Heteroatom Chemistry
Volume 1, Number 1, 1990

# Facile Synthesis of 2,4-Dienals via an Arsonium Salt and Its Application to Some Natural Products†

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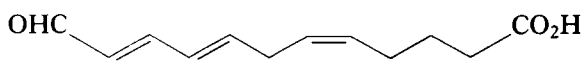
*Received 10 March 1989.*

## ABSTRACT

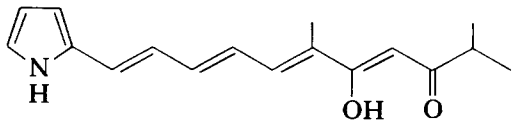
*2,4-Dienals were synthesized conveniently by using a new formylenylolefination method. The aldehydes were reacted with formylallyltriphenylarsonium bromide* (**2**) *in* $Et_2O$–$THF$–$H_2O$ (*9 : 1 : 0.05*) *in the presence of* $K_2CO_3$ *at room temperature to give* (2E,4E)- *and* (2E,4Z)*-dienals, in favor of the former. They could be easily separated by chromatography, and the latter, in* $CH_2Cl_2$, *could be converted to the former on treatment with a catalytic amount of iodine in daylight. The configurations of the* (E,E) *products have been conveniently identified by* $^1H$ *NMR determined in* $C_6D_6$. *The syntheses of two natural products, navenone A and* Otanthus maritima *amide, by this method are also reported in detail.*

A 2,4-Dienal is an important intermediate from which a variety of biologically active natural products can be synthesized. Moreover, some 2,4-dienals themselves are biologically active; for example, a metabolite (**1**), isolated from the red algae *Laurencia hybrida*, possesses antimicrobial activity [1].



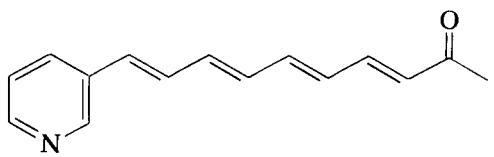

**1**

Therefore, methodology for synthesizing dienals has attracted the attention of synthetic organic chemists. The methods reported in the literature use LiCH=CH—CH=CHOEt [2] or $CH_3COCH$ $=CHSCMe_3$ [3] with aldehyde, but both of these suffer from difficulty in obtaining the reagents or from the need for multiple-step reactions to afford the desired dienal. Alternatively, a Wittig reagent, $Ph_3P$=CHCH=CHCHO, has been used [4]. Its application to the synthesis of leukotriene has appeared in the literature [5]. A roundabout procedure to achieve formylenylolefination has been used, for example, in the synthesis of *Wallemia* A [6].




*Wallemia* A

In extension of our previously reported formylolefination via an arsonium salt [7] we would like to report here a facile formylenylolefination via the arsonium salt, formylallyltriphenylarsonium bromide (**2**), and its application in the syntheses of navenone A [8] and *Otanthus maritima* amide [9].




Navenone A

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† This is paper 73 in the series on the application of organic compounds substituted with elements of groups 15 and 16 in organic synthesis.



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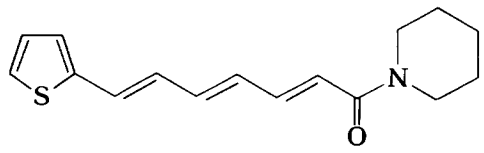
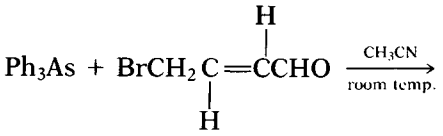
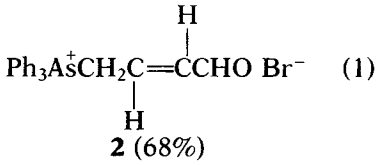


*Otanthus maritima* amide

The reaction of triphenylarsine with bromocrotonaldehyde [10] in acetonitrile gave a 68% yield of **2**.

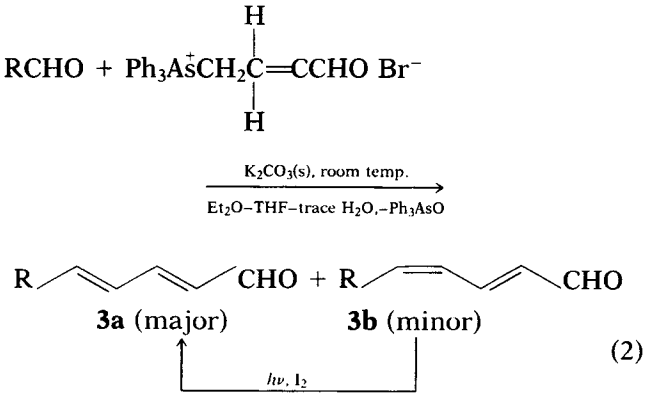




**2** (68%) (1)

It is noteworthy that the arsonium bromide (**2**) is a very stable, white, crystalline compound, capable of being stored for a long time without decomposition.

Because **2** bears a reactive aldehyde group, the formylenylolefination should be carried out under very mild conditions. We found that the reaction could be performed under phase-transfer conditions with a weak base, potassium carbonate, in a mixed solvent, $Et_2O$–THF–$H_2O$ (9 : 1 : 0.05), at room temperature. The dienals formed always contain (2*E*,4*E*) and (2*E*,4*Z*), isomers, but in general the ratio is in favor of the former. The two isomers were separated easily by TLC. When petroleum ether-ethyl acetate, was used as the eluent, $R_f(2E,4E) < R_f(2E,4Z)$. After chromatography on a silica-gel column, both (2*E*,4*E*)- and (2*E*,4*Z*)-dienals could be obtained in pure form, and in $CH_2Cl_2$ the latter could be converted easily into the former on treating with a catalytic amount of iodine in daylight for a few hours. The reaction is shown in Eq. (2) and the results are summarized in Table 1.



(2)

The simplicity of our method, the mildness of the reaction conditions, and the excellent yields make it a practical approach to the synthesis of polyenals and related natural products. We have also applied this method to the synthesis of $LTA_4$ in cooperation with Wu's group of our institute [11]. Recently, Le Meerer and co-workers reported their synthesis of the key intermediate of $LTB_4$ by means of this method [12].

In the synthesis of dienals, we encountered a bit of difficulty in identifying the configuration, especially when an aliphatic substituent was located at C5. No report has ever shown the proton NMR coupling constant of H4 and H5 [2, 3, 13]. Bloch and co-workers, in their total synthesis of a hypotensive vasodilator, could not determine the coupling constants of H4 and H5 of the key intermediate **4** with a 400-MHz spectrometer [14]. Higgs reported that it was hard to clearly distinguish the

**TABLE 1** Formylenylolefination of Aldehydes via Arsonium Salt (**2**)[a]

| Entry | Aldehyde R | Reaction time (h) | Product | Yield[b] (%) | 2E,4E/2E,4Z[c] |
|---|---|---|---|---|---|
| a | p-$O_2NC_6H_4$— | 12 | $O_2NC_6H_4(CH{=}CH)_2CHO$ (**3a, 3a'**) | 98 | 4 : 1 |
| b | $C_6H_5$— | 12 | $C_6H_5(CH{=}CH)_2CHO$ (**3b, 3b'**) | 85 | 3.5 : 1 |
| c |  | 19 |  $(CH{=}CH)_2CHO$ (**3c, 3c'**) | 81 | 1.4 : 1 |
| d |  | 8 |  $(CH{=}CH)_2CHO$ (**3d, 3d'**) | 81 | 1 : 1 |
| e | $C_5H_{11}$— | 20 | $C_5H_{11}(CH{=}CH)_2CHO$ (**3e, 3e'**) | 79 | 4 : 1 |
| f | $C_9H_{19}$— | 23 | $C_9H_{19}(CH{=}CH)_2CHO$ (**3f, 3f'**) | 85 | 4 : 1 |

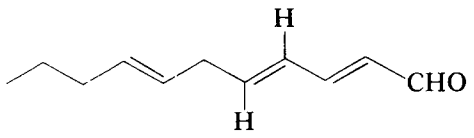
[a] All reactions were carried out at room temperature.
[b] Isolated yields.
[c] Estimated by $^1H$ NMR.

**TABLE 2** Proton NMR of (2*E*,4*E*)-Decadienal $C_5H_{11}$ CHO[a]

| *A (in $CDCl_3$)* | | | | *B (in $C_6D_6$)* | | | |
|---|---|---|---|---|---|---|---|
| *Description of signal* | *Chemical shift (δ)* | *Coupling constant (Hz)* | *Assignment* | *Description of signal* | *Chemical shift (δ)* | *Coupling constant (Hz)* | *Assignment* |
| d | 9.55 | 7.8 | 1-H | d | 9.46 | 7.8 | 1-H |
| m | 7.09 | | 3-H | dd | 6.51 | 15.2 9.8 | 3-H |
| m | 6.30 | | 4.5-H | dt | 5.75 | 15.1 6.5 | 5-H |
| | | | | dd | 5.81 | 15.1 9.8 | 4-H |
| dd | 6.08 | 15.2, 7.8 | 2-H | dd | 5.97 | 15.2 7.8 | 2-H |

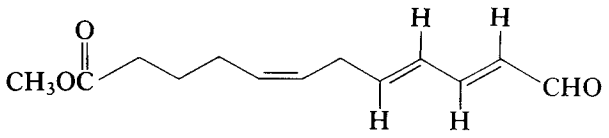
[a] Determined in $CDCl_3$ related to TMS at 0 or in $C_6D_6$ related to benzene-H at 7.20.

configuration of the conjugated diene of **5** by its $^1H$ NMR spectrum (360 MHz) and the configuration of the 8*E*, 10*E* isomer has only been confirmed by computer simulation [1].



**4**

We have noticed that all the above-mentioned $^1H$ NMR values were determined in $CDCl_3$ solution. The H4 and H5 configuration of our products, (2*E*,4*E*)-dienal, in $CDCl_3$ also could not be distinguished by $^1H$ NMR with a 200-MHz spectrometer. When deuterated benzene was used as the solvent, making it possible to change the chemical shift of the proton, we determined the $^1H$ NMR of our

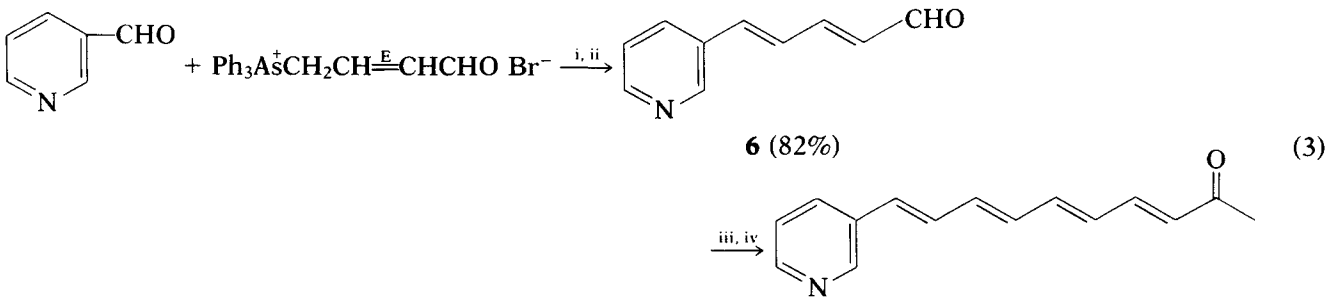


**5**

(2*E*,4*E*)-dienals in $C_6D_6$ with satisfactory results. Table 2 shows our results in connection with the decoupling data.

The configuration of the vinyl protons were easily distinguished in $CDCl_3$ by $^1H$ NMR with a 200-MHz spectrometer. Thus, we found a convenient method to assign the (*E*,*E*) configurations of 2,4-dienals by determining $^1H$ NMR spectra in $C_6D_6$.

Our formylenylolefination was successfully applied to the synthesis of two natural products, navenone A and *Otanthus maritima*, amide as shown in the following equations:

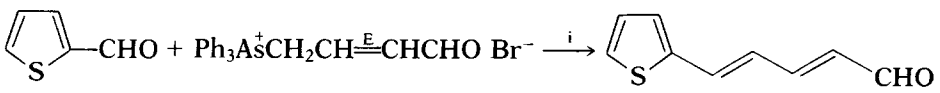


**6** (82%)

navenone A **(8)** (56%)

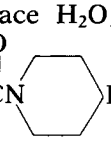
(3)

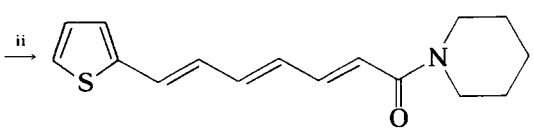
where i = $Et_2O$–THF (9 : 1), trace $H_2O$, $K_2CO_3$, 25°C, 12 h; ii = *hν*, $I_2$, $CH_2Cl_2$; iii = $Ph_3\overset{+}{A}sCH_2CH\overset{E}{=}CHCOCH_3\ Br^-$ (**7**), $K_2CO_3$, $Et_2O$ (trace $H_2O$), 12°C, 16 h; iv = *hν* $I_2$, $CH_2Cl_2$.



**9** (79%)

(4)

where i = $Et_2O$–THF (9 : 1), trace $H_2O$, $K_2CO_3$, 15°C, 15 h, and ii = $Ph_3\overset{+}{A}sCH_2CN$  $Br^-$ (**10**), $CH_3CN$, trace $H_2O$, $K_2CO_3$, 20°C, 12 h.



*Otanthus maritima* amide **(11)** (98%)

It is noteworthy that navenone A (**8**) has been synthesized by Sakakibara et al. by a seven-step reaction sequence in 1.1% overall yield [15], whereas *Otanthus maritima* amide has been synthesized by Bohlmann et al. by a six-step reaction in 3% overall yield [16].

## EXPERIMENTAL

Proton nuclear magnetic resonance ($^1$H NMR) spectra were determined with a Varian EM-360L (60 MHz) or an XL-200 (200 MHz) spectrometer using tetramethylsilane as the internal standard. Infrared (IR) spectra were recorded on an IR-440 or a Perkin-Elmer 983 instrument. Mass spectral data were obtained with electron ionization (EI) on a Finnigan 4021 spectrometer. High-resolution MS (HRMS) results were obtained on a Finnigan MAT 711 spectrometer. Gas chromatography–mass spectroscopy analyses were performed on a QP-1000 equipped with a PEG fused-silica capillary column 50 m × 0.2 mm id. Gas chromatographic analyses were performed on an HP 5880 fitted with an FFAP capillary column, 50 m × 0.2 mm id, and 102-G instrument.

All reactions were carried out under nitrogen. All solvents were dried and redistilled before use. Boiling and melting points were uncorrected.

4-Bromocrotonaldehyde was prepared according to Ref. [10] from 1-acetoxybutadiene [17].

### *3-Formylallyltriphenylarsonium Bromide* (**2**)

A mixture of 4-bromocrotonaldehyde (1.65 g, 11 mmol), triphenylarsine (4.0 g, 13 mmol), and acetonitrile (5 mL) was stirred at 25°C for 30 h. The solvent was evaporated under reduced pressure and anhydrous ether was added to the residue. The resulting white solid was collected by filtration, washed with ether, and dried, affording the desired **2** (3.4 g, 68%), mp 150–151°C. It is sufficiently pure for further use. Recrystallization with $CH_2Cl_2$–$Et_2O$ gave plates, mp 153–154°C; IR (KCl), 1690, 1005 cm$^{-1}$; $^1$H NMR (200 MHz, $CDCl_3$–TMS, δ) 9.44 (d, $J$ = 7.20 Hz, 1H, CHO) 7.82 (m, 15H, Ar–H), 7.03 (m, 1H, 3-H), 6.50 (dd, $J$ = 16, 7.20 Hz, 1H, 2-H), 5.44 (d, $J$ = 8 Hz, 2H, 4-H); *analysis*, calculated for $C_{22}H_{20}AsBrO$: C, 58.05; H, 4.43; Br, 17.55; found, C, 58.26; H, 4.39; Br, 17.65%.

### *Condensation of Aldehyde with Arsonium Salt* (**2**)

In the general procedure, a mixture of aldehyde (1 mmol), arsonium salt **2** (550 mg, 1.2 mmol), $K_2CO_3$ (165 mg, 1.2 mmol), $Et_2O$–THF (9 : 1, 10 mL), and $H_2O$ (50 μL) was stirred at 15–25°C for several hours. After disappearance of the starting aldehyde, the reaction mixture was passed through a silica gel column and eluted with petroleum ether–ethyl acetate (9 : 1) to afford the product.

### *5-(4-Nitrophenyl)-(2E,4E)-pentadienal* (**3a**)

Using the general procedure, **3a** was obtained from *p*-nitrobenzaldehyde in 71% yield, mp 117.5–118.5°C, and its (2*E*,4*Z*) isomer (**3a′**) was obtained in 20% yield, mp 102–103°C. It has been reported [18] that the (2*E*,4*E*) isomer has a mp of 106–107.5°C. For **3a**, IR (KCl) results are 1680, 1350, 1020, 1000 cm$^{-1}$; by MS, *m/z* (relative intensity), 203 ($M^+$, 93), 157 (15), 128 (100); by $^1$H NMR (200 MHz, $C_6D_6$, δ), 9.47 (d, $J_{1,2}$ = 7.5 Hz, 1H, CHO), 7.83 (d, $J$ = 8.9 Hz, 2H, Ar-H), 7.20 (s, benzene-H), 6.70 (d, $J$ = 8.9 Hz, 2H, Ar-H), 6.43 (dd, $J_{2,3}$ = 15.0 Hz, $J_{3,4}$ = 10 Hz, 1H, 3-H), 6.23 (dd, $J_{4,5}$ = 15.2 Hz, $J_{3,4}$ = 10.0 Hz, 1H, 4-H), 6.07 (d, $J_{4,5}$ = 15.2 Hz, 1H, 5-H), 6.05 (dd, $J_{2,3}$ = 15.0 Hz, $J_{1,2}$ = 7.5 Hz, 2-H).

### *5-(4-Nitrophenyl)-(2E,4Z)-pentadienal* (**3a′**)

Results from MS, *m/z* (relative intensity), 203 ($M^+$, 70), 157 (15), 128 (100); by $^1$H NMR (200 MHz, $C_6D_6$, δ), 9.34 (d, $J_{1,2}$ = 7.7 Hz, 1H, CHO), 7.78 (d, $J$ = 8.8 Hz, 2H, Ar-H), 7.20 (s, benzene-H), 6.74–6.88 (m, 1H, 3-H), 6.60 (d, $J$ = 8.8 Hz 2H, Ar-H), 6.06 (d, $J_{4,5}$ = 11.7 Hz, characteristic *Z* double bond, 1H, 5-H), 6.00 (dd, $J_{2,3}$ = 15.3 Hz, $J_{1,2}$ = 7.7 Hz, 1H, 2-H), 5.84 (dd, $J_{4,5}$ = 11.7 Hz, $J_{3,4}$ = 11.5 Hz, 1H, 4-H).

### *5-Phenyl-(2E,4E)-pentadienal* (**3b**)

From benzaldehyde, **3b** (105 mg) was obtained as an oil in 66% yield, and the (2*E*,4*Z*) isomer **3b′** (30 mg) was also obtained as an oil in 19% yield. On standing in a refrigerator, **3b** solidified, mp 36–37° C (literature [3] reported mp 38.5–39°C). By IR (film), 1675, 1618, 1592, 985 cm$^{-1}$; by MS, *m/z* (relative intensity), 159 ($M^+$ + 1, 58), 130 (100), 103 (14), 81 (20), 77 (30); by $^1$H NMR ($CDCl_3$–TMS, 200 MHz, δ), 9.59 (d, $J$ = 7.0 Hz, 1H, CHO), 6.96–7.51 (m, Ar-H + 3 vinyl-H, 8H), 6.24 (dd, $J_{2,3}$ = 15.1 Hz, $J_{1,2}$ = 7.0 Hz, 1H, 2-H).

### *5-Phenyl-(2E,4Z)-pentadienal* (**3b′**)

Results by IR (film), 1676, 1618, 1582, 986 (*E* double bond), 706 (*Z* double bond) cm$^{-1}$; by MS, *m/z* (relative intensity), 159 (M + 1, 45), 130 (100), 103 (17), 81 (19), 77 (29); by $^1$H NMR ($CDCl_3$–TMS, 200 MHz, δ), 9.59 (d, $J$ = 8.0 Hz, 1H, CHO), 7.31–7.60 (m, 6H,Ar-H + 1 vinyl-H), 6.98 (m, 1H, 3-H) 6.51 (dd, $J_{4,5}$ = 11.4 Hz, $J_{3,4}$ = 11.4 Hz, characteristic *Z* double bond, 4-H), 6.29 (dd, $J_{2,3}$ = 15.5 Hz, $J_{1,2}$ = 8.0 Hz, 1H, 2-H).

### *$I_2$-Catalyzed Conversion of* **3b'** *to* **3b**

A mixture of **3b** and **3b'** (4 : 1) (250 mg), $CH_2Cl_2$ (15 mL), and $I_2$ (6 mg) in a quartz testtube was allowed to react under daylight for 10 h. Gas chromatography showed that the (*E,Z*) isomer had almost completely converted into the (*E,E*) form. The mixture was washed with 20 mL of 0.1 *M* $Na_2S_2O_3$ solution and extracted with $CH_2Cl_2$. After being dried with $Na_2SO_4$, the solution was chromatographed, giving 205 mg of yellowish solid, yield 82%. Gas chromatography showed the content of 2*E*,4*E* reached 98%.

### *5-(2-Furyl)-(2*E,*4*E)*-pentadienal* (**3c**)

From furfural, **3c** was obtained in 47% yield, mp 60–61°C (reported [19] mp 62–64°C) and the (2*E*,4*Z*) isomer **3c'** was obtained in 34% yield. For the (2*E*,4*E*) product, by IR (KCl), results are 1670, 1600, 1105, 1005 $cm^{-1}$; by $^1H$ NMR (200 MHz, $C_6D_6$, δ), 9.45 (d, $J$ = 7.7 Hz, 1H, CHO), 7.20 (s, benzene-H), 6.97 (d, $J$ = 1.0 Hz, 1H, 3'-H), 6.59 (dd, $J_{3,4}$ = 11.0 Hz, $J_{4,5}$ = 14.6 Hz, 1H, 4-H), 6.44 (dd, $J_{2,3}$ = 14.3 Hz, $J_{3,4}$ = 11.0 Hz, 1H, 3-H), 6.14 (d, $J_{4,5}$ = 14.6 Hz, 1H, 5-H), 6.06 (m, 2H, 4'-H, 5'-H), 5.60 (dd, $J_{2,3}$ = 14.3 Hz, $J_{1,2}$ = 7.8 Hz, 1H, 2-H).

### *6,7-Dihydroxyacetonide-(2*E,*4*E)*-heptadienal* (**3d**) *and (2*E, *4*Z)*-heptadienal* (**3d'**)

From glyceraldehyde acetonide, **3d** and **3d'** were obtained in 81% yield. They were easily separated by chromatography. Results for the (2*E*,4*E*) isomer, by $^1H$ NMR (200 MHz, $CDCl_3$–TMS, δ), 9.51 (d, $J_{1,2}$ = 7.8 Hz, 1H, CHO), 7.02 (dd, $J_{2,3}$ = 15.2 Hz, $J_{3,4}$ = 11 Hz, 1H, 3-H), 6.51 (dd, $J_{4,5}$ = 15.2 Hz, $J_{4,3}$ = 11 Hz, 1H, 4-H), 6.09–6.19 (m, 2H, 2,5-H), 4.59 (m, 1H, 6-H), 4.11 (m, 1H, 7-Ha), 3.60 (m, 1H, 7-Hb), 1.39 (s, 3H, $CH_3$), 1.35 (s, 3H, $CH_3$); for the (2*E*,4*Z*) isomer, by $^1H$ NMR ($CDCl_3$–TMS, 200 MHz, δ), 9.56 (d, $J_{1,2}$ = 7.8 Hz, 1H, 1-H), 7.40 (dd, $J_{2,3}$ = 15.1 Hz, $J_{3,4}$ = 11.0 Hz, 1H, 3-H), 6.28–6.39 (m, 1H, 5-H), 6.13 (dd, $J_{2,3}$ = 15.1 Hz, $J_{1,2}$ = 7.8 Hz, 1H, 2-H), 5.86 (dd, $J_{4,5}$ = 10.7 Hz, $J_{3,4}$ = 11 Hz, 1H, 4-H), 4.95 (m, 1H, 6-H), 4.09 (m, 1H, 7-Ha), 3.60 (m, 1H, 7-Hb), 1.39 (s, 3H, $CH_3$), 1.36 (s, 3H, $CH_3$).

### (2E,*4*E)*-Decadienal* (**3e**)

From *n*-caproaldehyde, (2*E*,4*E*)-decadienal (**3e**) was obtained in 62.5% yield and (2*E*,4*Z*)-decadienal (**3e'**) in 16% yield. For **3e**, bp, 71–73°C at 0.5 torr (reported [20], 58–61°C at 0.05 torr); by IR (film), 1684, 1637, 1594, 988 $cm^{-1}$; by MS, *m/z* (relative intensity), 151 ($M^+ - 1$, 21), 95 (42), 80 (100), 67 (72), by $^1H$ NMR (200 MHz, $C_6D_6$, δ), 9.46 (d, $J_{1,2}$ = 7.8 Hz 1H, CHO), 7.20 (s, benzene-H), 6.51 (dd, $J_{2,3}$ = 15.2 Hz, $J_{3,4}$ = 9.8 Hz, 1H, 3-H), 5.97 (dd, $J_{1,2}$ = 7.8 Hz, $J_{2,3}$ = 15.2 Hz, 1H, 2-H), 5.81 (dd, $J_{4,5}$ = 15.1 Hz, $J_{3,4}$ = 9.8 Hz, 1H, 4-H), 5.75 (dt, $J_{5,6}$ = 6.5 Hz, $J_{4,5}$ = 15.1 Hz, 1H, 5-H), 1.80–1.90 (m, 2H, 6-H), 1.16–1.33 (m, 6H, 7-, 8-, 9-H), 0.93 (t, 3H, 10-H).

### (2E,*4*Z)*-Decadienal* (**3e'**)

For this compound bp is 71–73°C at 0.5 torr (reported [20], 58–61°C at 0.05 torr); results by IR (film), 1679, 1629, 1589, 988 (trans double bond), 737 (cis double bond) $cm^{-1}$; by MS, *m/z* (relative intensity), 151 ($M^+ - 1$, 7), 95 (16), 80 (100), 67 (25); by $^1H$ NMR (200 MHz, $C_6D_6$, δ), 9.46 (d, $J_{1,2}$ = 7.8 Hz, 1H, CHO), 7.20 (s, benzene-H), 7.00 (dd, $J_{2,3}$ = 15.4 Hz, $J_{3,4}$ = 11.0 Hz, 1H, 3-H), 6.02 (dd, $J_{2,3}$ = 15.4 Hz, $J_{1,2}$ = 7.8 Hz, 1H, 2-H), 5.85 (dd, $J_{4,5}$ = 11.6 Hz, $J_{3,4}$ = 11.0 Hz, 1H, 4-H), 5.55 (dt, $J_{4,5}$ = 11.6 Hz, 1H, 5-H, characteristic *Z* bond), 1.91–1.98 (m, 2H, 6-H), 1.18–1.40 (m, 6H, 7-, 8-, 9-H), 0.90 (t, 3H, 10-H).

### (2E,*4*E)*-Tetradecadienal* (**3f**) *and* (2E,*4*Z)*-Tetradecadienal* (**3f'**)

From 1 mmol of *n*-decaldehyde, after reaction according to the general procedure and chromatography with petroleum ether–EtOAc (97 : 3), (2*E*,4*E*)-tetradecadienal (**3f**, 95 mg), the (2*E*,4*Z*)-isomer (**3f'**, 25 mg), and a mixture of both isomers (50 mg) were obtained; total yield was 85%. The **3f** and **3f'** mixture in $CH_2Cl_2$ was treated with catalytic amounts of $I_2$ in daylight for 15 h to convert it completely to the (2*E*,4*E*) isomer. Results for **3f**, bp 80–82°C at 0.6 torr (reported [21], 76–78°C at 0.5 torr); by IR (film), 1684, 1639, 986 (trans double bond) $cm^{-1}$; by MS, *m/z* (relative intensity), 209 ($M^+ + 1$, 85), 81 (100); by $^1H$ NMR (200 MHz, $C_6D_6$, δ), 9.45 (d, $J$ = 7.8 Hz, 1H, CHO), 7.20 (s, benzene-H), 6.50 (dd, $J_{2,3}$ = 15.4 Hz, $J_{3,4}$ = 10.0 Hz, 1H, 3-H, trans double bond), 5.97 (dd, $J_{2,3}$ = 15.0 Hz, $J_{1,2}$ = 7.8 Hz, 1H, 2-H), 5.80 (m, 1H, 4-H), 5.73 (dt, 1H, $J_{4,5}$ = 15.4 Hz, $J_{5,6}$ = 6.6 Hz, 5-H, trans double bond), 1.90 (m, 2H, 6-H), 1.27 (m, 14H, (7 ~ 13)-H), 0.97 (t, 3H, 14-H). For the (2*E*,4*Z*) isomer (**3f'**), results by IR (film), 1725, 1682, 1631, 738 $cm^{-1}$, by MS, *m/z* (relation intensity), 209 ($M^+ + 1$, 11), 81 (100).

### *5-(3'-Pyridyl)-(2*E,*4*E)*-2,4-pentadienal* (**6**)

A mixture of 3-pyridinecarboxaldehyde (215 mg, 2.0 mmol), arsonium bromide (**2**) (1.10 g, 2.4 mmol), $K_2CO_3$ (330 mg, 2.4 mmol), THF–$Et_2O$ (1 : 9, 20 mL), and $H_2O$ (80 μL) was stirred at 25°C for 12 h. Thin-layer chromatography (petroleum ether–EtOAc, 3 : 2) showed two spots ($R_f$ = 0.3, 0.2). To the reaction mixture was added 30 mL of ether. The resulting mixture, after filtration on a short column of silica gel to remove inorganic salts, was chromatographed (eluent: petroleum ether–EtOAc, 1 : 1) affording a yellow viscous liquid (40 mg, $R_f$ = 0.3), a yellowish solid (115 mg, $R_f$ = 0.2), and a mixture (140 mg, $R_f$ = 0.3, 0.2). Proton NMR showed that

the compounds with $R_f$ = 0.3 and 0.2 are two isomers; the latter is the desired 5-(3′-pyridyl)-(2*E*,4*E*)-2,4-pentadienal, and the former is its (2*E*,4*Z*) isomer. Total yield was 93%. To a solution of the mixture (95 mg) of the two isomers in $CH_2Cl_2$ (8 mL) was added 3 mg of $I_2$. The solution was irradiated in quartz testtube in daylight for 8 h and washed successively with 0.1 M $Na_2S_2O_3$ solution and then with $H_2O$. After chromatography, the (2*E*,4*E*) product (84 mg) was obtained. Thin-layer chromatography showed that the (2*E*,4*Z*) isomer had completely converted to the (2*E*,4*E*) isomer; results by IR (KCl), 1670, 1620, 1150, 1100, 1050 $cm^{-1}$; by MS, *m/z* (relative intensity); 159 ($M^+$, 58), 130 (100), 103 (14), 77 (30), 51 (30); by $^1H$ NMR (200 MHz, $C_6D_6$, δ); 9.50 (d, $J_{1,2}$ = 7.8 Hz, 1H, CHO), 8.55 (s, 1H, 2′-H), 8.44 (d, $J_{5,6}$ = 4.7 Hz, 1H, 6′-H), 7.20 (s, benzene-H), 7.04 (d, $J$ = 8.1 Hz, 1H, 4′-H), 6.66 (dd, $J_{4,5}$ = 8.1 Hz, $J_{5,6}$ = 4.7 Hz, 1H, 5′-H), 6.45 (dd, $J_{2,3}$ = 14.6 Hz, $J_{3,4}$ = 9.9 Hz, 1H, 3-H), 6.30 (m, 1H, 4-H), 6.14 (d, $J_{4,5}$ = 15.0 Hz, 1H, 5-H), 6.03 (dd, $J_{1,2}$ = 7.8 Hz, $J_{2,3}$ = 14.6 Hz, 1H, 2-H).

The analysis calculated for $C_{10}H_9NO$ (159.18) is C, 75.45; H, 5.70; N, 8.80; found, C, 75.95; H, 5.82; N, 8.40.

### *5-(3′-Pyridyl)-(2E,4Z)-2,4-pentadienal*

This compound is a viscous liquid; by MS, *m/z* (relative intensity), 159 ($M^+$, 45), 130 (100), 103 (17), 81 (19), 77 (29), 51 (23); by $^1H$ NMR (200 MHz, $CDCl_3$–TMS, δ), 9.61 (d, $J_{1,2}$ = 8.0 Hz, 1H, CHO), 8.59 (m, 2H, Ar-H), 7.35–7.70 (m, 3H, Ar-H + 3-H), 6.91 (d, $J_{4,5}$ = 11.2 Hz, 1H, 5-H), 6.63 (dd, $J_{4,5}$ = 11.2 Hz, $J_{3,4}$ = 11.4 Hz, 1H, 4-H, Z bond), 6.34 (dd, $J_{2,3}$ = 15.3 Hz, $J_{1,2}$ = 8.0 Hz, 1H, 2-H).

### *3-Acetylallyltriphenylarsonium Bromide* (**7**)

A mixture of (*E*)-5-bromo-3-penten-2-one (4.88 g, 0.03 mol) (prepared according to the literature [22]) and triphenylarsine (10.80 g, 0.036 mol) was allowed to react in a sealed tube at 50°C for 4 h. Absolute benzene was injected into the tube to dissolve the excess starting materials. The resulting product (6.5 g) was collected, yield, 43%, mp 127–128°C. Results by IR (KCl), 1620, 1670, 1695 $cm^{-1}$, by $^1H$ NMR ($CDCl_3$–TMS, δ), 7.70 (m, 15H), 6.68 (m, 2H), 5.20 (d, 2H), 2.10 (s, 3H).

The analysis calculated for $C_{23}H_{22}AsBrO$ (469.23), C, 58.87; H, 4.72; Br, 17.03; found, C, 58.78; H, 4.59; Br, 17.10.

### *Navenone A* (**8**)

A mixture of 5-(3′-pyridyl)-(2*E*,4*E*)-2,4-pentadienal (**6**) (195 mg, 1.22 mmol), 3-acetylallyltriphenylarsonium bromide (**7**) (870 mg, 1.86 mmol), $K_2CO_3$ (260 mg, 1.86 mmol), absolute $Et_2O$ (20 mL), and $H_2O$ (75 μL) was allowed to react at 12°C for 16 h. After the reaction was complete, the reaction mixture was extracted with $Et_2O$. The ethereal solution was concentrated and the resulting residue was dissolved in $CH_2Cl_2$. After treatment with a catalytic amount of $I_2$ and irradiation under daylight, the $CH_2Cl_2$ solution was chromatographed (eluent, petroleum ether–EtOAc, 6 : 4), giving navenone A as yellow crystals, mp 138–140°C (petroleum ether–$CH_2Cl_2$) (reported [23] 144–145°C; yield, 56%. Results by IR (KCl), 1675, 1570 $cm^{-1}$; by UV, $\lambda_{max}^{MeOH}$ 367 (ε 59,930), 378 nm (ε 58,003); by MS, *m/z* (relative intensity): 225 ($M^+$), 210 ($M^+$-$CH_3$), 182 ($M^+$-Ac); by HRMS, calculated for $C_{15}H_{15}NO$, 225.1162, and found, 225.1152; by $^{13}C$ NMR(22.5 MHz), 198.2, 148.7, 148.4, 142.9, 141.0, 136.7, 133.5, 132.8, 132.7, 131.4, 131.1, 130.5, 130.3, 123.6, 27.5 ppm; by $^1H$ NMR ($CDCl_3$, 200 MHz, δ), 8.62 (1H, 2′-H), 8.45 (1H, 6′-H), 7.72 (1H, 4′-H), 7.26 (1H,5′-H), 6.36–7.17 (m, 7H), 6.18 (d, $J$ = 15 Hz, 1H, 3-H), 2.28 (s, 3H); HPLC of the synthetic specimen did not reveal the presence of any other isomer.

### *5-(2′-Thienyl)-(2E,4E)-2,4-pentadienal* (**9**)

A mixture of 2-thiophenecarboxaldehyde (168 mg, 1.50 mmol), arsonium bromide (**2**) (751 mg, 1.65 mmol), $K_2CO_3$ (230 mg, 1.65 mmol), $Et_2O$–THF (9 : 1, 10 mL), and $H_2O$ (50 μL) was allowed to react at 15°C for 19 h. To the reaction mixture was added $Et_2O$ and it was allowed to stand overnight; workup proceeded in the usual manner. Chromatography (eluent, petroleum ether–EtOAc, 85 : 15) gave a yellowish solid (200 mg, 81% yield), mp 45–46·C (reported [16], a colorless liquid). Gas chromatography showed that the purity was >96%. No (*E,Z*) isomer was found by $^1H$ NMR (200 MHz); by IR (KCl), 1670, 1605, 985 $cm^{-1}$; by MS, *m/z* (relative intensity), 164 ($M^+$, 100), 135 (M − 29, 89), 91 (56); by $^1H$ NMR (200 MHz, $CDCl_3$–TMS, δ), 9.56 (d, $J_{1,2}$ = 8.0 Hz, 1H, CHO), 7.02–7.35 (m, 5H, 3′-, 4′-, 5′-, 3-, 5-H), 6.67 (dd, $J_{4,5}$ = 14.7 Hz, $J_{3,4}$ = 10.8 Hz, 1H, 4-H), 6.19 (dd, $J_{2,3}$ = 15.0 Hz, $J_{1,2}$ = 8.0 Hz, 1H, 2-H).

### *Piperidinocarbonylmethyltriphenylarsonium bromide* (**10**)

A mixture of bromoacetylpiperidine (3.10 g, 15 mmol), triphenylarsine (5.50 g, 20.0 mmol), and $C_6H_6$ (6 mL) was refluxed for 5 h, giving the arsonium bromide (**10**) as a white solid (7.42 g, 97% yield), mp 167–168°C ($CH_2Cl_2$–$Et_2O$); results by IR (KCl), 2920, 1620, 1460, 1380 $cm^{-1}$; by $^1H$ NMR ($CDCl_3$–TMS, δ), 7.70 (m, 5H, Ar-H), 5.70 (s, 2H, As-$CH_2$), 3.81 (br. s, 2H, α-H′), 3.35 (br. s, 2H, α-H′), 1.55 (m, 6H, β-, γ-H). Analysis, calculated for $C_{25}H_{27}AsBrNO$ (512.29), C, 58.61; H, 5.31; N, 2.73; found, C, 58.73; H, 5.41; N, 2.51.

## Otanthus maritima *amide* (**11**)

A mixture of 5-(2′-thienyl)-(2*E*,4*E*)-2,4-pentadienal (80 mg, 0.49 mmol), piperidinocarbonylmethyltriphenylarsonium bromide (**10**) (325 mg, 1.3 equiv), $K_2CO_3$ (90 mg, 1.3 equiv), $CH_3CN$ (8 mL), and $H_2O$ (20 $\mu$L) was stirred at 20°C for 12 h. Workup and chromatography (eluent, petroleum ether–EtOAc, 7 : 3) gave the desired product (130 mg, 98% yield) mp 100–101°C ($Et_2O$) (reported [16]; mp, 96.5°C). Results by IR (KCl), 1642, 1620, 1600, 1005 $cm^{-1}$; by MS, *m/z* (relative intensity): 274 ($M^+$ + 1, 100), 273 ($M^+$, 96), 189 ($M^+$-$C_5H_{10}N$, 27), 161 ($M^+$-$CONC_5H_{10}$, 36), 128 (39), 112 (52), 69 (35); by $^1H$ NMR (200 MHz, $C_6D_6$, $\delta$); 1.22 (m, 6H, 2′-, 3′-H), 3.03 (br. s, 2H, 2′-$H_{\alpha'}$), 3.61 (br. s, 2H, 2′-$H_{\alpha}$), 6.13–6.38 (m, 3H), 6.25 (d, $J_{2,3}$ = 14.7 Hz, 1H, 2-H), 6.44 (d, $J_{6,7}$ = 15.3 Hz, 1H, 7-H), 6.62–6.79 (m, 3H), 7.20 (s, benzene-H), 7.82 (dd, $J_{2,3}$ = 14.7 Hz, $J_{3,4}$ = 10.4 Hz, 1H, 3-H); by $^{13}C$ NMR (22.5 MHz, $CDCl_3$), 165.4, 142.4, 142.2, 138.5, 130.9, 128.2, 128.0, 127.9, 127.0, 125.4, 120.4, 24.7; by HRMS, calculated for $C_{16}H_{19}NOS$, 273.1187; found, 273.1190.

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