention is economical and useful for isolation of purified costalide and soulattrolide in kilogram quantities from latex.

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DETAILED DESCRIPTION OF THE INVENTION

All references, patents and published patent applications cited herein are incorporated by reference in their entirety.

The latex starting material may be obtained from *Calophyllum* plants such as
10 *C.teysmannii* Miq. and *C.teysmannii* Miq. var. *Inophylloide* (King) P.F.Stevens and *C.lanigerum* var. *austrocoriaceum* (T.C. Whitmore) P.F.Stevens, which are found typically in Southeast Asia, Sri Lanka, and Northern Australia.

C. teysmannii latex, provided by the Forest Research Centre of Sarawak, Malaysia, was isolated according to described procedures¹⁹ and was analyzed by
15 quantitative high performance liquid chromatography (HPLC) analysis. The results indicated that the latex consisted of costatolide (~ 37 %) and soulattrolide (~ 23 %), along with other unidentified components. A preliminary solubility study revealed that the latex was soluble in almost all organic solvents at room temperature with the following order: CH₂Cl₂ (400 mg/mL) > CH₂Cl₂/MeOH (1:1) $\simeq$ AcOEt (~200
20 mg/mL) > CH₂Cl₂/AcOEt (1:1) (50 mg/mL) > acetone $\simeq$ MeOH (40 mg/mL) > EtOH (30 mg/mL) > hexane (20 mg/mL). Hence, for a preliminary extraction of mostly non-costatolide components from the latex, it is preferred that the latex be treated with any suitable solvent that least solubilizes the latex such as a non-polar solvent, e.g., hexane and heptane.

25 The amount of solvent used relative to latex ranges between about 5 L/Kg latex and about 13 L/Kg latex, preferably about 8L/Kg latex. The preliminary extraction of the latex starting material may be conducted under solvent reflux conditions or preferably at room temperature. Thus, treatment of the latex with hexane dissolved approximately 50% of the latex by weight, resulting in an off-white solid residue
30 which contained approximately 50% costatolide (2) as determined by quantitative HPLC analysis. Additional amounts of crude costatolide may be obtained by allowing the hexane solution to stand at room temperature for several days. The resulting crude costatolide was then collected and pooled with the residue.

The solid residue is then dissolved in a suitable solvent, e.g., CH_2Cl_2 or acetone, to remove any insoluble bark debris by filtration of the resulting solution through a cotton cloth, glass cotton or other suitable filtering material. In practicing the invention, the solvent acetone is preferred because the resulting acetone solution was
5 more convenient to filter than the CH_2Cl_2 solution.

After removal of solvent by any suitable method such as reduced pressure evaporation or distillation, the solid product obtained is recrystallized repeatedly from a suitable solvent, e.g. a polar aprotic solvent such as acetone, t-butylmethyl ether, ethyl acetate or solvent mixtures of acetone/ethyl acetate, ethyl acetate/t-butylmethyl
10 ether, or acetone/t-butylmethyl ether, to produce a final product of costatolide with purity of greater than 96%. In practicing this invention, acetone is the preferred recrystallization solvent for costatolide. Mother liquors containing similar purity levels of costatolide (2) were combined, solvent was removed and the resulting residue was recrystallized from acetone to yield an additional quantity of costatolide
15 (2). It has been observed that each iteration of the recrystallization step resulted in an increase in costatolide (2) purity by an average of 10%, with recovery yield of 40 to 70%. Generally, the purity of the resulting crystalline product was inversely proportional to the recrystallization yield.

In practicing the invention, the appropriate volume (in milliliters) of solvent
20 needed for each recrystallization step ranged between about 5 mL to about 12 mL per gram of solid to be recrystallized, preferably about 10 mL of solvent, e.g., acetone, per gram of solid product.

A typical example described in Example No. 1, starting with 1.96 kilograms of latex, is presented in Scheme I. Another batch of 2.64 kilograms of latex yielded
25 similar results. From these two batches, representing a total of 4.60 kilograms of latex, a combined 490 grams of costatolide (2) was obtained with a purity greater than 96% in an overall yield of 10.6%, along with other less pure fractions (Table 1). A higher overall yield could be expected if the less pure fractions were combined and upgraded by silica gel column chromatography, followed by the recrystallization
30 processes described above. During this study, organic solvents employed were hexane (95 L), CH_2Cl_2 (25 L), and acetone (45 L). The fraction containing a mixture of costatolide (2) and soulattrolide (3) in a ratio of 1:1 was further purified either by repetitive recrystallization from ethanol (ca. 3-5 times) or by flash silica gel column

chromatography followed by recrystallization from ethanol to afford soulattrolide (3) with a purity greater than 96%.

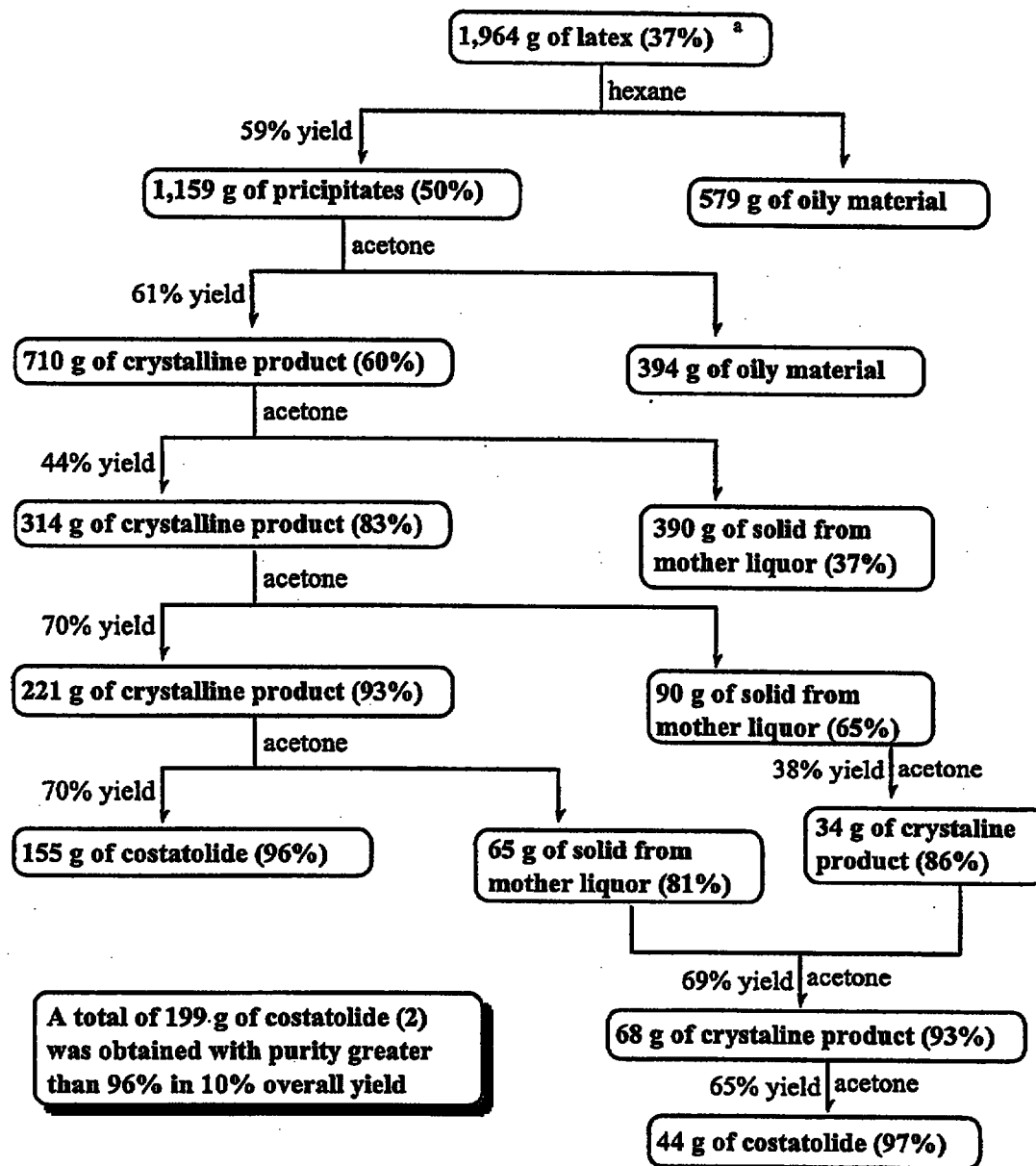
The structures of purified costatolide (2) and soulattrolide (3) were elucidated by MS and 2D-NMR and their physical (mp, $[\alpha]_D$) and spectral data (UV, IR, ^1H NMR, and ^{13}C NMR) were identical with those reported in the literature.^{1,6,16,17} In addition, the anti-HIV activities of both compounds were also confirmed in the *in vitro* XTT assay. The isolated costatolide (2) and soulattrolide (3) had EC_{50} values of 0.18 μM and 0.62 μM , respectively, in CEM-SS cells against the HIV-1 RF strain.

10 Table 1. Summary of Results Obtained from 4.60 Kilograms of Latex

Fractions	Purity of Costatolide
490 g	>96%
75 g	90% ^a
129 g	80% ^a
80 g	60% ^a
60 g	50% ^a
917 g	30 - 40%
2450 g	oily material
4201 g (total) ^b	

^a The remaining major constituent was soulattrolide (3).

^b The bark debris and volatiles accounted for the loss.



^a The values in parentheses represent the purity of costatolide (2) determined by quantitative HPLC

Scheme I

In summary, an efficient and scalable method has been demonstrated for the isolation of costatolide (2), an anti-HIV agent, from the latex of *C. teysmannii*. It is therefore possible that sufficient supplies of 2 could be obtained in a relatively low-cost manner from natural sources. The purified 490 grams of 2 will be utilized for further preclinical development of this compound.

Another anti-HIV agent, soulattrolide (3), has also been isolated utilizing this process, using the mother liquor fractions that were enriched with soulattrolide, preferably the fractions containing a weight ratio of at least 1:1 (w/w) soulattrolide to costatolide. The soulattrolide, however, was preferably recrystallized from any suitable polar solvent such as ethanol, methanol, diethyl ether, or solvent mixtures such as diethylether with ethanol or methanol. In practicing this invention, the preferred recrystallization solvent for soulattrolide is ethanol.

15 **EXPERIMENT NO. 1: Isolation of Costatolide (2) from Latex**

Plant Material. The latex of *Calophyllum teysmannii* var. *inophylloide* was collected¹⁹ at Kubah N. P. and Bedaun (Pueh F. R.), Kuching Division, Sarawak, Malaysia.

General Experimental Procedure. Optical rotations were measured on a Perkin Elmer Model #241 Polarimeter Serial #4677. NMR spectra were recorded with a Varian Gemini spectrometer (300 MHz for ¹H and 75.5 MHz for ¹³C) using CDCl₃ as solvent. UV spectra were recorded on a Hitachi U-2001 Spectrometer. IR Spectra were acquired on a Perkin Elmer Model Paragon 1000 FT-IR spectrometer, with samples being prepared as KBr pellets. MS were obtained with a Finnigan MAT 90 mass spectrometer. An APCI or ESI probe was used for APCIMS or EIMS spectra. HPLC analyses were performed on a Hitachi HPLC system equipped with a L-4000 H UV detector and L-6000 pump. A normal phase column (B17419 Zorbax, 4.6 mm x 25 cm) was purchased from Rockland Technologies, Inc., and the mobile phase was 30% AcOEt in hexane with a flow rate of 1 mL/min.

30 **Treatment of Latex with Hexane.**

Method A. at R.T.: Latex (1,964 g) containing approximately 37% costatolide (2) and 23% soulattrolide (3), as determined by quantitative HPLC analysis, was stirred in 15 L of hexane at r.t. for 1 hr. The solid was allowed to settle, and then was filtered through a filter stick by vacuum transfer and washed with hexane (10 L x 2). The

solid product thus obtained was dissolved in 15 L of CH_2Cl_2 and filtered through cotton cloth to remove bark debris. Removal of solvent afforded 1,026 g of a light yellowish solid, with the purity of costatolide (2) being increased to approximately 50%.

- 5 The combined greenish yellow hexane solution and washes were concentrated under vacuum. When the volume was reduced to approximately 10 L, precipitates formed, which were collected by filtration to yield an additional 133 g of an off-white solid which contained 30% of 2, resulting in a total of 1,159 g of costatolide-containing solid in a yield of 59% recovered from latex after the hexane treatment.
- 10 The filtrate was concentrated to dryness to leave a 579 g of greenish oil with less than 3% 2, as determined by HPLC.

Method B. Refluxing: A quantity of 2.64 kg of latex and 15 L of hexane was heated to reflux for one hour. The solid was allowed to settle, and then was filtered through a filter stick by vacuum transfer and washed with hexane (15 L x 2) to afford

15 844 g of an off-white solid containing approximately 50% of costatolide (2). An additional 242 g of a light yellow solid, with 39% of 2, was obtained from the combined hexane solutions after standing at r.t. for one week. The filtrate was concentrated to 1/3 volume and allowed to stand at r.t. for one week to yield 107 g of a pale yellow solid with a purity of 57% of costatolide (2). A total of 1,080 g of oily

20 material was obtained after concentration from all the filtrates, which had less than 3% 2 as determined by HPLC. The recovery yield of costatolide-containing solid from this batch was 45% after the hexane treatment.

Step 1 Recrystallization to Increase the Purity of 2 from 50% to 60%: An amount of 1,026 g (50 % pure) of the off-white solid was refluxed in 10 L of acetone

25 until a clear brown solution was obtained, which was filtered hot through a glass fritted funnel under vacuum. The resulting solution was allowed to stand at r.t. for 2 days. The resulting solid was collected and washed with hexane to yield 678 g (66% yield) of a crystalline product, with the purity of 2 being increased to 60%. The filtrate was concentrated to 1/2 the volume and 50 g of precipitate, with a purity of

30 32% of 2 were collected through filtration. The filtrate was evaporated to dryness to afford 250 g of oil without detectable amounts of 2.

Step 2 Recrystallization to Increase the Purity of 2 from 60% to 80%: An amount of 678 g (60% pure) of the solid obtained above was recrystallized in the same manner described above from 5.5 L of acetone to yield 184 g (27% yield) of

crystals with a purity of 82% of 2 and 492 g (50% pure) of material from the mother liquor.

Step 3 Recrystallization to Increase the Purity of 2 from 80% to 90%: An amount of 184 g (82% pure) of the solid obtained above was recrystallized in the same manner described above from 1.9 L of acetone to yield 119 g (65% yield) of crystals with a purity of 93% of 2 and 65 g (50% pure) of material from the mother liquor.

Step 4 Recrystallization to Increase the Purity of 2 from 90% to 96%: An amount of 393 g (93% pure) of the solid was recrystallized in the same manner described above from 2.9 L of acetone to yield 277 g (71%) of crystalline costatolide (2) with purity of 96% and 125 g (82% pure) of material from the mother liquor. Costatolide (2): ^{1,6,16} mp. 174 - 175 °C (Lit. ¹⁶ 181-182 °C); [α]_D -22.2 (c 0.71, CHCl₃) { Lit. ¹⁶ [α]_D -19.9 (c 0.42, CHCl₃)}; UV (CHCl₃) λ_{max} (log ϵ) 222 (4.67), 285 (4.43), 327 (4.10) nm; IR (KBr) ν_{max} 3477, 2961, 2931, 1703, 1638, 1584, 1569 cm⁻¹; APCI-MS: *m/z* 371 (M+H)⁺; ¹H NMR: 1.03 (3H, t, J = 7.2 Hz, CH₃), 1.14 (3H, d, J = 6.9 Hz, CH₃), 1.43 (3H, d, J = 6.3 Hz, CH₃), 1.48 (3H, s, CH₃), 1.49 (3H, s, CH₃), 1.65 (2H, sextet, J = 7.2 Hz, CH₂), 1.74 (1H, m, H-11), 2.67 (1H, d, J = 3.9 Hz, OH), 2.88 (2H, m, CH₂), 4.27 (1H, dq, J = 6.6, 6.9 Hz, H-10), 4.97 (1H, broad, H-12), 5.53 (1H, d, J = 9.9 Hz, H-7), 5.94 (1H, s, H-3), 6.63 (1H, d, J = 9.9 Hz, H-8); ¹³C NMR: 12.5 (CH₃), 14.0 (CH₃), 18.8 (CH₃), 23.2 (CH₂), 27.6 (CH₃), 27.8 (CH₃), 38.2 (C-11), 38.5 (CH₂), 61.8 (C-12), 73.0 (C-6), 77.6 (C-10), 103.5 (C-4a), 106.1 (C-8a or C-12a), 106.3 (C-12a or C-8a), 110.3 (C-3), 116.6 (C-8), 126.7 (C-7), 151.4 (C-4b), 153.1 (C-8b or C-12b), 153.9 (C-12b or C-8b), 158.7 (C-4), 161.0 (C=O); Elem. Anal.: C 71.40%, H 7.20%; Calcd. for C₂₂H₂₆O₅: C 71.33%, H 7.08%.

Soulattrolide (3): An amount of 20 g of solid obtained from the above acetone recrystallization, which contained approximately 1:1 ratio of costatolide (2) and soulattrolide (3), was subjected to flash silica gel column chromatography (Biotage Flash Column), eluting with a stepwise gradient of AcOEt in hexane: 10% (5L), 15% (10 L), 20% (15 L), and 100% AcOEt (5 L). A volume of 500 mL was collected for each fraction. Fractions 28 and 29 contained soulattrolide (3) (~70 % by HPLC). Crystalline needles (300 mg, 89 % purity of 3) were formed in fraction 29 and collected. The crystals were recrystallized from EtOH twice to afford 170 mg of soulattrolide (3) with a purity of 97 % by HPLC. Soulattrolide (3): ¹⁷ mp 200 - 201 °C

(Lit.¹⁷ 201 - 202 °C); $[\alpha]_D$ -34.2 (c 0.24, CHCl₃) {Lit.¹⁷ $[\alpha]_D$ -29.6° (CHCl₃)}; UV (CHCl₃) λ_{max} (log ϵ) 216 (4.74), 232 (4.53), 286 (4.56), 335 (4.29) nm; IR (KBr) ν_{max} 3457, 2862, 1698, 1584, 1366, 1139, 837, 762 cm⁻¹; APCIMS m/z 405 [M+H]⁺; ¹H NMR: 0.93 (6H, s, 2 CH₃), 1.16 (3H, d, J = 7.2 Hz, CH₃), 1.44 (3H, d, J = 7.2 Hz, CH₃), 1.76 (1H, m, H-11), 2.79 (1H, d, J = 3.6 Hz, OH), 4.26 (1H, dq, J = 6.4, 10.7 Hz, H-10), 4.96 (1H, d, J = 3.2 Hz H-12), 5.34 (1H, d, J = 9.8 Hz, H-7), 5.94 (1H, s, H-3), 6.51 (1H, d, J = 9.8 Hz, H-8), 7.3 (5H, m, C₆H₅); ¹³C NMR: 12.4 (CH₃), 18.7 (CH₃), 26.7 (CH₃), 26.8 (CH₃), 38.7 (C-11), 61.7 (C-12), 73.0 (C-10), 76.6 (C-6), 103.6 (C-4a), 106.1 (C-8a or C-12a), 106.2 (C-12a or C-8a), 111.7 (C-3), 116.0 (C-8), 127.3 (*para*- and *meta*-C₆H₅), 127.4 (*ortho*-C₆H₅), 127.6 (C-7), 140.1 (*ipso*-C₆H₅), 151.2 (C-4b), 153.6 (C-8b or C-12b), 153.9 (C-12b or C-8b), 156.4 (C-4), 160.8 (C=O); Elem. Anal.: C 73.94 %, H 6.10 %, Calcd. for C₂₅H₂₄O₅, C 74.24 %, H 5.98%.

15 EXPERIMENT NO. 2: Isolation of Soulattrolide from enriched mother liquors

Solid material obtained from mother liquor of costatolide recrystallization as described in Experiment No. 1, which contained soulattrolide and costatolide in the weight ratio of about 1:1, was purified via recrystallization (3X) from ethanol to produce solattrolide (3) of 95.5% purity in a total yield of 41.5% starting from latex.

20 **Step No. 1: Recrystallization to purity of (3) from 49% to 63%:** A quantity of 13 g of solid (soulattrolide 49%, costatolide 49%) was dissolved in 260 mL of hot ethanol by refluxing, and filtered. The clear filtrate was let stand at room temperature overnight. The precipitate shown was filtered to produce 9.28 g of off-white crystals with a purity of 63.4% of 3 (yield 71.5%).

25 **Step No. 2. Recrystallization to increase purity of (3) from 63% to 93%:** An amount of 9.28 g of solid (soulattrolide 63%, costatolide 33%) was recrystallized in the same manner described above from 250 mL of ethanol to produce 7.04 g of white crystals with a purity of 93% of 3 (yield 75.9%).

30 **Step No. 3. Recrystallization to increase purity of (3) from 93% to 95.5%:** An amount of 7.04 g of solid (soulattrolide 93%, costatolide 5.1%) was recrystallized in the same manner described above from 250 mL of ethanol to produce 5.38 g of white crystals with a purity of 95.5% of 3 (yield 76.4%).

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WHAT IS CLAIMED:

1. A method for isolating costatolide from latex of a *Calophyllum* plant comprising the steps of:

- 5 (a) extracting latex with a non-polar organic solvent to obtain a crude residue including costatolide as the major component;
- (b) recrystallizing the crude residue with a polar organic solvent to produce crystalline costatolide; and
- (c) recovering costatolide.

10 2. A method for isolating soulattrolide from *Calophyllum* latex comprising the steps of:

- (a) extracting latex with a non-polar organic solvent to obtain a crude residue including soulattrolide as the major component;
- (b) recrystallizing the crude residue with a polar organic solvent to produce crystalline soulattrolide; and
- 15 (c) recovering soulattrolide.

3. The method according to claims 1 or 2 wherein said step (b) recrystallization is performed more than once.

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4. The method according to claims 1 or 2 wherein step (a) non-polar organic solvent is hexane.

5. The method according to claims 1 or 2 wherein debris in the latex is removed prior to step (b).

25

6. The method according to claim 1 wherein said polar organic solvent is at least one member selected from the group consisting of acetone, t-butylmethyl ether, and ethyl acetate.

30

7. The method according to claim 1 wherein said polar organic solvent is acetone.



8. The method according to claim 2 wherein said polar organic solvent is at least one member selected from the group consisting of ethanol, methanol, and diethyl ether.

5 9. The method according to claim 2 wherein said polar organic solvent is ethanol.

10 10. The method according to claims 1 or 2 wherein said latex is derived from *Calophyllum lanigerum* Miq.

11. The method according to claims 1 or 2 wherein said latex is derived from *Calophyllum lanigerum* Miq. var. *austrocoriaceum* (T. C. Whitmore) P. F. Stevens.

15 12. The method according to claims 1 or 2 wherein said latex is from *Calophyllum teysmannii* Miq.

13. The method according to claims 1 or 2 wherein said latex is derived from *Calophyllum teysmannii* Miq. var. *inophylloide* (King) P. F. Stevens.



This Sheet Has Been Replaced

