Syntheses of Decadiendiyndials and Tetradecatetraendiyndials and Intramolecular Cyclization of Former Dialdehydes

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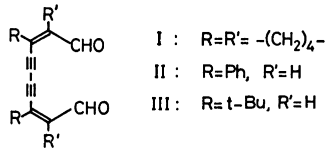
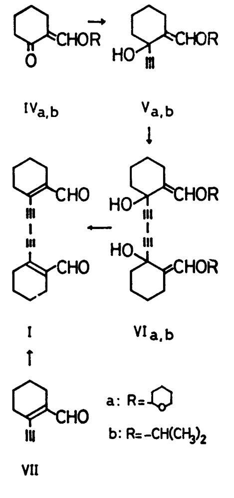
Substituted 2,8-decadien-4,6-diyndials (I, II and III) were synthesized by the oxidative coupling of corresponding substituted pentenynals (VII and XIII) or acetal (XI). It was found that decadiendiyndials (I, II and III) give readily dihydrofuranylidene derivatives (X, XIV and XXV) by the addition of methanol followed by intramolecular cyclization. Thermal reaction of dialdehyde (I, II, and III) afforded difuranylacetylene derivatives (IX, XXI and XXII). 5-Phenyl-2,4-heptadien-6-ynal (XXXII) was prepared from 3-phenyl-2-penten-4-ynal (VIII) or its acetal (XI) by a modified Wittig reaction or by the condensation of ethyl vinyl ether. Oxidative Coupling of XXXII or 5-*t*-butyl-2,4-heptadien-6-ynal afforded 5,10-diphenyl-(XXIX) or 5,10-di-*t*-butyl-2,4,10,12-tetradecatetraen-6,8-diyndial (XXX) which showed no tendency for intramolecular cyclization.

During the course of studies on the syntheses of dehydroannulenes, we have investigated the syntheses of substituted decadiendiyndials (I, II and III) and tetradecatetraendiyndials (XXIX and XXX) which seemed to be potential precursors of dehydroannulenes.

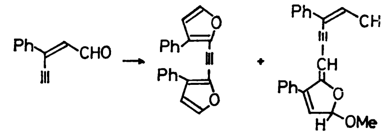


It was found that the dialdehydes (I, II and III) give readily difuranylacetylene derivatives (IX, XXI and XXII) by thermal reaction and dihydrofuranylidene derivatives (X, XIV and XXV) by nucleophilic addition of methanol followed by intramolecular cyclization.

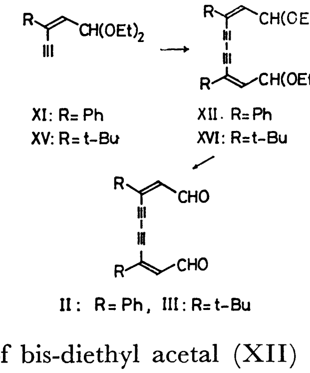
Synthesis. Bis-tetramethylene derivative (I) could be obtained by the reaction sequence outlined in Scheme 1. Acetylenic alcohol (V) obtained by ethynylation of 2-alkoxymethylenecyclohexanone (IV)[1] was treated with cupric acetate in pyridine[2] (the Eglinton's method) to yield hexadiyndiol (VI). Hydrolysis of VI afforded dialdehyde (I). I was also prepared by the Eglinton's oxidative coupling of 1-ethynyl-2-formylcyclohexene[1] (VII) in the presence or absence of methanol. However, the oxidative coupling of 3-phenyl-2-penten-4-ynal (VIII)[3] in the presence of methanol resulted in the formation of bis(3-phenyl-2-furanyl)acetylene (IX, 13%) and dihydrofuranylidene derivative (X, 41%). In the absence of methanol, IX was obtained in a yield of 30.5%. Phenylpentenynal (VIII) was converted into diethyl acetal (XI).



Scheme 1.



VIII IX X



Hydrolysis of bis-diethyl acetal (XII) obtained by the oxidative coupling of XI yielded extremely unstable dialdehyde (II) in a yield of 74%. Formation of appreciable amount of IX was observed when II was allowed to stand for 2 days at room temperature. The Eglinton's reaction of *t*-butylpentenynal (XIII)[4] in the absence of methanol at a low temperature (15—20 °C) afforded dialdehyde (III). However, the re-

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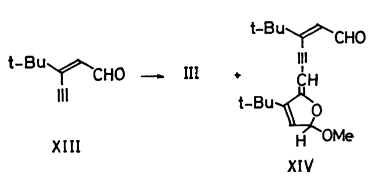
[1] a) W. S. Johnson and H. Posvic, *J. Amer. Chem. Soc.*, **69**, 1361 (1947); b) R. B. Woodward and W. H. McLamore, *ibid.*, **71**, 379 (1949); c) A. S. Dreiding and S. N. Nickel, *ibid.*, **76**, 3965 (1954); d) P. Schiess and H. L. Chia, *Helv. Chim. Acta*, **53**, 485 (1970); e) G. M. Pilling and F. Sondheimer, *J. Amer. Chem. Soc.*, **93**, 1970 (1971).

[2] G. Eglinton and A. R. Galbraith, *J. Chem. Soc.*, **1959**, 889.

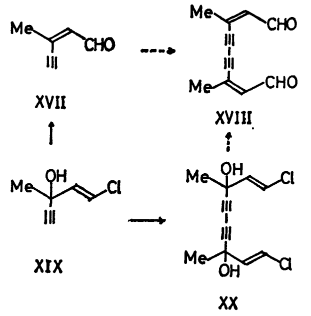
[3] K. Fukui, T. Okamoto, and M. Nakagawa, *Tetrahedron Lett.*, **1971**, 3121.

[4] T. Katakami, S. Tomita, K. Fukui, and M. Nakagawa, *Chem. Lett.*, **1972**, 225.



action performed in the presence of methanol gave a mixture of III and dihydrofuranylidene derivative (XIV). NMR spectroscopy revealed that the mixture consists of 50% of III and 10—15% of XIV. III could be obtained by the hydrolysis of bis-diethyl acetal (XVI) which was prepared by the oxidative coupling of diethyl acetal (XV).[5]

Dialdehyde (XVIII) could not be obtained by the Eglinton's reaction of methylpentenynal (XVII)[6] in the presence of methanol, but the UV spectrum of the product (λ_{max}^{EtOH} 247, 285, 357 nm) was found to be similar with that of X. Attempts to prepare XVIII from diacetylenic glycol (XX) obtained by the Glaser reaction of XIX[6] gave fruitless results owing to sluggish anionotropic rearrangement.



Thermal Cyclization of Dialdehydes (I, II and III). Formation of bis(2-furanyl)acetylene derivatives (IX, XXI and XXII) was observed on heating solutions of dialdehydes (II, III and I) in organic solvents. The results are summarized in Table 1. This results indicate that the formation of IX in the oxidative coupling of phenylpentenynal (VIII) is attributable to a secondary reaction of initially formed dialdehyde (II). The possibility of catalytic action of cupric acetate in pyridine for the cyclization reaction could be excluded by the experiments performed in benzene or ether containing cupric acetate and pyridine (see Experimental). Intramolecular cyclization of acetylenic compounds containing oxygen function has been well-known.[7] However, the formation of difuranylacetylene derivatives (IX, XXI and XXII) from II, III and I seems to be symmetry-allowed thermal process.

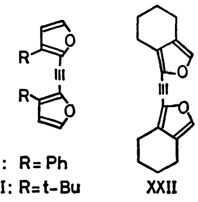


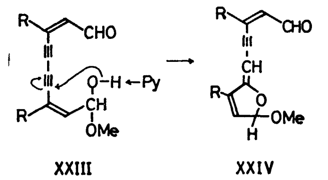
Table 1. Formation of difuranylacetylenes

Dialdehyde	Solvent	Temperature (°C)	Reaction period (hr)	Yield (%)
I	xylene	120	5	XXII 57
II	benzene	50	8	IX 86
III	benzene	60	20	XXI 82
III	pyridine	60	6.5	XXI 54[a]

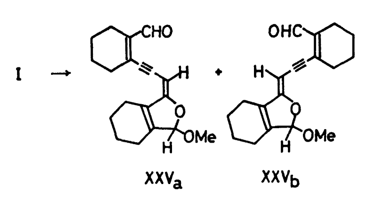
a) Low yield of XXI can be attributed to gradual decomposition of III in pyridine.

It is to be noted that the mass spectral patterns of II and III were found to be similar to those of IX and XXI indicating facile formation of difuranyl derivatives from II and III prior to the fragmentation.

Formation of Dihydrofuranylidene Derivatives (X, XIV and XXV). The formation of dihydrofuranylidene derivatives (X or XIV) by the Eglinton's oxidative coupling of pentenynals (VIII or XIII) in the presence of methanol can be regarded as a result of secondary reaction of initially formed dialdehydes (II or III), *i. e.*, addition of methanol to carbonyl carbon of dialdehyde forms hemiacetal (XXIII), and nucleophilic attack of oxygen atom of hemiacetal (XXIII) to acetylenic carbon atom gives rise to dihydrofuranylidene compound (XXIV). Because the cyclization reaction did not proceed without pyridine, it is evident that pyridine has a role of proton acceptor.



In the case of dialdehyde (I), no cyclization took place by pyridine–methanol. However, treatment of I in ether with sodium methoxide–methanol at 0 °C afforded dihydrofuranylidene derivative (XXV). Dihydrofuranylidene derivative (XXV) could be separated into *cis*-(XXVa) and *trans*-isomers (XXVb) on chromatography on silica gel.



It is to be noted that acetylenic compounds with analogous dihydrofuranylidene system (XXVIa, XXVIb and XXVII) have been found in naturally occurring poly-ynes.[8] An intramolecular cyclization of ketoalcohol (XXVIII) in biogenetic path way to form XXVII has been postulated by Bohlmann and Florenz.[9]

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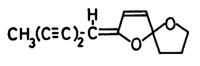
[5] M. Iyoda, H. Miyazaki, and M. Nakagawa, *Chem. Commun.*, **1972**, 431.

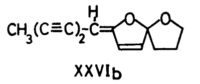
[6] I. Heilbrom, E. R. H. Jones, and M. Julia, *J. Chem. Soc.*, **1949**, 1430.

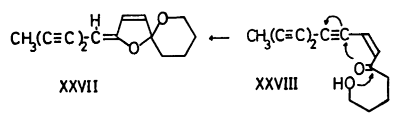
[7] *E. g.*, F. Toda and M. Nakagawa, This Bulletin, **32**, 514 (1959); **33**, 1287 (1960); W. Ried, *Angew. Chem.*, **70**, 273 (1958).

[8] F. Bohlmann, P. Herbst, C. Arndt, H. Schonowsky, and H. Gleinig, *Chem. Ber.*, **94**, 3193 (1961).

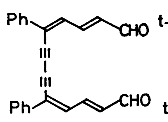
[9] F. Bohlmann and G. Florenz, *ibid.*, **99**, 990 (1966).

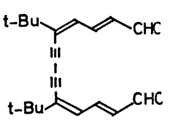

XXVIa


XXVIb

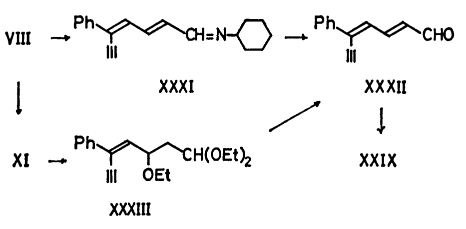

XXVII XXVIII

Syntheses of Tetradecatetraendiyndials (XXIX and XXX). Facile intramolecular cyclization observed in decadiendiyndials (I, II and III) can be attributed to the proximate position of oxygen atom of formyl group to acetylenic carbon atom favorable for the formation of stable five-membered ring which is caused by the *cis*-configuration of ethylenic linkage with respect to acetylene and formyl functions. We have prepared diphenyl- (XXIX) and di-*t*-butyltetradecatetraendiyndials (XXX). Expectedly intramolecular cyclization could not be observed in these dialdehydes (XXIX and XXX).


XXIX


XXX

Phenylheptadienynal (XXXII) was prepared by different two routes. Phenylpentenynal (VIII)[3] was treated with diethyl 2-(cyclohexylimino)ethylphosphonate carbanion[10] and the product (XXXI) was hydrolyzed to yield XXXII in a yield of 51%. Condensation of ethyl vinyl ether in the presence of borontrifluoride[11] with acetal (XI) derived from VIII afforded ethoxy acetal (XXXIII) which gave XXXII on treatment with hydrochloric acid in tetrahydrofuran. Oxidative coupling of XXXII by the Eglinton's method yielded XXIX in a high yield. Di-*t*-butyltetradecatetraendiyndial (XXX) was obtained similarly from 5-*t*-butyl-2,4-heptadien-6-ynal.[6] Quite recently the preparation of 4,5 : 10,11-bis(tetramethylene)-2,4,10,12-tetradecatetraen-6,8-diyndial, a vinylog of I, was reported by Yamamoto and Sondheimer.[12]



Experimental

All the melting points are not corrected. The UV and IR spectra were obtained on a Hitachi EPS-3T and a Hitachi EPI-2 spectrophotometers, respectively. Shoulder was indicated by an asterisk. The NMR and mass spectra were obtained on a Varian A-60 (internal standard, TMS) and a Hitachi RM-50 (ionization energy, 70 eV) spectrometers, respectively. Chemical shifts are recorded in τ-unit. Silica gel (Merck, Kieselgel 60) and alumina (Merck, act. II–III) were used in the chromatography.

2-Tetrahydropyranoxymethylenecyclohexanone (IVa). 2-Hydroxymethylenecyclohexanone (105.6 g, 0.84 mol) was added over 40-min period to freshly distilled pure 2,3-dihydropyran (84 g, 1.0 mol) containing few drops of phosphoryl chloride under stirring and cooling with running water. After being kept overnight at room temperature, the mixture was stirred for 3 hr at 30 °C and then mixed with ether (150 ml), washed successively with saturated sodium carbonate and sodium chloride solutions. IVa was obtained as a colorless liquid, bp 117—130 °C/6×10^{-4} mmHg, 43.5 g (24.7%), IR (neat): 1670, 1660*, 1590, 1195, 1110, 1075, 1035 cm^{-1}.

Found: C, 67.69; H, 8.58%. Calcd for $C_{12}H_{18}O_3$: C, 68.53; H, 8.63%.

1-Ethynyl-2-tetrahydropyranoxymethylenecyclohexanol (Va). To a suspension of lithium acetylide [from acetylene and lithiumamide (lithium 1.89 g, 0.275 g-atom)] in liquid ammonia (300 ml) was added over a period of 30 min a solution of IVa (52.5 g, 0.25 mol) in ether (100 ml). After the mixture had been stirred for 3.5 hr, the ammonia was allowed to evaporate. The residue was mixed with a saturated solution of ammonium chloride and extracted with ether. The extract was worked up by the usual way. Va was obtained as a viscous liquid, bp 142—144 °C/10^{-3} mmHg, 43.15 g (73.0%).

Found: C, 70.72; H, 8.57%. Calcd for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53%.

1-Ethynyl-2-isopropoxymethylenecyclohexanol (Vb). The reaction of 2-isopropoxymethylenecyclohexanone (IVb)[1] with lithium acetylide in liquid ammonia by the procedure used in Va afforded Vb in a yield of 60% as a colorless liquid, bp 76.1—77.0 °C/4×10^{-3} mmHg, n_D^{20} 1.4936.

Found: C, 73.50; H, 9.25%. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34%.

2-Ethynyl-1-cyclohexenecarboxaldehyde (VII). To a stirred solution of Va (20 g) in tetrahydrofuran (250 ml) was added 10% aqueous sulfuric acid (35 ml). After being kept at room temperature overnight, the reaction mixture was washed successively with saturated sodium chloride, 10% sodium carbonate and saturated sodium chloride solutions, and dried. Evaporation of the solvent under reduced pressure afforded faint brown crystals, 7.3 g (64%). Vacuum sublimation of the crystals yielded pure VII, mp 50—51 °C [lit. 52—53 °C[13]; 49.5—50 °C[1e]].

Found: C, 80.17; H, 7.51%. Calcd for $C_9H_{10}O$: C, 80.56; H, 7.51%.

Bis(2-formyl-1-cyclohexenyl)-1,3-butadiyne (I). *1) From Va*: A solution of Va (43.0 g, 0.182 mol) in pyridine (150 ml) was added to a mixture of cupric acetate monohydrate (120 g) and pyridine (900 ml). After being stirred overnight at room temperature, the mixture was stirred at 40 °C for 7 hr. Insoluble material was removed by filtration and washed thoroughly with ether. The combined filtrate and washings were concentrated under reduced pressure (bath temp. below 80 °C). The residue was dissolved in ether. After being washed 4 times with saturated sodium chloride solution and dried, the solvent was removed under reduced pressure to give crude VIa. Crude VIa was dis-

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10) W. Nagata and Y. Hayase, *J. Chem. Soc., C*, **1969**, 460.

11) R. Rüegg, M. Montavon, G. Ryser, G. Saucy, U. Schwiter, and O. Isler, *Helv. Chim. Acta*, **42**, 854 (1959).

12) K. Yamamoto and F. Sondheimer, *Angew. Chem.*, **85**, 41 (1973).

13) P. Schiess, H. L. Chia, and Chr. Seeter, *Tetrahedron Lett.*, **1968**, 5747.

solved in a mixture of sulfuric acid (10 ml), water (90 ml) and tetrahydrofuran (900 ml) and the mixture was allowed to stand at room temperature for 22 hr. After being stirred for 1.5 hr at 50 °C, the reaction mixture was worked up by the usual way. The oily residue (29.5 g) obtained by evaporating the solvent *in vacuo* was chilled in a dry ice-acetone bath to result in crystallization. The crystals were filtered and recrystallized from benzine to give pure I, pale yellow crystals, 5.4 g, mp 89.0—90.5 °C; UV: $\lambda_{\max}^{95\%\mathrm{EtOH}}$ (ε) 205.5 (22150), 231* (10050), 238.5 (13470), 258* (12300), 270 (14550), 290 (15900), 317 (15800), 334(16800), 358(12400) nm, IR (KBr-disk): 1670 (C=O), 1580 (C=C) cm^{-1}, NMR ($CDCl_3$): −0.12 (s, 2H, CHO), 7.62 (m, 8H, allylic CH_2), 8.32 (m, 8H, non-allylic CH_2), Mass (*m/e*): 266 (M$^+$), 239 (M–29).

Found: C, 80.91; H, 6.95%. Calcd for $C_{18}H_{18}O_2$: C, 81.17; H, 6.81%.

The mother liquors were chromatographed on alumina to yield second crop of I.

2) From VII. a) Oxidative Coupling in the Presence of Methanol: A solution of VII (200 mg, 1.49 mmol) in pyridine (2 ml) was added to a mixture of cupric acetate monohydrate (1.00 g, 5.01 mmol), pyridine (5 ml) and methanol (3 ml). After being stirred for 2 hr at 16 °C, the reaction mixture was poured onto 3 M hydrochloric acid (50 ml) and extracted with ether (20 ml × 3). The extract, after being washed and dried, was evaporated under reduced pressure. The crystals thus obtained was chromatographed on alumina. Elution with *n*-hexane-benzene (1 : 1) and benzene afforded pure I, 171 mg (86%).

b) Oxidative Coupling in the Absence of Methanol: To a mixture of cupric acetate monohydrate (1.00 g, 5.01 mmol) and pyridine (7 ml) was added a solution of VII (200 mg, 1.49 mmol) in ether (3 ml). After being stirred for 6 hr at 16 °C, the reaction mixture was worked up to give I, 183 mg (92%).

3-Phenyl-2-penten-4-ynal Diethyl Acetal (XI). A solution of *p*-toluenesulfonic acid monohydrate (0.385 g, 2.02 mmol) in ethanol (2 ml) was added to a mixture of VIII[3)] (3.852 g, 24.7 mmol) and ethyl orthoformate (13.25 g, 89.4 mmol). After being stirred for 24 hr at room temperature, the reaction mixture was chilled in an ice-bath and then poured onto ice-water containing sodium hydrogen carbonate, and extracted with ether. The extract, after being washed and dried (potassium carbonate), was concentrated under reduced pressure. The residue was distilled *in vacuo* to yield XI, 4.948 g (87%), bp 93—96 °C/0.005 mmHg, Mass (*m/e*): 230 (M$^+$), IR (CCl_4): 3321 (C≡CH), 2090 (–C≡C–), 1615 (C=C), 1000—1150 (C–O–C) cm^{-1}. NMR (CCl_4): 2.31—2.82 (m, 5H, phenyl), 3.62 (d, *J*=7.5 Hz, 1H, olefinic), 4.60 (d, *J*=7.5 Hz, 1H, acetal), 6.38 (q, *J*=7.0 Hz, 2H, CH_2), 6.42 (q, *J*=7.0 Hz, 2H, CH_2), 6.70 (s, 1H, C≡CH), 8.82 (t, *J*=7.0 Hz, 6H, CH_3).

Elemental analysis gave unsatisfactory result owing to extremely unstable nature of XI to hydrolysis.

3,8-Diphenyl-2,8-decadien-4,6-diyndial (II). To a solution of XI (327 mg, 1.42 mmol) in ether (3 ml) was added a mixture of cupric acetate monohydrate (566 mg, 2.83 mmol), pyridine (6 ml) and ether (2 ml). The mixture was stirred at 15 °C for 17 hr and then poured onto 3 M hydrochloric acid (49 ml), and extracted with ether (20 ml × 4). The extract was washed successively with water, saturated solutions of sodium hydrogen carbonate and sodium chloride, and evaporated under reduced pressure. The residue (XII) containing water was mixed with 20% aqueous acetic acid (5 ml) and the mixture was stirred for 15 min at room temperature. The reaction mixture containing light brown crystals was mixed with water (40 ml) and extracted with dichloromethane (30 ml × 4). The extract, after being washed and dried, was concentrated under reduced pressure to yield crystals. Chromatography of the crystals on silica gel followed by elution with carbon tetrachloride containing 10—20% dichloromethane afforded pure II, yellow crystals, 163 mg (74%), mp 119.4—120.3 °C, Mass (*m/e*): 310 (M$^+$), IR (KBr-disk): 2850, 2740 (CHO), 2135 (–C≡C–), 1668 C=O), 1581, 1560 (C=C) cm^{-1}, NMR ($CDCl_3$): −0.27 (d, *J*=8.0 Hz, 2H, CHO), 2.01—2.68 (m, 10H, phenyl), 3.07 (d, *J*=8.0 Hz, 2H, olefinic).

Found: C, 84.86; H, 4.57%. Calcd for $C_{22}H_{14}O_2$: C, 85.14; H, 4.55%.

Bis(3-phenyl-2-furanyl)acetylene (IX). A solution of II (93 mg, 0.30 mol) in benzene (4 ml) was kept at 50 °C for 8 hr. The reaction mixture was concentrated unduer reduced pressure and chromatographed on alumina. Elution with carbon tetrachloride–20% dichloromethane afforded IX, colorless crystals, 81 mg (86%), mp 131.5—131.8 °C (from benzene–*n*-hexane), Mass (*m/e*): 310 (M$^+$), IR (KBr-disk): 3140, 3215 (furan CH), 892 (furan) cm^{-1}, NMR ($CDCl_3$): 2.50 cd, *J*=2.0 Hz, 2H, α–H of furan), 2.10—2.87 (m, 10H, phenyl), 3.76 (d, *J*=2.0 Hz, 2H, β–H of furan), UV: $\lambda_{\max}^{\mathrm{EtOH}}$ (ε) 231.5, (32900), 258.5* (14800), 342.5 (17500) nm.

Found: 84.84; H, 4.52%. Calcd for $C_{22}H_{14}O_2$: C, 85.14; H, 4.55%.

6-(5-Methoxy-3-phenyl-2-dihydrofuranylidene)-3-phenyl-2-penten-4-ynal (X). a) In the Presence of Pyridine and Methanol: A solution of II (83 mg, 0.26 mmol) in pyridine (5 ml) and methanol (8 ml) was stirred for 2 hr at 30 °C, and then the mixture was poured onto 3 M hydrochloric acid (40 ml). The mixture was extracted with dichloromethane (30 ml × 4). The extract, after being washed and dried, was concentrated under reduced pressure. Brownish oily residue was chromatographed on silica gel and eluted with benzene to yield X as pale brown oil, 78 mg (85%), Mass (*m/e*): 342 (M$^+$), IR (neat): 2180 (–C≡C–), 1662 (C=O), 1620 (C=C) cm^{-1}. The NMR spectrum of X showed complexes pattern owing to the presence of *cis*- and *trans*-isomers.

A solution of 2,4-dinitrophenylhydrazine (97 mg, 0.49 mmol) and phosphoric acid (1.2 ml) in ethanol (0.8 ml) was added to a solution of X (47 mg, 0.13 mmol) in ethanol (8 ml) and the mixture was stirred for 15 hr at room temperature. Red crystals deposited were washed thoroughly with benzene. Red crystals obtained by evaporating the washings under reduced pressure were chromatographed on silica gel. Elution with benzene afforded pure 2,4-dinitrophenylhydrazone of X red crystals, mp 208.4—209.8 °C, 58 mg (81%).

Found: C, 66.61; H, 4.22; N, 10.51%. Calcd for $C_{22}H_{22}N_4O_6$: C, 66.66; H, 4.24; N, 10.27%.

b) In the Absence of Pyridine: A solution of II (108 mg, 0.34 mmol) in methanol (10 ml) and ether (5 ml) was stirred for 28 hr at 30 °C. Brown oily residue obtained by evaporating the solvent was chromatographed on silica gel, and eluted with benzene. IX (39 mg, 36%) was obtained from early fractions and the following fractions afforded II (28 mg, 26%) and then X (35 mg, 29%).

Oxidative Coupling of Phenylpentenynal (VIII). a) In the Presence of Methanol. A solution of VIII[3)] (1.00 g, 6.4 mmol) in pyridine (10 ml) and methanol (10 ml) was added to a mixture of cupric acetate monohydrate (5.00 mg, 0.025 mol), pyridine (30 ml) and methanol (10 ml). After being stirred for 30 min at room temperature, the mixture was poured onto 3 M hydrochloric acid (200 ml) and extracted with benzene. The extract was washed successively with water, saturated sodium hydrogen carbonate and sodium chloride solutions and dried. Chromatography of the residue obtained by evaporating the extract afforded IX, 127 mg (13%) and X, 449 mg (41%).

b) In the Absence of Methanol. To an ice-cooled sosolution of cupric acetate monohydrate (2.00 g, 0.010 mol) in pyridine (20 ml) was added a solution of VIII (1.00 g, 0.0064 mol) in ether (15 ml). After the mixture had been stirred for 12 hr at 15—20 °C, ice-cooled 3 M hydrochloric acid (100 ml) was added and the mixture was extracted with dichloromethane (30 ml × 3). The extract, after being washed and dried, was concentrated under reduced pressure. The residue was chromatographed on alumina. The fractions eluted with carbon tetrachloride containing 10—20% of dichloromethane afforded IX (303 mg, 30.5%).

*3,8-Di-*t*-butyl-2,8-decadien-4,6-diyndial (III).* *a) From XIII:* A solution of XIII (945 mg, 6.94 mmol) in ether (12 ml) was added to a mixture of cupric acetate monohydrate (2.10 g, 10.5 mmol) and pyridine (20 ml) and the mixture was stirred for 24 hr at 15—20 °C. The reaction mixture was poured onto 3 M hydrochloric acid (110 ml) and extracted with ether (40 ml × 3). The extract was worked up by the usual way. Crude crystals obtained were chromatographed on alumina. Elution with benzene yielded pure III, mp 83.3—84.5 °C (from benzene-*n*-hexane), pale yellow needles, 765 mg (80%), Mass (*m/e*): 270 (M^+), IR (KBr-disk): 2115 (-C≡C-), 1681 (C=O), 1574 (C=C) cm^{-1}; NMR ($CDCl_3$): −0.09 (d, J=7.5 Hz, 2H, CHO), 3.61 (d, J=7.5 Hz, 2H, olefinic), 8.74 (s, 18H, *t*-Bu), UV: $\lambda_{\max}^{\mathrm{EtOH}}$ (ε) 224.5* (13200), 232.0 (14400), 253.5 (13200), 264.5 (14300), 280.0 (14100), 303.5* (10500), 322.0 (12200), 343.5 (8300) nm.

Found: C, 80.14; H, 8.20%. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20%.

b) From XV: To a stirred mixture of cupric acetate monohydrate (50 g) and pyridine (300 ml) was added a solution of XV[5] (9.50 g, 0.045 mol) in pyridine (50 ml) at 50 °C and the mixture was stirred for 2 hr at the same temperature. The cooled reaction mixture was poured onto a mixture of cracked ice and dilute hydrochloric acid, and extracted with ether. The extract, after being washed and dried, was concentrated under reduced pressure to give crude XVI [NMR (CCl_4): 3.19 (d, J=7.0 Hz, 2H, olefinic), 4.86 (d, J=7.0 Hz, 2H, acetal), 6.44 (q, J=7.0 Hz, 4H, CH_2), 6.49 (q, J=7.0 Hz, 4H, CH_2), 8.82 (t, J=7.0 Hz, 12H, CH_3), 8.82 (s, 18H, *t*-Bu)]. Crude XVI was mixed with acetic acid (250 ml) and water (80 ml). After being stirred for 30 min, the mixture was worked up by the usual way and chromatographed on alumina to yield pure III, 6.6 g (55% based on XV).

Oxidative Coupling of XIII in the Presence of Methanol. A mixture of XIII (500 mg, 3.64 mmol), cupric acetate monohydrate (1.706 g, 8.54 mmol), pyridine (15 ml) and methanol (11 ml) was stirred for 22 hr at room temperature. The reaction mixture was worked up by the usual way to give brownish crystals. The crystals were chromatographed on alumina and eluted with benzene. A mixture of III and 6-(5-methoxy-3-*t*-butyl-2-dihydrofuranylidene)-3-*t*-2-penten-4-ynal (XIV was obtained by evaporating the benzene eluate. The approximate composition of the mixture could be estimated to be III, 250 mg (50%) and XIV, 70—75 mg (10—15%) by an NMR spectroscopy.

Oxidative Coupling of 1-Chloro-3-methyl-1-penten-4-yn-3-ol (XIX). A mixture of XIX[6] (2.7 g, 0.0207 mol), methanol (20 ml), cuprous chloride (0.3 g), ammonium chloride (1.7 g) and one drop of concentrated hydrochloric acid was stirred vigorously for 3.5 hr under a slightly elevated pressure of oxygen. Insoluble material was removed by filtration and washed with methanol. The combined filtrate and washings were concentrated under reduced pressure and the residue was extracted with ether. The extract was washed with 5% hydrochloric acid and water, successively, and dried. The residue obtained by evaporating the solvent was chromaotgraphed on alumina. Elution with benzene afforded 1,10-dichloro-3,8-dimethyl-1,9-decadien-4,6-diyn-3,8-diol (XX), colorless crystals, mp 65—70 °C, IR (Nujol mull): 3350, 3090, 3000, 2950, 2880, 2160, 1630, 1485, 1450, 1375, 930, 825 cm^{-1}, NMR (CCl_4): 3.47 (d, J=13.4 Hz, 2H, H^1), 4.00 (d, J=13.4 Hz, 2H, H^2), 6.60 (s, 2H, OH), 8.40 (s, 6H, CH_3).

Found: C, 55.03; H, 4.58; Cl, 27.15%. Calcd for $C_{12}H_{12}O_2Cl_2$: C, 55.62; H, 4.67; Cl, 27.39%.

Treatment of XIX with cupric acetate-pyridine resulted in recovery of the starting material.

*Bis(3-*t*-butyl-2-furanyl)acetylene (XXI).* *a) Thermal Cyclization in the Absence of Pyridine.* A solution of III (82 mg, 0.3 mmol) in benzene (4 ml) was stirred for 20 hr at 60 °C. Concentration of the reaction mixture under reduced pressure afforded yellow crystals (81 mg) which were chromatographed on alumina and eluted with *n*-hexane containing 20—30% of benzene. Evaporation of the eluate yielded XXI, pale yellow crystals, 68 mg (82%), mp 42.0—42.6 °C (from ether-*n*-hexane), Mass (*m/e*): 270 (M^+), IR (KBr-disk): 3130 (furan C-H), 1585 (C=C), 890 (furan) cm^{-1}, NMR ($CDCl_3$): 2.69 (d, J=2.0 Hz, 2H, α-H of furan), 3.62 (d, J=2.0 Hz, 2H, β-H of furan), 8.64 (s, 18H, *t*-Bu), UV: $\lambda_{\max}^{\mathrm{EtOH}}$ (ε) 253.0 (16200), 296.0* (19700), 300.5 (20100), 318.5* (12600) nm.

Found: C, 80.20; H, 8.27%. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20%.

Bis(3,4-tetramethylene-2-furanyl)acetylene (XXII). a) Cyclization at 120 °C. A solution of I (112 mg) in *p*-xylene (5 ml) was kept at 120 °C for 5 hr. Crystals obtained by removing the solvent under reduced pressure was chromatographed on alumina (5 g). Elution with *n*-hexane-benzene (1 : 1) afforded XXII, colorless crystals, mp 146—147 °C (from benzine), 64 mg (57%), Mass (*m/e*): 266 (M^+, base peak), IR (KBr-disk): 2170 (-C≡C-), 1547 (C=C), 1505 (C=C) cm^{-1}, NMR ($CDCl_3$): 2.87 (s, 2H, α-H of furan), 7.43 (m, 8H, allylic CH_2), 8.29 (m, 8H, non-allylic CH_2).

Found: C, 81.02; H, 6.88%. Calcd for $C_{18}H_{18}O_2$: C, 81.17; H, 6.81%.

b) Cyclization at 60 °C. A solution of I (104.5 mg) in benzene (5 ml) was heated to 60 °C for 2 hr. Chromatography on alumina (3 g) of the reaction mixture yielded XXII, 1.9 mg (1.8%) and recovered I, 76.9 mg (73.6%).

Cyclization of III in the Presence of Cupric Acetate and Pyridine. To a mixture of cupric acetate monohydrate (184 mg, 0.92 mmol) and pyridine (4 ml) maintained at 60±2 °C was added a solution of III (198 mg, 0.73 mmol) in benzene (10 ml). The mixture was stirred in nitrogen atmosphere at the same temperature for 5 hr, then poured onto 3 M hydrochloric acid (30 ml) and extracted with ether (30 ml × 3). The extract was washed and dried. A mixture of light brown crystals and liquid obtained by evaporating the extract was chromatographed on alumina and eluted with *n*-hexane containing 20% of benzene to yield XXI, 91 mg (46%). The results of reactions performed under different conditions are summarized in Table 2.

cis- and trans-1-(2-Formylcyclohexenyl)-3-(3,4-tetramethylene-5-methoxy-2-dihydrofuranylidene)-1-propyne (XXVa and XXVb). To an ice-cooled solution of I (186 mg, 0.698 mmol) in ether (10 ml) was added 1 M solution of sodium methoxide in methanol (2 ml). After being stirred for 30 min at the same temperature, the mixture was mixed with 3 M hydro-

TABLE 2. FORMATION OF XXI IN THE PRESENCE OF CUPRIC ACETATE

Temp. °C	II (mg)	$Cu(OAc)_2 \cdot H_2O$ (mg)	Solvent (ml)	Reaction time (hr)	XXI (mg) (%)
40	221	250	pyridine 4 + benzene 10	24	92 (41)
50	193	409	pyridine 4 + ether 3	24	109 (56)

chloric acid (1 ml) and extracted with ether (20 ml). The extract, after being washed and dried, was concentrated under reduced pressure. Brownish yellow oily residue was chromatographed on silica gel to yield a mixture of XXVa and XXVb (187 mg, 90%). The mixture was re-chromatographed on silica gel. Elution with benzene resulted in the separation of isomers. XXVa was obtained from early fractions, yellow crystals, mp 115.6—116.2 °C (from benzene-methanol), Mass (*m/e*): 298 (M^+), 267 (M–31), 266 (M–32), IR (KBr-disk): 2160 (–C C–), 1670 (C=O), 1626 (C=C), 1580 (C=C) cm^{-1}, NMR ($CDCl_3$): -0.10 (s, 1H, CHO), 4.26 (s, 1H, hemiacetal), 4.80 (s, 1H, olefinic), 6.58 (s, 3H, OCH_3), 7.25—8.00 (m, 8H, allylic CH_2), 8.29 (m, 8H, non-allylic CH_2), UV: λ_{max}^{EtOH} (ε) 249* (10900), 256 (11200), 286.5 (8750), 360 (20500) nm.

Found: C, 76.33; H, 7.44%. Calcd for $C_{19}H_{22}O_3$: C, 76.48; H, 7.43%.

Evaporation of the following benzene eluates afforded XXVb, yellow crystals, mp 91.5—93.0 °C (from methanol), Mass (*m/e*): 298 (M^+), IR (KBr-disk): 2175 (–C≡C–), 1663 (C=O), 1626 (C=C), 1578 (C=C) cm^{-1}, NMR ($CDCl_3$): -0.27 (s, 1H, CHO), 4.18 (s, 1H, hemiacetal), 5.33 (s, 1H, olefinic), 6.50 (s, 3H, OCH_3), 7.40—8.00 (m, 8H, allylic CH_2), 8.29 (m, 8H, non-allylic CH_2).

Found: C, 75.86; H, 7.42%. Calcd for $C_{19}H_{22}O_3$: C, 76.48; H, 7.43%.

XXVa and XXVb showed closely related mass, IR and UV spectra. However, marked difference of chemical shifts of olefinic protons between XXVa (4.80) and XXVb (5.33) was observed. The structure of XXVa was assigned to the isomer with low τ-value, because the olefinic proton in XXVa is dishielded by the magnetic anisotropy of oxygen atom of dihydrofuran ring.

5-Phenyl-2,4-heptadien-6-ynal (XXXII). *a) By the Modified Wittig Reaction*: Sodium hydride dispersion in mineral oil (50%, 1.84 g, 0.383 mol) was washed under nitrogen atmosphere with petroleum ether (3 ml×4). The sodium hydride, after being dried *in vacuo*, was mixed with tetrahydrofuran (10 ml) and a solution of diethyl 2-(cyclohexylimino)ethylphosphonate[10] (10.0 g, 0.0383 mol) in the same solvent (30 ml) was added under ice-cooling and the mixture was stirred for 15 min. A solution of VIII (2.00 g, 0.0128 mol) in the same solvent (15 ml) was then added at −15 °C. The mixture was stirred at −10—−15 °C for 15 hr, then poured onto ice-water, and extracted with ether (30 ml×3). After being washed and dried, the extract was evaporated under reduced pressure to yield a crude mixture containing XXXI, dark brown oil, 8.07 g. The material was dissolved in benzene (60 ml) and mixed with 1% aqueous solution of oxalic acid (180 ml). After being stirred for 15 hr at 20—25 °C, the organic layer was separated and the aqueous layer was extracted with dichloromethane (20 ml×2). The combined organic layer was washed and dried. The residue obtained by evaporating the solvent was chromatographed on silica gel. Elution with carbon tetrachloride and dichloromethane afforded XXXII, yellow crystals (from carbon tetrachloride-methanol), mp 69.5—70.3 °C, 1.18 g (51%), IR ($CHCl_3$): 3300 (≡C–H), 2085, 2710 (CHO), 1686 (C=O), 1608 (C=C) cm^{-1}, NMR (CCl_4): 0.33 (d, J=7.5 Hz, 1H, CHO), 2.06—2.95 (m, 8H, phenyl and olefinic), 3.75 (dd, J=7.5 and 15 Hz, α-position of CHO), 6.32 (s, 1H, ≡C–H).

Found: C, 85.73; H, 5.48%. Calcd for $C_{13}H_{10}O$: C, 85.69; H, 5.53%.

b) By the Isler's Method: A solution of borontrifluoride etherate (72 mg) in benzene (1 ml) was added to a solution of acetal (XI, 16.98 g, 0.0737 mol) in the same solvent (23 ml). at 40 °C and a solution of ethyl vinyl ether (6.233 g, 0.0864 mol) in the same solvent (10 ml) was slowly added at 40—45 °C. The mixture was kept at the same temperature for 4 hr and then allowed to cool on standing. Finely powdered potassium carbonate was added to the mixture. The filtrate was concentrated under reduced pressure to give crude XXXIII, brown oil, 22.68 g. A mixture of crude XXXIII, tetrahydrofuran (187 ml) and 3 M hydrochloric acid (125 ml) was vigorously stirred at 25 °C for 48 hr. The reaction mixture was extracted with ether. The extract, after being washed and dried, was concentrated under reduced pressure. Oily residue containing crystals was purified by a chromatography on silica gel to yield pure XXXII, 8.168 g (61% based on XI).

5,10-Diphenyl-2,4,10,12-tetradecatetraen-6,8-diyndial (XXIX). To a mixture of XXXII (740 mg, 4.07 mmol), methanol (5 ml) and pyridine (5 ml) was added a solution of cupric acetate monohydrate (3.50 g) in methanol (25 ml) and pyridine (25 ml). After being stirred for 3 hr at 25 °C, the mixture was chilled on an ice-bath, mixed with 3 M hydrochloric acid, and extracted with chloroform (30 ml×3). The extract, after being washed and dried, was concentrated under reduced pressure. The residue was chromatographed on silica gel (30 g) and eluted with carbon tetrachloride-dichloromethane to yield XXIX, yellow crystals, 691 mg (94%). The crystals dissolved in benzene was passed through a short column of alumina. Concentration of the filtrate afforded pure XXIX, orange yellow crystals, mp *ca.* 155 °C (decom.) (from benzene-cyclohexane), IR ($CHCl_3$): 1677 (C=O), 1603 (C=C) cm^{-1}, NMR ($CDCl_3$): 0.31 (d, J=8.0 Hz, 2H, CHO), 1.93—2.78 (m, 16H, phenyl and olefinic), 3.58 (dd, J=8.0 Hz and 15 Hz, 2H, olefinic H^2).

Found: C, 86.56; H, 4.98%. Calcd for $C_{26}H_{18}O_2$: C, 86.16; H, 5.01%.

5,10-Di-t-butyl-2,4,10,12-tetradecatetraen-6,8-diyndial (XXX). A solution of 5-*t*-butyl-2,4-heptadien-6-ynal[5] (1.20 g, 7.4 mmol) in pyridine (10 ml) and methanol (10 ml) was added to a mixture of cupric acetate monohydrate (5.00 g), pyridine (40 ml) and methanol (40 ml). After being kept at 25 °C for 21 hr, the reaction mixture was worked by up by the way used for XXIX. Crude yellow crystals thus obtained were chromatographed on alumina to yield pure XXX, 1.01 g (85%), yellow crystals, mp 154.4—155.7 °C (from benzene-*n*-hexane), IR (KBr-disk): 2745 (CHO), 2230 (–C≡C–), 1677 (C=O), 1604 (C=C) cm^{-1}, NMR ($CDCl_3$): 0.29 (d, J=8.0 Hz, 2H, CHO), 2.39 (dd, J=11 Hz and 15 Hz, 2H, H^3, H^{12}), 3.30 (d, J=11 Hz, 2H, H^4, H^{11}), 3.67 (dd, J=8.0 Hz and 15 Hz, 2H, H^2, H^{13}), 8.73 (s, 18H, *t*-Bu).

Found: C, 81.91; H, 8.17%. Calcd for $C_{22}H_{26}O_2$: C, 81.95; H, 8.13%.