added to the residue. The precipitate was filtered, washed with acetone (160 mL), and dried to provide a light brownish solid. This solid was added to a solution of alloxan monohydrate (0.5 g) in HCl (5 mL, 1 N) and heated in a refluxing acetone bath for 30 min. After the reaction mixture was cooled to room temperature, acetone (100 mL) was added to the reaction mixture to give a yellow precipitate which was filtered, washed with acetone, and purified by Sephadex chromatography to give two yellow fractions. The first yellow fraction between 250 and 320 mL was collected and concentrated to approximately 1 mL. Addition of acetone (100 mL) to this and filtration provided 30 mg (24%) of **14** as a yellow powder: mp >250 °C; R_f 0.28; ^{1}H NMR (DMSO-d_6) δ 11.41 (1 H, s, NH(3)), 8.2–7.9 (3 H, m, aromatic), 6.1–3.0 (protons of β-cyclodextrin moiety); ^{13}C NMR (DMSO-d_6) δ 160.2, 156.1, 151.5, 139.1, 136.5, 135.0, 134.7, 133.2, 130.5, 117.0 (carbons of flavin), 102.0 (C1), 100.02 (C'1), 81.60 (C4), 80.01 (C'2), 73.10 (C3), 72.41 (C5), 72.05 (C2), 60.0 (C6), 32.0 (CH_3); ^{1}H NMR (D_2O) δ 7.45–7.20 (3 H, aromatic protons), 4.35 (7 H, m, H1), 3.30–3.01 (28 H, m, H3, H6, H5), 3.01–2.75 (14 H, m, H2, H4); ^{13}C NMR (D_2O) δ 160.7, 157.4, 150.1, 137.2, 136.8, 136.4, 135.1, 133.0, 130.4, 117.1 (carbons of flavin), 101.6 (C1), 99.6 (C'1), 80.9 (C4), 79.8 (C'2), 72.9 (C3), 71.9 (C5), 71.6 (C2), 60.1 (C6), 33.0 (CH_3); INEPT ^{13}C NMR (D_2O) δ 136.8, 130.4, 117.1, 101.6, 99.6, 80.9, 79.8, 72.9, 71.9, 71.6, 33.0 (positive peaks for CH and CH_3), 160.7, 157.4, 150.1, 137.2, 136.4, 135.1, 133.0, 60.1 (negative peaks for C and CH_2); UV-vis (H_2O) λ_{max} 265 (ϵ 3.25 × 10^4), 342 (ϵ 7.24 × 10^3), and 435 nm (ϵ 8.40 × 10^3). Anal. Calcd for $C_{54}H_{78}N_4O_{37}\cdot 7H_2O$: C, 43.20; H, 6.18; N, 3.73. Found: C, 43.29; H, 6.17; N, 3.78.

2-[4-(Methylamino)-3-nitrobenzyl]-α-cyclodextrin (16). Sodium hydride (160 mg, 60% in oil, 4.0 mmol) was added to a solution containing α-cyclodextrin (3.9 g, 4.0 mmol) in a mixture of DMF (40 mL) and DMSO (40 mL), and the mixture was stirred for 5 h. To this mixture was added a DMF (5 mL) solution containing **11** (0.80 g, 4.0 mmol), and the resultant mixture was allowed to stand at room temperature for 2 h. At the end of this time, cyclodextrin and its derivatives were precipitated by addition of 1 L of acetone. The precipitate was collected and washed with acetone to give 4.0 g of crude products containing only **16** and unreacted α-cyclodextrin as indicated by TLC; 300 mg of this crude product was purified by Sephadex chromatography to provided 50 mg (15%) of **16** as an orange powder: R_f 0.56; ^{1}H NMR (D_2O) δ 8.07 (1 H, s), 7.57 (1 H, d, $J_{5,6}$ = 9.2 Hz), 6.93 (1 H, d, $J_{5,6}$ = 9.1 Hz), 5.04 (7 H, m, H1), 4.10–3.72 (28 H, m, H3, H6, H5), 3.70–3.48 (14 H, m, H2, H4), 2.98 (3 H, s, CH_3); ^{13}C NMR (D_2O) δ 147.8, 139.0, 131.5, 127.8, 125.3, 115.8 (for aromatic carbons), 102.2 (C1), 100.8 (C1'), 82.4 (C4), 80.1 (C2'), 74.3 (C3), 73.8, 73.4 (C5), 72.8 (C2), 61.5 (C6), 31.4 (CH_3); INEPT ^{13}C NMR (D_2O) δ (negative peaks for C and CH_2) 147.8, 131.5, 125.3, 73.8, 61.5, (positive peaks for CH or CH_3) the rest of the peaks shown in the above ^{13}C NMR. Anal. Calcd for $C_{44}H_{68}N_2O_{32}\cdot 5H_2O$: C, 43.05; H, 6.44; N, 2.28. Found: C, 43.32; H, 6.26.; N, 2.42.

2-[(7α-*O*-10-Methyl-7-isoalloxazino)methyl]-α-cyclodextrin (17). A solution of 1.5 g of crude **16** containing 17% of pure **16** in methanol (250 mL) was hydrogenated in the presence of Pd/C (5%, 0.3 g) at room temperature for approximately 24 h to give a colorless solution. After the mixture was filtered, the filtrate was evaporated under vacuum below 40 °C, and acetone (20 mL) was added to the residue, filtered, washed with acetone, and dried to afford 1.5 g of a light yellow solid; 0.70 g of the solid was added to a solution of alloxan monohydrate (2.8 g, 18 mmol) in HCl (10 mL, 1 N) and heated in a refluxing acetone bath for 40 min. After the reaction mixture was cooled to room temperature, acetone (200 mL) was added to give a yellow precipitate which was filtered, washed with acetone, and purified by Sephadex chromatography to afford 50 mg (40%) of **17** as a yellow powder: R_f 0.24; ^{1}H NMR (D_2O) δ 7.38 (1 H, d, $J_{8,9}$ = 8.8 Hz), 7.35 (1 H, s), 7.22 (1 H, d, $J_{8,9}$ = 8.8 Hz), 4.34 (7 H, m, H1), 3.3–3.1 (28 H, m, H3, H6, H5), 3.0–2.8 (14 H, m, H2, H4); ^{13}C NMR (D_2O) δ 160.9, 157.6, 150.2, 137.6, 137.0, 136.4, 135.2, 133.1, 130.3, 117.3 (carbons of flavin), 101.4 (C1), 99.2 (C'1), 81.2 (C4), 79.6 (C'2), 73.3 (C3), 72.0 (C5), 71.5 (C2), 60.3 (C6), 33.0 (CH_3); INEPT ^{13}C NMR (D_2O) δ 160.9, 157.6, 150.2, 137.6, 136.4, 135.2, 133.1, 60.3 (negative peaks for C or CH_2), 137.0, 130.3, 117.3, 101.4, 99.2, 81.2, 79.6, 73.3, 72.0, 71.5, 33.0 (positive peaks for CH or CH_3); UV-vis (H_2O) λ_{max} 265 (ϵ 3.47 × 10^4), 342 (7.42 × 10^3), and 435 nm (ϵ 9.38 × 10^3). Anal. Calcd for $C_{48}H_{68}O_{32}N_4\cdot 9H_2O$: C, 41.92; H, 6.30; N, 4.07. Found: C, 41.58; H, 5.89; N, 4.15.

Acknowledgment. We gratefully acknowledge the financial support from the University of Missouri—St. Louis, Mallinckrodt Specialty Chemicals Company, the Missouri Research Assistance Act, and the donors of the Petroleum Research Fund, administered by the American Chemical Society. We thank the National Science Foundation for an instrumentation grant (CHE-8506671).

Supplementary Material Available: ^{1}H NMR spectra of **7–9, 11–13, 15, 17,** and **18**; ^{13}C NMR spectra of **7–9, 12, 15, 17,** and **18**; and ^{13}C INEPT NMR spectra of **8, 9, 12, 15, 17,** and **18** (25 pages). Ordering information is given on any current masthead page.

3-Vinylcoumarins and 3-Vinylchromenes as Dienes. Application to the Synthesis of 3,4-Fused Coumarins and Chromenes

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Received May 7, 1991

The reaction of α-(diethylphosphono)-γ-butyrolactones **1** with *o*-hydroxyaryl aldehydes **2** and **7** gave 3-(2-hydroxyethyl)coumarins **3** in excellent yields. Treatment of **3** or 3-(2-hydroxyethyl)-2,2-dimethylchromenes **11** derived from **3** with triphenylphosphine dibromide led to the corresponding 3-(2-bromoethyl)coumarins **8** or 3-(2-bromoethyl)chromenes **12** in good yields. The Diels–Alder reaction of the 3-vinylcoumarins **13** or the 3-vinylchromenes **31**, generated in situ from treatment of the bromides **8** or **12** with DBU, with a variety of dienophiles **14–19** and **35** produced regiospecific [2 + 4] cycloadducts, 3,4-fused coumarins **20–28** or 3,4-fused chromenes **32–34** and **36** in good to moderate yields.

Although the development of useful synthetic routes to coumarins[1] and chromenes[2] with 3,4-fused ring systems has been widely studied, it is still an interesting subject since they exhibit a variety of physiological activities. We have

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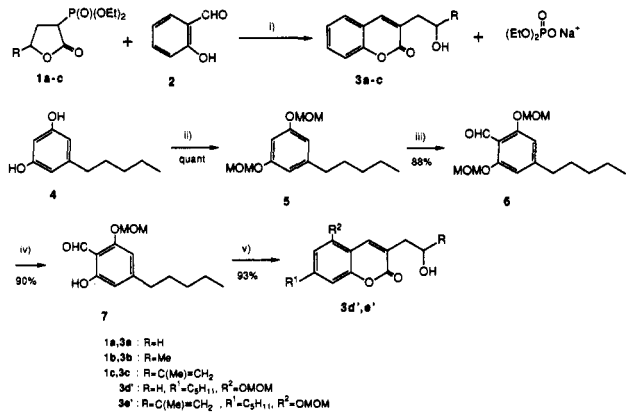
Scheme I[a]



[a] Reagents and conditions: (i) NaH/THF, reflux; (ii) NaH/THF–DMF, CH_3OCH_2Cl (MOMCl), rt; (iii) *n*-BuLi/ether, reflux 8 h, then DMF, reflux, 3 h; (iv) dil HCl/THF, rt; (v) NaH/THF, **1a** or **1c**, reflux, 2 h.

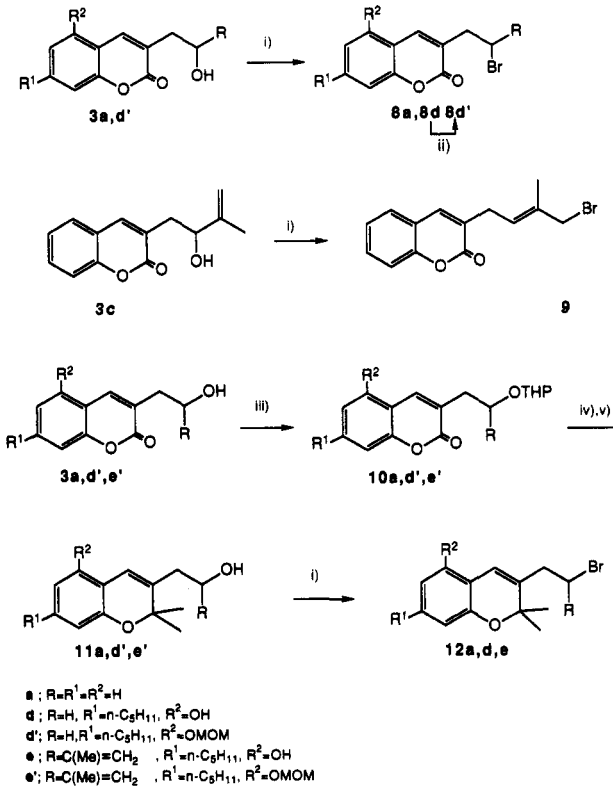
previously reported the synthesis of α-ylidene γ-lactones by the Horner–Emmons reaction of α-phosphono γ-lactone carbanions with aldehydes.[3] In this paper we report that the reaction of α-phosphono γ-lactone carbanions with 2-hydroxybenzaldehydes gave 3-(2-hydroxyethyl)-coumarins, and the resulting coumarins were converted into 3-vinylcoumarins and 3-vinylchromenes, which in turn reacted with various dienophiles to afford coumarins and chromenes with a 3,4-fused 6-membered ring via the Diels–Alder reaction.

Results and Discussion

Synthesis of 3-(2-Bromoethyl)coumarins and 3-(2-Bromoethyl)-2*H*-chromenes. The reaction of α-(diethylphosphono)-γ-butyrolactone (**1a**) with salicylaldehyde (**2**) and 1 equiv of sodium hydride (NaH) in tetrahydrofuran (THF) at reflux for 3 h gave 3-(2-hydroxyethyl)-coumarin (**3a**) in quantitative yield. A similar reaction of various α-phosphono γ-lactones **1b,c** with **2** produced the corresponding 3-(2-hydroxyethyl)coumarins **3b,c** in excellent yields (Scheme I). For the purpose of the synthesis of biologically active coumarins and cannabinol analogues, 2-formyl-5-pentylresorcinol 1,3-bis(methoxymethyl) ether (**6**) was prepared as a starting *o*-hydroxyaryl aldehyde in 88% yield by treatment of 1,3-dimethoxymethylated 2-lithio-5-pentylresorcinol with dimethylformamide (DMF). Subsequent conversion of **6** into 2-formyl-5-pentylresorcinol 3-methoxymethyl ether (**7**) by treatment with dilute hydrochloric acid, followed by the reaction with **1a**, afforded the expected 3-(2-hydroxyethyl)coumarin derivative **3d'** in 93% yield (Scheme I).

Treatment of the hydroxyethylcoumarins **3a** with **3d'** with a triphenylphosphine–bromine adduct[4] in refluxing acetonitrile easily produced the corresponding 3-(2-bromoethyl)coumarins **8a** and **8d** in 98% and 73% yields, respectively, whereas a similar treatment of **3c** caused rearrangement to give the bromide **9** in 35% yield (Scheme II). 3-(2-Bromoethyl)-2,2-dimethylchromenes **12a,d,e** were prepared according to the following processes: (i) protection of the hydroxy group in **3a,d',e'** as pyranyl ethers,

Scheme II[a]



[a] Reagents and conditions: (i) Br_2, PPh_3/CH_3CN, reflux or rt; (ii) NaH/THF–DMF, CH_3OCH_2Cl; (iii) DHP/CH_2Cl_2, cat. *p*-TosOH; (iv) MeLi/Et_2O–benzene, rt, 12 h; (v) *p*-TosOH/benzene, reflux, 5 h.

(ii) treatment with 2 equiv of methyllium and then with *p*-toluenesulfonic acid leading to **11a,d',e'**, and (iii) bromination with triphenylphosphine dibromide (Scheme II).

Synthesis of 3,4-Fused Coumarins and Chromenes. Treatment of the bromide **8a** with 1,8-diazabicyclo-[5,4,0]undec-7-ene (DBU) in DMF at 80 °C for 3 h gave 3-vinylcoumarin (**13a**) in 59% yield together with the dimerization product of **13a** (28% yield). Since this result suggests that the vinylcoumarin **13a** functions not only as a diene component but also as a dienophile, synthetic application of **13a** to coumarins with 3,4-fused 6-membered ring systems via the Diels–Alder reaction was explored.[5]

The reaction of **8a** with an excess amount (10 equiv) of methyl acrylate (**14**) in the presence of DBU in DMF at 80 °C for 6 h resulted in the formation of a single regioisomeric Diels–Alder adduct, 10-(methoxycarbonyl)-7,8,9,10-tetrahydrodibenzo-α-pyrone (**20**) in 54% yield. The regiochemistry of **20** was assigned on the basis of the ^{13}C NMR spectrum (see Experimental Section), which exhibited C-7, C-8, C-9, and methoxycarbonylated C-10 at δ 26.0,[6] 18.0, 24.1,[6] and 41.0, respectively, because the chemical shift of C-8 in the corresponding 9-methoxycarbonylated isomer is predicted to shift downfield (ca. 3–5 ppm) from that (δ 18.0) of C-8 in **20** by comparison of the ^{13}C shift increment[7] of the ester substituent to C-8 in the two regioisomers and by reference to the ^{13}C NMR chemical shifts[8] of methyl 3-cyclohexene-1-carboxylate. The

(1) For a review, see: Darbarwar, M.; Sundaramurthy, V. *Synthesis* **1982**, 337.

(2) For some reviews of cannabinoids, see: (a) Mechoulam, R.; Mccallum, N. K.; Burstein, S. *Chem. Rev.* **1976**, *76*, 75. (b) Razdan, R. *The Total Synthesis of Natural Products*; ApSimon, J., Ed.; Wiley-Interscience: New York, 1981; Vol. 4, p 186.

(3) Minami, T.; Niki, I.; Agawa, T. *J. Org. Chem.* **1974**, *39*, 3236.

(4) For a review of halogenation of alcohols by the triphenylphosphine–bromine reagent, see: Castro, B. R. *Org. React.* **1983**, *29*, 1.

(5) The Diels–Alder reaction of 4-styrylcoumarins with dienophiles to give 3,4-carbocyclic fused coumarins have been previously reported (Mustafa, A.; Kamel, M. *J. Am. Chem. Soc.* **1955**, *77*, 1829). However, synthesis and utilization of coumarins bearing the vinyl group at the 3-position has not been studied.

(6) Assignments may be interchanged.

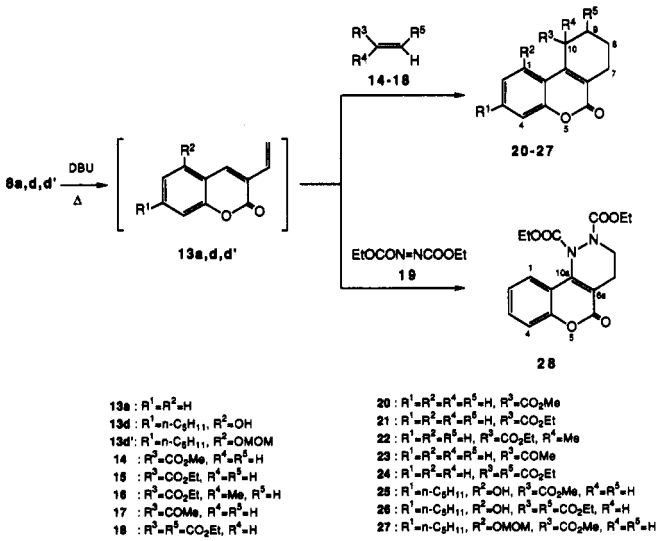
(7) Breitmaier, E.; Voelter, W. *Carbon-13 NMR Spectroscopy*, 3rd ed.; VCH: Weinheim, 1987; p 316.

Table I. Diels–Alder Reactions of Vinylcoumarins 13 or Vinylchromenes 31 with Dienophiles

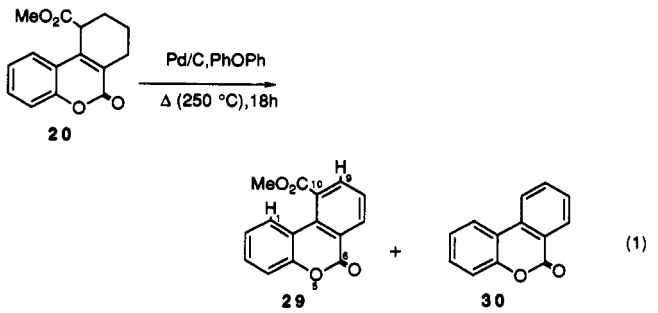
entry	dienes[a]	dienophiles	cond[b] temp (°C)	cond[b] time (h)	products	yield[c] (%)
1	**13a**	**14**	80	6	**20**	54
2	**13a**	**15**	100	6	**21**	68
3	**13a**	**16**	100	12	**22**	78
4	**13a**	**17**	80	4	**23**	76
5	**13a**	**18**	100	8	**24**	52
6	**13d**	**14**	80	8	**25**	34
7	**13d**	**18**	100	6	**26**	35
8	**13d'**	**14**	80	7.5	**27**	67
9	**13a**	**19**	80	8	**28**	42
10	**31a**	**14**	100	3	**32a + 33a**	83
11	**31d**	**14**	100	3	**32d + 33d**	36
12	**31a**	**19**	100	4	**34**	63
13	**31a**	**35**	80	12	**36**	46

[a] In situ generated from **8a,d,d'** or **12a,d** and DBU in the reaction system. [b] All reactions were carried out using 8 (2 mmol) or 12 (3 mmol), 10 equiv of dienophiles, and 1 equiv of DBU in DMF (30 mL) containing a small amount of 2,6-di-*tert*-butyl-4-methylphenol (BHT stabilizer). [c] No attempts to optimize the yields have been made.

Scheme III



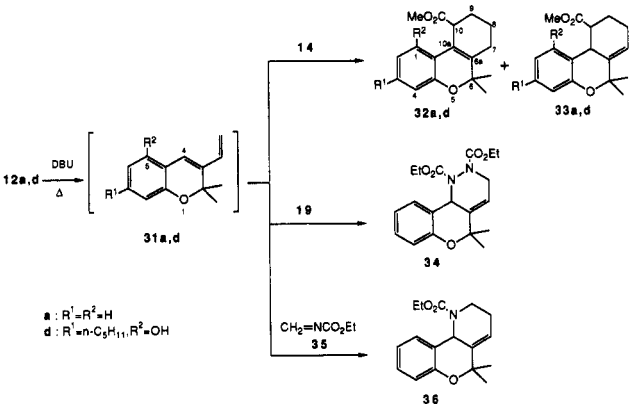
compound **20** was subjected to dehydrogenation by a palladium catalyst (5% palladium on carbon) in diphenyl ether at 250 °C for 18 h to produce 10-(methoxycarbonyl)dibenzo-α-pyrone (**29**) (14%) and dibenzo-α-pyrone (**30**) (31%) (eq 1).



(1)

The Diels–Alder addition of **13a** to ethyl acrylate (**15**), ethyl methacrylate (**16**), and methyl vinyl ketone (**17**) similarly led to the corresponding single regioisomers **21–23** in 68–78% yields (entries 2–4 in Table I) (Scheme III). In contrast, 1,2-disubstituted dienophiles such as diethyl maleate (**18**) and diethyl azodicarboxylate (**19**) gave cycloadducts **24** and **28** in rather low yields (entries 5 and 9). Furthermore, reaction of **13d** or **13d'**, generated in situ from **8d** or **8d'** and DBU, with **14** produced single Diels–Alder adducts **25** or **27** in 34% or 67% yield (entries 6 and 8). Although the hydroxy group or the MOM ether group in the 5-position of the vinylcoumarins **13d,d'** may be anticipated to influence regiochemistry as well as yield in the Diels–Alder adducts, the above results show that these groups have no influence on the regiochemistry.

Scheme IV



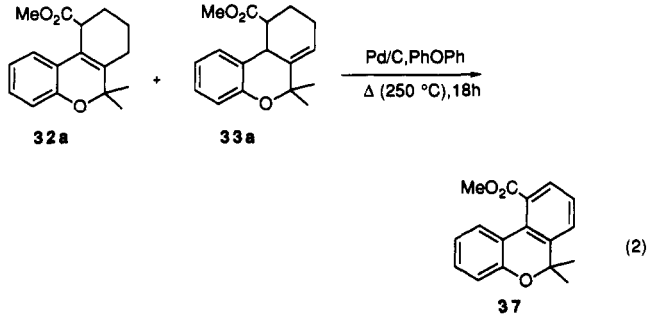
In order to develop a new synthetic method of biologically active cannabinoids and their analogues, the Diels–Alder reaction of 3-vinylchromenes with dienophiles with the expectation of giving 3,4-fused chromenes has been explored.

The reaction of the 3-vinylchromene **31a**, similarly prepared in situ from 3-(bromoethyl)chromene **12a** and DBU, with **14** under similar conditions resulted in a 4.5:1 mixture of 6,6-dimethyl-10-(methoxycarbonyl)-7,8,9,10-tetrahydrodibenzopyran (**32a**) and its isomer, 6,6-dimethyl-10-(methoxycarbonyl)-8,9,10,10a-tetrahydrodibenzopyran (**33a**) in 83% yield (Scheme IV). Structural assignment of each of **32a** and **33a** was clearly made on the basis of their ^{1}H NMR spectra, which showed the following notable differences.[9] The ^{1}H NMR spectrum of **32a** shows the ester methyl protons as a singlet at δ 3.64 and no signal assignable to olefinic protons, while that of **33a** exhibits the corresponding methyl protons as a singlet at δ 3.80 and the olefinic proton at δ 5.50–5.84 (m, H-7). These observations are consistent with the assigned structures of **32a** and **33a**. For further confirmation of the

(8) Nakagawa, K.; Sawai, M.; Ishii, Y.; Ogawa, M. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 2487.

(9) The ^{1}H NMR spectral data ($CDCl_3$) of **32a** and **33a** are as follows. **32a**: δ 1.36 (s, 3 H, CH_3), 1.40 (s, 3 H, CH_3), 1.52–2.28 (br, 7 H, CH_2, CH), 3.64 (s, 3 H, CO_2CH_3), 6.70–7.20 (m, 4 H, Ar*H*). **33a**: δ 1.45 (s, 6 H, CH_3), 1.60–2.32 (m, 5 H, CH_2, CH), 2.56–3.04 (dt, J = 4.1, 9.4 Hz, 1 H, CH), 3.80 (s, 3 H, CO_2CH_3), 5.50–5.84 (m, 1 H, olefinic H), 6.66–7.20 (m, 4 H, Ar*H*).

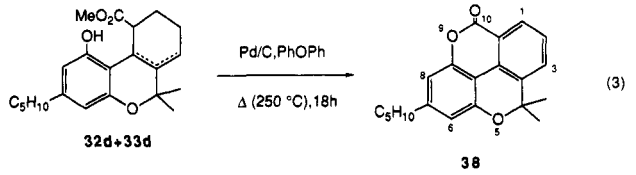
structures of **32a** and **33a**, a similar treatment of the mixture with palladium on charcoal (250 °C, 18 h) was carried out to give 6,6-dimethyl-10-(methoxycarbonyl)dibenzopyran (**37**) as a single aromatization product in 81% yield (eq 2).



(2)

Accordingly, this result indicates that the vinylchromene **31a** undergoes the regiospecific Diels–Alder reaction with the dienophile **14** to give the cycloadduct **33a**, followed by a facile exo–endo isomerization of the double bond into the more stable adduct **32a**.

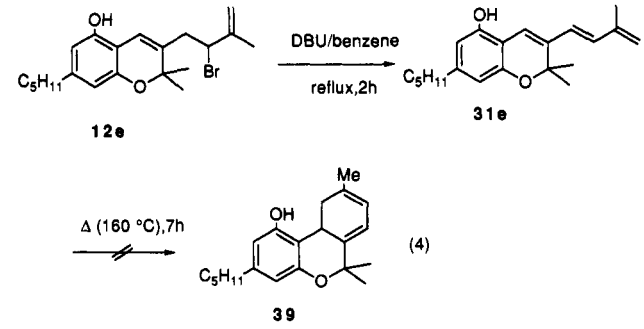
In the Diels–Alder reaction of 5-hydroxy-2,2-dimethyl-7-pentyl-3-vinylchromene (**31d**) with **14**, a 4:1 mixture of methyl 11-nor-$\Delta^{6a,10a}$- and -$\Delta^{6a,7}$-tetrahydrocannabinol-10-carboxylate (**32d** and **33d**)[10] was also obtained in 36% yield. When the mixture of **32d** and **33d** was treated with palladium on charcoal under similar conditions, the lactone **38** was exclusively produced in 74% yield, exhibiting the methoxycarbonyl group is clearly located at the 10-position (eq 3).



(3)

In contrast to the vinylcoumarin **13a**, the Diels–Alder reaction of the vinylchromene **31a** with **19** has been found to produce the stable initial [4 + 2] adduct **34** without undergoing isomerization of the double bond. Furthermore, the Diels–Alder addition of **31a** to methyleneurethan,[11] generated in situ from methylenebisurethan and boron trifluoride etherate, similarly gave the regiospecific cycloadduct **36** in 46% yield (Scheme IV). Thus, these regiospecific [4 + 2] cycloadditions of the vinylcoumarins **13** and the vinylchromenes **31** with various dienophiles would be presumably caused by "the secondary orbital interaction"[12] between the benzene π-orbitals of **13** or **31** and the substituent π-orbitals of the dienophiles.

Since the Diels–Alder reaction of vinylchromenes with a variety of dienophiles has proven to be versatile for construction of 3,4 6-membered ring fused chromenes, the possibility of the synthesis of cannabinol via an electrocyclic reaction of the dienylchromene **31e** was studied. Thus, treatment of the 3-(2-bromo-3-methyl-3-butenyl)-chromene **12e** with DBU brought about dehydrobromination to give the 3-(3-methyl-1,3-butadienyl)chromene **31e** in 81% yield. Heating an acetonitrile solution of **31e** in a sealed tube at 160 °C for 7 h afforded no desired 10,10a-dihydrocannabinol (**39**), but only uncharacterizable polymeric products were obtained (eq 4).



(4)

In conclusion, we note the following points from this investigation: (1) a new type of diene components, 3-vinylcoumarins and 3-vinylchromenes, were synthesized; (2) the 3-vinylcoumarins and the 3-vinylchromenes are versatile reagents for the construction of 3,4-fused coumarins and chromenes; and (3) the 5-hydroxy-7-pentyl-3-vinylchromene **31d** provided a simple method to synthesize cannabinoids **32d**, and **33d**.

Experimental Section

General. ^{1}H NMR and ^{13}C NMR spectra were obtained on a JEOL JNM-FX-60 spectrometer in $CDCl_3$ operating at 60 and 15.04 MHz with Me_4Si as an internal standard. IR spectra were recorded with a Shimadzu IR-408 instrument. Mass spectra were taken with a JEOL DX-300 spectrometer. Melting points were measured in open capillary tubes and are uncorrected.

Materials. α-(Diethylphosphono)-γ-butyro- (**1a**)[3], α-(diethylphosphono)-γ-valero- (**1b**)[3], and α-(diethylphosphono)-γ-isopropenyl γ-lactones (**1c**)[13] were prepared according to the established procedures.

Preparation of 2-Formyl-5-pentylresorcinol 1,3-Bis(methoxymethyl) Ether (6). To a stirred THF (200 mL) solution of olivetol bis(methoxymethyl) ether (**5**) (49.97 g, 186 mmol), prepared from olivetol (**4**), chloromethyl methyl ether, and NaH, was added *n*-butyllithium (128 mL of a 1.62 M solution in hexane, 205 mmol) at room temperature, and then the mixture was stirred at reflux for 3 h. After the solution was cooled to room temperature, DMF (4.95 g, 205 mmol) was added and stirring was continued at reflux for additional 3 h. After the usual workup, the residue was chromatographed on silica gel (ethyl acetate:hexane = 1:4) to give the product **6**: yield 48.09 g (162 mmol, 87%); R_f 0.45 (ethyl acetate:hexane = 1:4); IR (neat) 1675, 1600 cm^{-1}; ^{1}H NMR δ 0.50–2.00 (m, 9 H, CH_2, CH_3), 2.00–2.75 (br, 2 H, ArCH_2–), 3.50 (s, 6 H, OCH_3), 5.25 (s, 4 H, OCH_2O), 6.39 (s, 1 H, Ar*H*), 6.65 (s, 1 H, Ar*H*), 10.47 (s, 1 H, CHO); *m/z* 296 (M^+). Anal. Calcd for $C_{16}H_{24}O_5$: C, 64.84; H, 8.16. Found: C, 65.04; H, 8.14.

Preparation of 2-Formyl-5-pentylresorcinol 3-Methoxymethyl Ether (7). A solution of **6** (44.89 g, 151 mmol) in THF (200 mL) containing hydrochloric acid (35%, 15 mL) was stirred at room temperature for 3 h. After a saturated aqueous NaCl solution was added to the reaction mixture, the mixture was extracted with ethyl acetate and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on silica gel (ethyl acetate:hexane = 1:4) to give **7**: yield 34.29 g (136 mmol, 90%); R_f 0.80 (ethyl acetate:hexane = 1:4); IR (neat) 3300, 1690, 1605, cm^{-1}; ^{1}H NMR δ 0.33–2.20 (m, 9 H, CH_2, CH_3), 2.20–2.93 (br, 2 H, ArCH_2–), 3.51 (s, 3 H, OCH_3), 5.25 (s, 2 H, OCH_2O), 6.42 (s, 2 H, Ar*H*), 10.28 (s, 1 H, CHO), 11.91 (s, 1 H, OH); MS *m/z* 252 (M^+). Anal. Calcd for $C_{14}H_{20}O_4$: C, 66.65; H, 7.99. Found: C, 66.62; H, 8.14.

General Procedure for the Synthesis of 3-(2-Hydroxyethyl)coumarins 3a–c,d′,e′. To a stirred suspension of NaH (0.8 g, 60% in oil, 20 mmol) in dry THF (50 mL) at room temperature

(10) Attempts to isolate each of pure **32d** and **33d** from the mixture were unsuccessful.

(11) (a) Cava, M. P.; Wilkins, C. K., Jr.; Dalton, D. R.; Bessho, K. *J. Org. Chem.* **1965**, *30*, 3772. (b) Merten, R.; Müller, G. *Angew. Chem.* **1962**, *74*, 866.

(12) Woodward, R. B.; Hoffmann, R. *The Conversation of Orbital Symmetry*; Verlag: Weinheim, 1970; p 145.

(13) Minami, T.; Hirakawa, K.; Koyanagi, S.; Nakamura, S.; Yamaguchi, M. *J. Chem. Soc., Perkin Trans. 1* **1990**, 2385.

(14) Heacock, R. A.; Hey, D. H. *J. Chem. Soc.* **1954**, 2481.

was carefully added a solution of *o*-hydroxyxaryl aldehydes **2** or **7** (20 mmol) in dry THF (5 mL), and then the mixture was stirred at this temperature for 1 h. After the addition of α-diethylphosphono lactones **1a–c** (20 mmol) to the mixture, the reaction mixture was heated at reflux for 3 h with stirring, cooled to room temperature, treated with a saturated aqueous ammonium hydrochloride solution, and then extracted with ethyl acetate, followed by washing with water and drying over Na_2SO_4. After evaporation of the solvent, the resulting residue was chromatographed or recrystallized to give the coumarins **3**.

3a: yield 98%; mp 184.5–185.5 °C; IR (KBr) 3200, 1705, 1640, 1600 cm^{-1}; ^1H NMR (DMSO-d_6) δ 3.00–3.32 (m, 2 H, CH_2), 4.40 (t, J = 7.2 Hz, 2 H, CH_2O), 6.76–7.80 (m, 5 H, olefinic H, Ar*H*), 10.12 (s, 1 H, OH); HRMS m/z calcd for $C_{11}H_{10}O_3$ 190.0630, found 190.0620. Anal. Calcd for $C_{11}H_{10}O_3$: C, 69.46; H, 5.30. Found: C, 69.29; H, 5.29.

3b: yield 94%; mp 118–119 °C; IR (KBr) 3300, 1720, 1650, 1600 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.37 (d, J = 6.2 Hz, 3 H, CH_3), 2.25–3.35 (m, 2 H, CH_2), 4.40–5.00 (m, 1 H, methine H), 6.50–8.20 (m, 5 H, olefinic H, Ar*H*), 9.50–10.80 (br, 1 H, OH); MS m/z 204 (M^+). Anal. Calcd for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92. Found: C, 70.35; H, 5.92.

3c: yield 71%; mp 173.5–174.5 °C; IR (KBr) 3150, 1710, 1630, 1610 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.72 (s, 3 H, CH_3), 2.25–3.75 (m, 2 H, CH_2), 4.50–5.25 (m, 3 H, –C*H*(OH)–, C=CH_2), 6.50–8.00 (m, 5 H, ArC*H*=C, Ar*H*), 10.08 (s, 1 H, OH); MS m/z 230 (M^+). Anal. Calcd for $C_{14}H_{14}O_5$: C, 73.03; H, 6.13. Found: C, 72.65; H, 6.12.

3d′: yield 93%; oil; IR (neat) 3300, 1720, 1645, 1610 cm^{-1}; ^1H NMR δ 0.50–2.25 (m, 9 H, $(CH_2)_3CH_3$), 2.25–2.75 (br, 2 H, ArCH_2–), 2.75–3.12 (br t, 2 H, CH_2CH$_2$OH), 3.45 (s, 3 H, OCH_3), 4.35 (t, J = 7.3 Hz, 2 H, CH_2CH_2OH), 5.16 (s, 2 H, OCH_2O), 6.50 (s, 2 H, Ar*H*), 7.44 (s, 1 H, OH), 7.72 (t, J = 2.8 Hz, 1 H, ArC*H*=C); HRMS m/z calcd for $C_{18}H_{24}O_5$ 320.1624, found 320.1643. Anal. Calcd for $C_{18}H_{24}O_5$: C, 67.48; H, 7.55. Found: C, 67.59; H, 7.67.

3e′: yield 83%; oil; IR (neat) 3250, 1720, 1645, 1605 cm^{-1}; ^1H NMR δ 0.64–1.52 (m, 9 H, $(CH_2)_3CH_3$), 1.71 (s, 3 H, –C(CH_3)=CH_2), 2.20–3.16 (m, 4 H, ArCH_2, CH_2CH(OH)–), 3.45 (s, 3 H, OCH_3), 4.68–5.28 (m, 3 H, –C*H*(OH)–, C=CH_2), 5.16 (s, 2 H, OCH_2O), 6.50 (s, 2 H, Ar*H*), 7.00–7.52 (br, 1 H, OH), 7.74 (t, J = 2.7 Hz, 1 H, ArC*H*=C); HRMS m/z calcd for $C_{21}H_{28}O_5$ 360.1937, found 360.1895. Anal. Calcd for $C_{21}H_{28}O_5$: C, 69.98; H, 7.83. Found: C, 69.65; H, 7.87.

General Procedure for the Synthesis of 3-(2-Bromoethyl)coumarins 8a,d. To a stirred solution of triphenylphosphine dibromide (4.5 mmol) in acetonitrile (15 mL) was added a solution of **3a,d′** (3.0 mmol) in acetonitrile (5 mL), and the mixture was heated at reflux for 3 h. After the solvent was removed in vacuo, the residue was dissolved in $CHCl_3$ (30 mL), washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on preparative TLC (silica gel, ethyl acetate:hexane = 1:4) to give **8a,d**.

8a: yield 0.75 g (2.96 mmol), 98%); mp 99–99.5 °C; IR (KBr) 1705, 1630, 1610 cm^{-1}; ^1H NMR δ 3.10 (t, J = 6.2 Hz, 2 H, CH_2CH$_2$Br), 3.70 (t, J = 6.2 Hz, 2 H, CH$_2$CH_2Br), 6.50–7.75 (m, 5 H, ArC*H*=C, Ar*H*); MS m/z 252 (M^+).

8d: yield 0.74 g (2.18 mmol, 73%); mp 138.5–139.5 °C; IR (KBr) 3200, 1670, 1615 cm^{-1}; ^1H NMR δ 0.50–1.85 (br, 9 H, $(CH_2)_3CH_3$), 2.10–2.65 (br, 2 H, ArCH_2), 2.99 (dt, J = 2.7, 7.3 Hz, 2 H, CH_2CH$_2$Br), 4.32 (t, J = 7.3 Hz, 2 H, CH$_2$CH_2Br), 6.24 (s, 2 H, Ar*H*), 7.62 (t, J = 2.7 Hz, 1 H, ArC*H*=C), 9.22 (s, 1 H, OH); HRMS m/z calcd for $C_{16}H_{19}O_3Br$ 340.0498, found 340.0456. Anal. Calcd for $C_{16}H_{19}O_3Br$: C, 56.65; H, 5.65. Found: C, 56.87; H, 5.66.

Preparation of 3-(2-Bromoethyl)-5-(methoxymethoxy)-7-pentylcoumarin (8d′). To a stirred THF (15 mL) solution containing NaH (0.16 g, 60% in oil, 3.9 mmol) was carefully added a solution of **8d** (1.02 g, 3.0 mmol) in THF (5 mL) at room temperature, and then the mixture was stirred at this temperature for 1 h. After the addition of chloromethyl methyl ether (0.29 g, 3.3 mmol) to the mixture, the reaction mixture was stirred for 2 h. Then, the reaction mixture was treated with a saturated aqueous NH_4Cl solution, extracted with ethyl acetate, washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on silica gel (ethyl acetate:hexane = 1:7) to give **8d′**: yield 1.12 g (2.92 mmol, 97%); mp 58.5–59.5 °C; IR (KBr) 1715, 1615 cm^{-1}; ^1H NMR δ 0.60–1.08 (br, 3 H, CH_3), 1.08–1.88 (m, 6 H, CH_2), 2.65 (t, J = 7.9 Hz, 2 H, ArCH_2), 3.10 (t, J = 6.5 Hz, 2 H, CH_2CH$_2$Br), 3.52 (s, 3 H, CH_3O), 3.70 (t, J = 6.5 Hz, 2 H, CH$_2$CH_2Br), 5.30 (s, 2 h, OCH_2O), 6.79 (s, 2 H, Ar*H*), 7.92 (s, 1 H, ArC*H*=C); MS m/z 383 (M^+). Anal. Calcd for $C_{18}H_{23}O_4Br$: C, 56.41; H, 6.05. Found: C, 56.54; H, 5.93.

Synthesis of 3-(4-Bromo-3-methyl-2-butenyl)coumarin (9). The compound **9** was similarly synthesized from triphenylphosphine dibromide (2.51 mmol) and **3c** (0.48 g, 2.09 mmol) in acetonitrile (20 mL) as a 4:3 mixture of two geometric isomers: yield 0.21 g (0.72 mmol, 35%); mp 100–101.5 °C; IR (KBr) 1710, 1630, 1605 cm^{-1}; ^1H NMR δ 1.87 (d, J = 0.7 Hz, $^4/_7$ × 3 H, CH_3), 1.94 (d, J = 1.0 Hz, $^3/_7$ × 3 H, CH_3), 3.10–3.50 (br, 2 H, CH_2), 4.04 (s, $^4/_7$ × 2 H, CH_2Br), 4.06 (s, $^3/_7$ × 2 H, CH_2Br), 5.20–6.00 (m, 1 H, olefinic H), 6.80–7.70 (m, 5 H, Ar*H*, ArC*H*=C); MS m/z 293 (M^+).

General Procedure for the Synthesis of 3-[2-(2-Tetrahydropyranyloxy)ethyl]coumarins 10a,d′,e′. To a solution of **3** (20 mmol) in CH_2Cl_2 (20 mL) and DMF (7 mL) at room temperature was added 3,4-dihydro-2*H*-pyran (8.4 g, 0.1 mol) containing a trace amount of *p*-toluenesulfonic acid. After being stirred at this temperature for 12 h, water was added to the reaction mixture. The organic layer was extracted with CH_2Cl_2, washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on silica gel (ethyl acetate:hexane = 1:4) to give **10**.

10a: yield 4.0 g (14.6 mmol, 73%); mp 172–173 °C; IR (KBr) 1740, 1640, 1590 cm^{-1}; ^1H NMR δ 1.20–2.40 (br, 6 H, CH_2), 3.17 (dt, J = 2.9, 7.3 Hz, 2 H, allylic CH_2), 3.36–4.10 (br, 2 H, OCH_2), 4.40 (t, J = 7.3 Hz, 2 H, OCH_2), 5.17 (br s, 1 H, OCHO), 6.70–7.54 (m, 4 H, Ar*H*), 8.01 (t, J = 2.9 Hz, 1 H, ArC*H*=C); HRMS m/z calcd for $C_{16}H_{18}O_4$ 274.1205, found 274.1183. Anal. Calcd for $C_{16}H_{18}O_4$: C, 70.06; H, 6.61. Found: C, 69.99; H, 6.59.

10d′: yield 8.09 g (20 mmol, 100%); oil; R_f 0.47 (ethyl acetate:hexane = 1:4); IR (neat) 1750, 1660, 1600 cm^{-1}; ^1H NMR δ 0.60–2.20 (br, 15 H, CH_2, CH_3), 2.20–2.76 (br, 2 H, ArCH_2), 3.07 (dt, J = 2.8, 7.2 Hz, 2 H, allylic CH_2), 3.46 (s, 3 H, OCH_3), 3.55–4.00 (br, 2 H, OCH_2), 4.37 (t, J = 7.2 Hz, 2 H, OCH_2), 5.18 (s, 2 H, OCH_2O), 5.30–5.50 (br, 1 H, OCHO), 6.68 (s, 2 H, Ar*H*), 7.68 (t, J = 2.8 Hz, 1 H, ArC*H*=C); MS m/z 405 (M^+). Anal. Calcd for $C_{23}H_{32}O_6$: C, 68.29; H, 7.96. Found: C, 68.13; H, 8.06.

10e′: yield 8.90 g (19.2 mmol, 90%); oil; R_f 0.53 (ethyl acetate:hexane = 1:4); IR (neat) 1745, 1650, 1600, 1565 cm^{-1}; ^1H NMR δ 0.68–1.96 (m, 15 H, CH_2, CH_3), 1.74 (s, 3 H, C(*Me*)=CH_2), 2.36–3.06 (m, 4 H, ArCH_2, allylic CH_2), 3.46 (s, 3 H, OCH_3), 3.52–4.08 (br m, 2 H, OCH_2), 4.68–5.20 (m, 3 H, C*H*OTHP, C-(Me)=CH_2), 5.17 (s, 2 H, OCH_2O), 5.42 (br, 1 H, OCHO), 6.66 (s, 2 H, Ar*H*), 7.68 (t, J = 2.7 Hz, 1 H, ArC*H*=C); MS m/z 445 (M^+). Anal. Calcd for $C_{26}H_{36}O_6$: C, 70.24; H, 8.16. Found: C, 70.07; H, 8.19.

General Procedure for the Synthesis of 3-(2-Hydroxyethyl)-2,2-dimethylbenzo[*b*]pyrans [3-(2-Hydroxyethyl)-2,2-dimethylchromenes] 11a,d′,e′. To a solution of **10** (5.0 mmol) in benzene (30 mL) was added dropwise methyllithium (8.9 mL of a 1.15 M solution, 10.0 mmol). The mixture was stirred at room temperature for 12 h then poured into saturated aqueous ammonium chloride. The organic layer was extracted with ethyl acetate, washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was dissolved in benzene (30 mL) containing a small amount of *p*-toluenesulfonic acid, stirred at room temperature or at reflux for 2 h, and then poured into water. After similar workup, the residue was chromatographed on silica gel to give **11a,d′,e′**.

11a: yield 0.85 g (4.16 mmol, 83%); mp 116–116.5 °C; IR (KBr) 3200, 1600, 1580, 1500 cm^{-1}; ^1H NMR δ 1.44 (s, 6 H, C(CH_3)$_2$, 2.82 (dt, J = 2.5, 6.9 Hz, 2 H, allylic CH_2), 3.95 (t, J = 6.9 Hz, 2 H, OCH_2), 5.93 (s, 1 H, OH), 6.46 (t, J = 2.5 Hz, 1 H, ArC*H*=C), 6.55–7.35 (m, 4 H, Ar*H*); HRMS m/z calcd for $C_{13}H_{16}O_2$ 204.1150 (M^+), found 204.1174. Anal. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90. Found: C, 76.27; H, 7.94.

11d′: yield 1.39 g (4.34 mmol, 87%); yellow oil; R_f 0.37 (ethyl acetate:$CHCl_3$ = 1:10); IR (neat) 3300, 1610, 1560 cm^{-1}; ^1H NMR δ 0.60–1.00 (br, 3 H, CH_3), 1.00–1.80 (br, 12 H, CH_2, C(CH_3)$_2$), 2.00–2.80 (m, 5 H, ArCH_2, allylic CH_2, OH), 3.47 (s, 3 H, OCH_3), 3.82 (t, J = 6.9 Hz, 2 H, CH_2OH), 5.14 (s, 2 H, OCH_2O), 6.20–6.50

(m, 3 H, ArH, ArCH=C); HRMS m/z calcd for $C_{20}H_{30}O_4$ 334.2144 (M^+), found 334.2112. Anal. Calcd for $C_{20}H_{30}O_4$: C, 71.82; H, 9.04. Found: C, 71.83; H, 9.19.

11e': yield 0.99 g (2.65 mmol, 53%); oil; R_f 0.42 (ethyl acetate:hexane = 1:4); IR (neat) 3400, 1610, 1570 cm^{-1}; ^1H NMR δ 0.68–1.00 (br, 3 H, $(CH_2)_3CH_3$), 1.12–1.60 (br, 6 H, $(CH_2)_3CH_3$),, 1.43 (s, 6 H, $C(CH_3)_2$), 1.79 (s, 3 H, $C(CH_3)=CH_2$), 1.96–2.14 (br, 1 H, OH), 2.20–2.64 (br, 4 H, $ArCH_2$, allylic CH_2), 3.48 (s, 3 H, OCH_3), 4.12–4.44 (br, 1 H, CHOH), 4.76–4.92 (br, 1 H, olefinic H), 4.96–5.08 (br, 1 H, olefinic H), 5.15 (s, 2 H, OCH_2O), 6.20–6.62 (m, 3 H, ArH, ArCH=C); HRMS m/z calcd for $C_{23}H_{34}O_4$ 374.2457 (M^+), found 374.2422.

General Procedure for the Synthesis of 3-(2-Bromoethyl)-2,2-dimethylbenzo[*b*]pyrans [3-(2-Bromoethyl)-2,2-dimethylchromenes] 12a,d,e. Bromination of **11a,d',e'** with triphenylphosphine dibromide in acetonitrile was carried out in a similar manner to that for **8**. After similar workup, the residue was chromatographed on silica gel to give **12a,d,e**.

12a: yield 60%; oil; R_f 0.5 ($CHCl_3$:hexane = 1:2); IR (neat) 1600, 1570 cm^{-1}; ^1H NMR δ 1.39 (s, 6 H, $C(CH_3)_2$), 2.62 (t, J = 7.2 Hz, 2 H, CH_2CH_2Br), 3.51 (t, J = 7.2 Hz, 2 H, CH_2CH_2Br), 6.10 (s, 1 H, ArCH=C), 6.80–7.30 (m, 4 H, ArH); HRMS m/z calcd for $C_{13}H_{15}OBr$ 266.0306 (M^+), found 266.0280.

12d: yield 42%; oil; R_f 0.31 (ethyl acetate:hexane = 1:10); IR (neat) 3350, 1620, 1580 cm^{-1}; ^1H NMR δ 0.60–1.00 (br, 3 H, $(CH_2)_3CH_3$), 1.00–1.80 (br, 12 H, $(CH_2)_3CH_3$, $C(CH_3)_2$), 2.10–2.80 (m, 4 H, $ArCH_2$, CH_2CH_2Br), 3.50 (t, J = 7.9 Hz, 2 H, CH_2CH_2Br), 5.23 (brs, 1 H, OH), 6.13 (s, 1 H, ArH), 6.26 (s, 1 H, ArH), 6.40 (s, 1 H, ArCH=C); MS m/z 353 (M^+).

12e: yield 84%; oil; R_f 0.37 (ethyl acetate:hexane = 1:7); IR (neat) 3300, 1610, 1570 cm^{-1}; ^1H NMR δ 0.68–1.72 (m, 9 H, $(CH_2)_3CH_3$), 1.42 (s, 6 H, $C(CH_3)_2$), 1.91 (s, 3 H, $C(CH_3)=CH_2$), 2.20–2.96 (br, 4 H, $ArCH_2$, allylic CH_2), 3.88–4.12 (br, 1 H, CHBr), 4.60–5.20 (m, 3 H, $C(CH_3)=CH_2$, OH), 6.08–6.52 (m, 3 H, ArH, ArCH=C); HRMS m/z calcd for $C_{21}H_{28}O_2Br$ 393.1253 (M^+), found 393.1272.

Synthesis of 3-Vinylcoumarin (13a). To a stirred solution of **8a** (2.53 g, 10 mmol) and DBU (1.52 g, 10 mmol) in $CHCl_3$ (30 mL) was added a solution of sodium iodide (1.50 g, 10 mmol) in DMF (20 mL). After the mixture was heated at reflux for 2 h, a saturated aqueous NH_4Cl solution was added to the reaction mixture. The mixture was extracted with $CHCl_3$, washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on silica gel with ethyl acetate–hexane (1:8) as eluate to give **13a** (1.01 g, 5.87 mmol, 59%) and the dimerization product (0.48 g, 1.4 mmol, 28%) of **13a**. The product **13a** had the following properties: mp 80–81.5 °C; IR (KBr) 1715, 1620, 1600 cm^{-1}; ^1H NMR δ 5.47 (dd, J = 1.9, 10.7 Hz, 1 H, vinylic H), 6.14 (dd, J = 1.9, 17.6 Hz, 1 H, vinylic H), 6.76 (ddd, J = 0.6, 10.7, 17.6 Hz, 1 H, vinylic H), 6.80–7.70 (m, 5 H, ArH, ArCH=C); HRMS m/z calcd for $C_{11}H_8O_2$ 172.0524 (M^+), found 172.0514. Anal. Calcd for $C_{11}H_8O_2$: C, 76.73; H, 4.68. Found: C, 76.53; H, 4.96.

The dimerization product of **13a** had the following properties: mp 157–159 °C; IR (KBr) 1710, 1605 cm^{-1}; ^1H NMR δ 1.40–2.68 (m, 4 H, CH_2), 3.28–3.84 (m, 1 H, CH–), 4.00–4.44 (br, 1 H, CH–), 6.72–7.76 (m, 10 H, olefinic H, ArH, ArCH=C); HRMS m/z calcd for $C_{22}H_{16}O_2$ 344.1049 (M^+), found 344.1023.

General Procedure for the Synthesis of 3,4-Fused Coumarins 20–28 from 8 and Dienophiles 14–19. A mixture of **8** (2.0 mmol), a dienophile (20 mmol), 2,6-di-*tert*-butyl-4-methylphenol (BHT stabilizer, 25 mg), and DBU (0.30 g, 2.0 mmol) in DMF (30 mL) was heated at 80–100 °C for 4–12 h in a sealed tube. After a saturated aqueous NH_4Cl solution was added to the reaction mixture, the mixture was extracted with $CHCl_3$, washed with water, and dried over Na_2SO_4. After evaporation of the solvent, the residue was chromatographed on preparative TLC (silica gel) to give Diels–Alder adducts, 3,4-fused coumarins. The yields of the adducts are summarized in Table I.

10-(Methoxycarbonyl)-7,8,9,10-tetrahydrodibenzo-α-pyrone (20): mp 105–106 °C; IR (KBr) 1720–1710, 1620, 1600 cm^{-1}; ^1H NMR δ 1.40–2.84 (br, 6 H, CH_2), 3.70 (s, 3 H, CO_2CH_3), 3.80–4.20 (br, 1 H, $CHCO_2CH_3$), 6.80–7.74 (m, 4 H, ArH); ^{13}C NMR δ 18.0, 24.1, 26.0, 41.0, 52.7, 117.0, 119.7, 122.9, 124.3, 125.7, 130.4, 142.9, 152.0, 161.5, 173.0; HRMS m/z calcd for $C_{15}H_{14}O_4$ 258.0892 (M^+), found 258.0892. Anal. Calcd for $C_{15}H_{14}O_4$: C, 69.76; H, 5.46. Found: C, 69.98; H, 5.52.

10-(Ethoxycarbonyl)-7,8,9,10-tetrahydrodibenzo-α-pyrone (21): mp 118–119 °C; IR (KBr) 1720–1710, 1625, 1605 cm^{-1}; ^1H NMR δ 1.22 (t, J = 7.1 Hz, 3 H, CH_3), 1.60–3.00 (br, 6 H, CH_2), 3.80–4.20 (br, 1 H, $CHCO_2C_2H_5$), 4.20 (q, J = 7.1 Hz, 2 H, OCH_2CH_3), 6.80–7.70 (m, 4 H, ArH); HRMS m/z calcd for $C_{16}H_{16}O_4$ 272.1049 (M^+), found 272.1050. Anal. Calcd for $C_{16}H_{16}O_4$: C, 70.58; H, 5.92. Found: C, 70.58; H, 5.98.

10-(Ethoxycarbonyl)-10-methyl-7,8,9,10-tetrahydrodibenzo-α-pyrone (22): mp 87–87.5 °C; IR (KBr) 1720–1710, 1620, 1605 cm^{-1}; ^1H NMR δ 1.07 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.69 (s, 3 H, CH_3), 1.76–2.80 (br, 6 H, CH_2), 4.12 (q, J = 7.1 Hz, 2 H, $CO_2CH_2CH_3$), 6.80–8.00 (m, 4 H, ArH); HRMS m/z calcd for $C_{17}H_{18}O_4$ 286.1205 (M^+), found 286.1198. Anal. Calcd for $C_{17}H_{18}O_4$: C, 71.31; H, 6.34. Found: C, 71.25; H, 6.33.

10-Acetyl-7,8,9,10-tetrahydrodibenzo-α-pyrone (23): mp 106–107.5 °C; IR (KBr) 1715, 1620, 1605 cm^{-1}; ^1H NMR δ 1.60–2.80 (m, 6 H, CH_2), 2.33 (s, 3 H, $COCH_3$), 3.80–4.30 (br, 1 H, CH-CO), 6.80–7.80 (m, 4 H, ArH); HRMS m/z calcd for $C_{15}H_{14}O_3$ 242.0932 (M^+), found 242.0943. Anal. Calcd for $C_{15}H_{14}O_3$: C, 74.36; H, 5.82. Found: C, 74.26; H, 5.84.

9,10-Bis(ethoxycarbonyl)-7,8,9,10-tetrahydrodibenzo-α-pyrone (24): oil; R_f 0.55 ($CHCl_3$); IR (neat) 1725–1710, 1620, 1600 cm^{-1}; ^1H NMR δ 1.22 (t, J = 7.0 Hz, 6 H, $CO_2CH_2CH_3$), 1.88–3.44 (m, 5 H, CH_2, $CHCO_2$), 3.84–4.58 (m, 5 H, $CHCO_2$, $CO_2CH_2CH_3$), 7.00–7.64 (m, 4 H, ArH); HRMS m/z calcd for $C_{19}H_{20}O_6$ 344.1259 (M^+), found 344.1283. Anal. Calcd for $C_{19}H_{20}O_6$: C, 66.27; H, 5.85. Found: C, 66.04; H, 5.96.

1-Hydroxy-10-(methoxycarbonyl)-3-pentyl-7,8,9,10-tetrahydrodibenzo-α-pyrone (25): oil; R_f 0.37 (ethyl acetate:hexane = 1:3); IR (neat) 3300, 1730–1720, 1625 cm^{-1}; ^1H NMR δ 0.60–1.04 (br, 3 H, $(CH_2)_3CH_3$), 1.04–1.84 (br, 6 H, $(CH_2)_3CH_3$), 1.84–2.40 (m, 4 H, CH_2), 2.40–2.96 (br, 4 H, $ArCH_2$, $=CCH_2-$), 3.44–3.80 (br, 1 H, $CHCO_2$), 3.64 (s, 3 H, CO_2CH_3) 6.52–6.88 (br, 1 H, OH), 6.76 (d, J = 1.2 Hz, 1 H, ArH), 6.89 (d, J = 1.2 Hz, 1 H, ArH); MS m/z 344 (M^+). Anal. Calcd for $C_{20}H_{24}O_5$: C, 69.75; H, 7.02. Found: C, 69.48; H, 6.62.

9,10-Bis(ethoxycarbonyl)-1-hydroxy-3-pentyl-7,8,9,10-tetrahydrodibenzo-α-pyrone (26): mp 162–163 °C; IR (KBr) 3300, 1760, 1705, 1620 cm^{-1}; ^1H NMR δ 0.60–2.00 (m, 15 H, $(CH_2)_3CH_3$, $CO_2CH_2CH_3$), 2.20–3.40 (br, 6 H, CH_2, $ArCH_2$), 3.40–4.50 (m, 6 H, $CHCO_2$, $CO_2CH_2CH_3$), 6.20–6.80 (br, 2 H, ArH), 7.00–7.20 (br, 1 H, OH); HRMS m/z calcd for $C_{24}H_{30}O_7$ 430.1991 (M^+), found 430.2020. Anal. Calcd for $C_{24}H_{30}O_7$: C, 66.96; H, 7.02. Found: C, 66.72; H, 7.11.

10-(Methoxycarbonyl)-1-(methoxymethoxy)-3-pentyl-7,8,9,10-tetrahydrodibenzo-α-pyrone (27): mp 95–96 °C; IR (KBr) 1730, 1715, 1610 cm^{-1}; ^1H NMR δ 0.64–2.76 (m, 17 H, pentyl H, CH_2), 3.48 (s, 3 H, OCH_3), 3.69 (s, 3 H, CO_2CH_3), 4.20–4.60 (br, 1 H, $CHCO_2$), 5.15 (s, 2 H, OCH_2O), 6.82 (s, 2 H, ArH); HRMS, m/z calcd for $C_{22}H_{28}O_6$ 388.1886 (M^+), found 388.1842. Anal. Calcd for $C_{22}H_{28}O_6$: C, 68.02; H, 7.27. Found: C, 68.01; H, 7.35.

9,10-Bis(ethoxycarbonyl)-9,10-diaza-7,8,9,10-tetrahydrodibenzo-α-pyrone (28): mp 113.5–114.5 °C; IR (KBr) 1750, 1720, 1620 cm^{-1}; ^1H NMR δ 1.24 (t, J = 7.1 Hz, 3 H, CH_3), 1.27 (t, J = 7.0 Hz, 3 H, CH_3), 2.50–3.80 (m, 4 H, CH_2), 3.80–4.60 (m, 4 H, $CO_2CH_2CH_3$), 7.00–7.80 (m, 4 H, ArH); HRMS m/z calcd for $C_{17}H_{18}N_2O_6$ 346.1217 (M^+), found 346.1191. Anal. Calcd for $C_{17}H_{18}N_2O_6$: C, 58.96; H, 5.24; N, 8.09. Found: C, 58.77; H, 5.36; N, 7.97.

General Procedure for the Synthesis of 3,4-Fused Chromenes 32–34 from 12 and Dienophiles 14, 19. A mixture of **12** (3.0 mmol), a dienophile (30 mmol), BHT (25 mg), and DBU (1.37 g, 3.0 mmol) in DMF (30 mL) was heated at 100 °C for 3 h. After similar workup, the residue was chromatographed on preparative TLC (silica gel) to give Diels–Alder adducts **32–34**. The yields of the adducts are summarized in Table I.

6,6-Dimethyl-10-(methoxycarbonyl)-7,8,9,10-tetrahydrodibenzopyran (32a): yield 68%; oil; R_f 0.40 (benzene); IR (neat) 1725, 1600, 1585 cm^{-1}; HRMS m/z calcd for $C_{17}H_{20}O_3$ 272.1412 (M^+), found 272.1441. Anal. Calcd for $C_{17}H_{20}O_3$: C, 74.97; H, 7.40. Found: C, 74.57; H, 7.40.

6,6-Dimethyl-10-(methoxycarbonyl)-8,9,10,10a-tetrahydrodibenzopyran (33a): yield 15%; oil; R_f 0.46 (benzene); IR (neat) 1730, 1600, 1585 cm^{-1}. Anal. Calcd for $C_{17}H_{20}O_3$: C, 74.97; H, 7.40. Found: C, 74.61; H, 7.60.

1-Hydroxy-6,6-dimethyl-10-(methoxycarbonyl)-7,8,9,10-tetrahydro- and -8,9,10,10a-tetrahydrodibenzopyrans (Methyl 11-Nor-$\Delta^{6a,10a}$- and -$\Delta^{6a,7}$-tetrahydrocannabinol-10-carboxylates) (32d and 33d): oil; IR (neat) 1730, 1625, 1585 cm^{-1}; ^1H NMR δ 0.60–1.06 (br t, 3 H, CH_3), 1.06–2.84 (br, 14–15 H, CH_2, CH–), 1.51 (s, 6 H, $C(CH_3)_2$), 3.61 (s, 3 × $^4/_5$ H, OCH_3 in **32d**), 3.67 (s, 3 × $^1/_5$ H, OCH_3 in **33d**), 3.40–3.76 (br, 1 H, CHCO), 5.68–5.96 (br, $^1/_5$ H, C=CH–), 6.20–6.50 (br, 2 H, Ar*H*), 7.16–7.34 (br, 1 H, OH); MS *m/z* 359 (M^+). Anal. Calcd for $C_{22}H_{30}O_4$: C, 73.71; H, 8.43. Found (for a mixture of **32d** and **33d**): C, 73.64; H, 8.77.

9,10-Bis(ethoxycarbonyl)-6,6-dimethyl-9,10-diaza-$\Delta^{6a,10a}$-tetrahydrodibenzopyran (34): mp 98.5–99 °C; IR (KBr) 1740, 1710, 1605, 1580 cm^{-1}; ^1H NMR δ 0.80–1.70 (m, 12 H, CH_3), 3.50–4.70 (br, 6 H, NCH_2, OCH_2), 5.60–6.00 (br, 2 H, CHN, olefinic H), 7.00–7.80 (m, 4 H, Ar*H*); HRMS *m/z* calcd for $C_{19}H_{24}N_2O_5$ 360.1718 (M^+), found 360.1686. Anal. Calcd for $C_{19}H_{24}N_2O_5$: C, 63.32; H, 6.71; N, 7.77. Found: C, 63.45; H, 6.88; N, 7.60.

Synthesis of 10-(Ethoxycarbonyl)-6,6-dimethyl-10-aza-$\Delta^{6a,7}$-tetrahydrodibenzopyran (36). The Diels–Alder reaction of **31a** (0.45 g, 2.42 mmol) with methyleneurethane,[11] generated in situ from methylenebisurethane (0.72 g, 3.63 mmol) and boron trifluoride etherate (0.37 g, 2.42 mmol), was carried out in benzene at reflux for 12 h. The reaction mixture was cooled to room temperature. The organic layer was washed with a saturated aqueous sodium bicarbonate solution, washed with water, dried over Na_2SO_4, and evaporated. The residue was chromatographed on preparative TLC (silica gel) to give **36**: yield 0.32 g (1.12 mmol, 46%); mp 94–95 °C; IR (KBr) 1695, 1665 cm^{-1}; ^1H NMR δ 1.25 (t, J = 7.0 Hz, 3 H, $CO_2CH_2CH_3$), 1.52 (s, 6 H, $C(CH_3)_2$), 1.76–2.92 (br, 4 H, CH_2), 4.26 (q, J = 7.0 Hz, 2 H, $CO_2CH_2CH_3$), 5.42–5.92 (br, 2 H, CHN–, olefinic *H*), 6.56–7.30 (m, 4 H, Ar*H*); HRMS *m/z* calcd for $C_{17}H_{21}O_3N$ 287.1521 (M^+), found 287.1483. Anal. Calcd for $C_{17}H_{21}O_3N$: C, 71.06; H, 7.37; N, 4.87. Found: C, 70.80; H, 7.28; N, 4.84.

Aromatization of 20. A solution of **20** (87 mg, 0.34 mmol) in diphenyl ether (20 mL) containing palladium on carbon (5%, 600 mg) was heated at 250 °C for 18 h. After the solution was cooled to room temperature, the precipitate was filtered. The filtrate was chromatographed on silica gel ($CHCl_3$) to give **29** (12 mg, 0.047 mmol, 14%) and **30** (20 mg, 0.1 mmol, 31%). The compound **29** had the following properties: mp 118.5–120 °C; IR (KBr) 1725, 1605, 1590 cm^{-1}; ^1H NMR δ 3.99 (s, 3 H, CH_3), 7.00–7.75 (m, 5 H, Ar*H*), 7.90 (dd, J = 1.9, 7.6 Hz, 1 H), 8.54 (dd, J = 1.8, 7.5 Hz, 1 H); HRMS *m/z* calcd for $C_{15}H_{10}O_4$ 254.0579 (M^+), found 254.0580. Anal. Calcd for $C_{15}H_{10}O_4$: C, 70.86; H, 3.96. Found: C, 70.48; H, 4.08. The compound **30** had the following properties: mp 89.5–91.5 °C (lit.[14] 92.5 °C); IR (KBr) 1725, 1600 cm^{-1}; ^1H NMR δ 7.00–8.50 (m, 8 H, Ar*H*); MS *m/z* 196 (M^+).

Aromatization of 32a and 33a. Aromatization of the mixture of **32a** and **33a** (0.15 g, 0.55 mmol) was similarly carried out using Pd on carbon (1.0 g) to give **37** (0.12 g, 0.45 mmol, 81%): oil; R_f 0.45 ($CHCl_3$); IR (neat) 1720, 1600, 1590 cm^{-1}; ^1H NMR δ 1.57 (s, 6 H, $C(CH_3)_2$), 3.80 (s, 3 H, CO_2CH_3), 6.72–7.58 (m, 7 H, Ar*H*); HRMS *m/z* calcd for $C_{17}H_{16}O_3$ 268.1099 (M^+), found 268.1084. Anal. Calcd for $C_{17}H_{16}O_3$: C, 76.10; H, 6.01. Found: C, 76.00; H, 6.36.

Aromatization of 32d and 33d. A similar treatment of the mixture of **32d** and **33d** (0.18 g, 0.5 mmol) with Pd on carbon (0.89 g) gave 4,4-dimethyl-7-pentyl-10-oxo-5,9-dioxapyrene (**38**): yield 0.12 g (0.37 mmol, 74%); oil; R_f 0.66 ($CHCl_3$); IR (neat) 1740, 1630 cm^{-1}; ^1H NMR δ 0.60–1.00 (br, 3 H, CH_3), 1.00–1.54 (m, 6 H, CH_2), 1.73 (s, 6 H, $C(CH_3)_2$), 2.30–2.80 (br, 2 H, $ArCH_2$), 6.60 (d, J = 1.2 Hz, 1 H, Ar*H*), 6.71 (d, J = 1.2 Hz, 1 H, Ar*H*), 7.14–7.60 (m, 2 H, Ar*H*), 7.88–8.24 (m, 1 H, Ar*H*); HRMS *m/z* calcd for $C_{21}H_{22}O_3$ 322.1569 (M^+), found 322.1527. Anal. Calcd for $C_{21}H_{22}O_3$: C, 78.23; H, 6.88. Found: C, 78.18; H, 7.12.

Synthesis of 3-(3-Methyl-1,3-butadienyl)-2,2-dimethyl-5-hydroxy-7-pentylbenzo[*b*]pyran (31e). The reaction was carried out in benzene (20 mL) at reflux for 2 h as described above using **12e** (0.63 g, 1.6 mmol), DBU (0.72 g, 4.8 mmol), and BHT (25 mg). After similar workup, the residue was chromatographed on TLC (silica gel, ethyl acetate:hexane = 1:7) to give **31e** (0.41 g, 1.3 mmol, 81%): oil; R_f 0.43 (ethyl acetate:hexane = 1:7); IR (neat) 3350, 1620 cm^{-1}; ^1H NMR δ 0.64–1.00 (br, 3 H, CH_3), 1.04–1.76 (m, 6 H, CH_2), 1.49 (s, 6 H, $C(CH_3)_2$), 1.89 (s, 3 H, $CH_2=C(CH_3)$–), 2.08–2.60 (br, 2 H, $ArCH_2$), 5.03 (br s, 2 H, $CH_2=C(CH_3)$–), 5.39 (br s, 1 H, OH), 5.88–6.38 (m, 3 H, Ar*H*, $ArCH=C$), 6.38–6.96 (m, 2 H, –CH=CH–); HRMS *m/z* calcd for $C_{21}H_{28}O_2$ 312.2089 (M^+), found 312.2045.

Acknowledgment. We are grateful for financial support of this work by a Grant-in-Aid for Scientific Research (01550654) and by a Grant-in-Aid for Scientific Research on Priority Areas from the Japan Ministry of Education, Science and Culture.

Registry No. **1a**, 2907-85-9; **1b**, 86725-67-9; **1c**, 131165-55-4; **2**, 90-02-8; **3a**, 20972-50-3; **3b**, 137059-99-5; **3c**, 137122-23-7; **3d'**, 137060-00-5; **3e'**, 137060-01-6; **4**, 500-66-3; **5**, 94450-80-3; **6**, 137059-80-4; **7**, 137059-81-5; **8a**, 20972-54-7; **8d**, 137060-02-7; **8d'**, 137060-03-8; (*E*)-**9**, 137059-82-6; (*Z*)-**9**, 137060-10-7; **10a**, 137059-83-7; **10d'**, 137091-81-7; **10e'**, 137060-04-9; **11a**, 137059-84-8; **11d'**, 137060-05-0; **11e'**, 137060-06-1; **12a**, 137059-85-9; **12d**, 137060-07-2; **12e**, 137091-82-8; **13a**, 99851-57-7; **13a** (dimer), 137091-83-9; **13d**, 137060-12-9; **13d'**, 137060-13-0; **14**, 96-33-3; **15**, 140-88-5; **16**, 97-63-2; **17**, 78-94-4; **18**, 141-05-9; **19**, 1972-28-7; **20**, 137059-86-0; **21**, 137059-87-1; **22**, 137059-88-2; **23**, 137059-89-3; **24**, 137059-90-6; **25**, 137059-91-7; **26**, 137059-92-8; **27**, 137059-93-9; **28**, 137059-94-0; **29**, 42523-40-0; **30**, 2005-10-9; **31a**, 137060-14-1; **31d**, 137060-15-2; **31e**, 137059-95-1; **32a**, 137059-96-2; **32d**, 137060-08-3; **33a**, 137091-78-2; **33d**, 137060-09-4; **34**, 137091-79-3; **35**, 34627-38-8; **36**, 137091-80-6; **37**, 137059-97-3; **38**, 137059-98-4; $C=(NCO_2Et)_2$, 137060-11-8.

Supplementary Material Available: ^1H NMR spectra of all compounds for which elemental analyses could not be obtained (7 pages). Ordering information is available on any current masthead page.