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Algal Carotenoids. XIII.** Chemical Reactions of Allenic Carotenoids

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The conversion of the allenic end group I to acetylenic (II) and chlorinated (presumably V) end groups on treatment with chloroformic hydrogen chloride is demonstrated.

Treatment with phosphorus oxychloride in pyridine of carotenoids with the allenic end group I also caused transformation to acetylenic products, in addition to previously reported allenic anhydro-products.

Facile dehydration and chlorine substitution of the secondary hydroxy group of peridinin (*1*) were observed.

Chlorinated carotenoids, identified by mass spectrometry, appear to be readily formed.

On the basis of electronic spectra and R_F-values alone Egger *et al.*[1] and Nitsche *et al.*[2,3] have claimed the conversion of carotenoids with the allenic end group I to carotenoids with the acetylenic end group II besides end group IV on treatment with chloroformic hydrogen chloride, Scheme 1B. More recently [3a] IR-evidence for the conversion of I (unacetylated) to II (unacetylated) has been published.

Such conversion was not observed on treating peridinin (*1*) with methanolic hydrogen chloride, and only products with the allenic end group intact were reported.[4,5]

Also lithium aluminium hydride treatment of carotenoids with end group I has been reported to give conversion to the acetylenic (ν_{max} 2150 cm^{-1}) end group II.[5a]

We now report further evidence on the reactions of carotenoids containing the allenic end group I in chloroformic hydrogen chloride and on treatment with phosphorus oxychloride, resulting in the formation of acetylenic and chlorinated derivatives.

RESULTS AND DISCUSSION

Carotenoids containing the allenic end group I were on treatment with chloroformic hydrogen chloride converted to products with acetylenic (II) and chlorinated (probably V) end groups, whereas products with end groups III, IV, and VI were not observed, Scheme 1. Further evidence for the position of the chloro substituent in end group V will be presented.[5b]

Thus peridinin (*1*, Scheme 2) on such treatment provided besides three minor products (*2**, *3**, and *5**) a major presumably mixed product (*4a*, *b*; Scheme 2) with highest mass number ion at *m/e* 648.3216 (calculated 648.3218 for $C_{39}H_{49}O_6{}^{35}Cl$) and with no allene, but a very weak acetylenic (2170 cm^{-1}) IR absorption. Asterisks indicate that the structural formulae are not given; numbers refer to compounds described in the Experimental part.

Likewise treatment of peridinin acetate (*6*) gave two major products (*7** and *8**) of similar polarity. The least polar product *7** had highest mass number ion at *m/e* 630 (consistent with $C_{39}H_{47}O_5{}^{35}Cl$, supported by ^{37}Cl isotope peak at *m/e* 632) compatible with the formation of end group V and elimination of acetic acid from one of the acetoxy groups. The more polar product *8** had molecular ion at *m/e* 690 and ^{37}Cl isotope peak at *m/e* 692 compatible with $C_{41}H_{51}O_7Cl$, again consistent with the formation of end group V.

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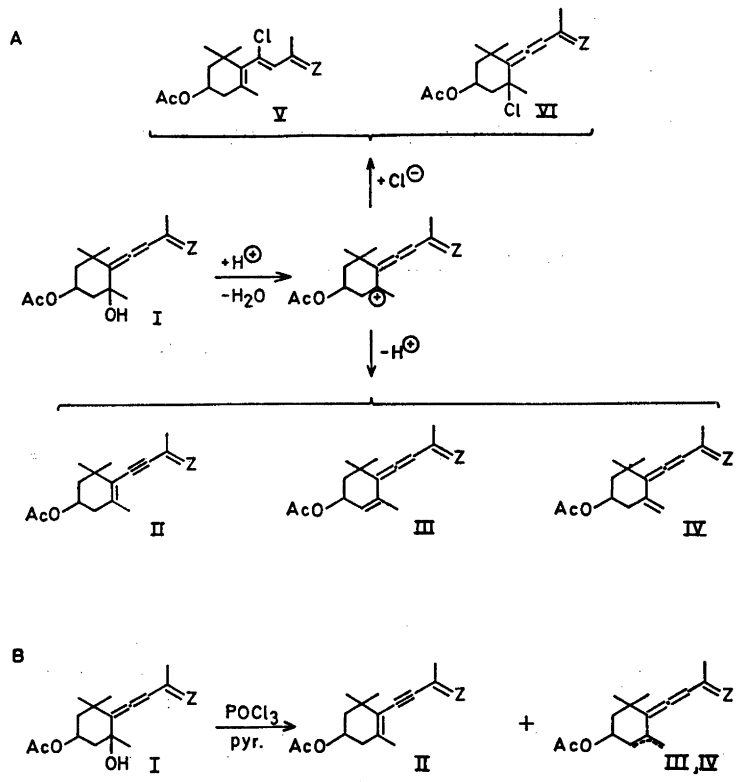
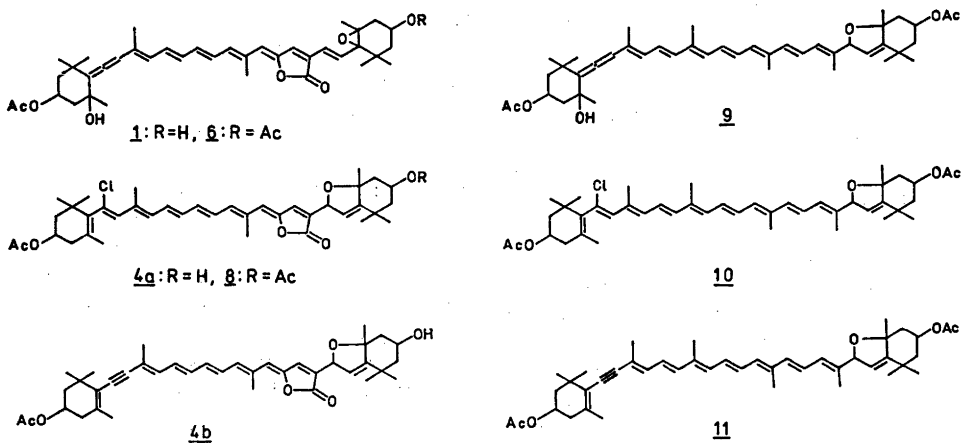


Scheme 1.



Scheme 2.

Small amounts of dinochrome acetate (*9* = neochrome diacetate [6]) were available. Treatment with chloroformic hydrogen chloride gave a product (*10*) with molecular ion at *m/e* 702 and ^{37}Cl isotope peak at *m/e* 704 (consistent with $C_{44}H_{59}O_5Cl$) and with a 4 nm bathochromic shift in the visible spectrum in acetone solution relative to *9*. The product was unseparable from diadinochrome diacetate (*11*) with the acetylenic end group II on kieselguhr paper.[1]

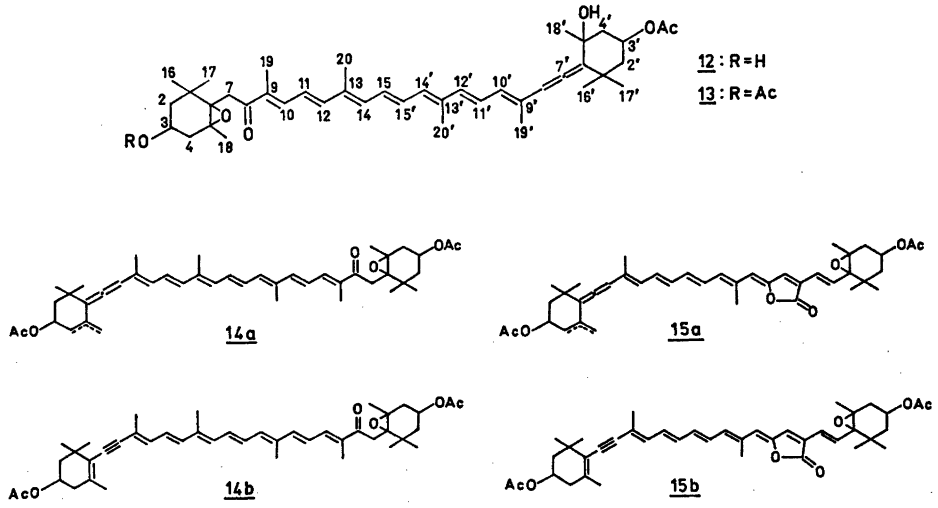
The mass spectra of the chlorinated products *2**, *4*, *5**, *7**, *8**, and *10* all showed strong M − 36 ions. This might be due to loss of HCl from the molecular ion, to the presence of carotenoids with end group II, or both of these possibilities.

Failure to effect chromatographic separation (TLC or paper) of the actylenic and chlorinated derivatives may partly be due to accompanying epoxide-furanoid rearrangement of the second end group in the carotenoids (*1* and *6*) studied, theoretically resulting in two epimeric furanoxides in each case.

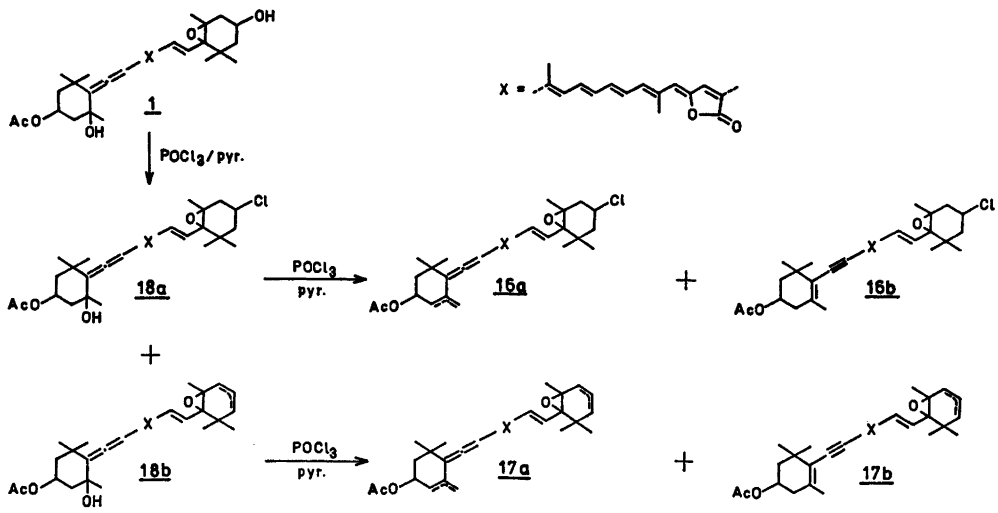
We further report the conversion of the allenic end group I to the acetylenic end group II on treatment with phosphorus oxychloride in pyridine, in addition to the transformation of I to III/IV previously reported by Bonnett *et al.*,[7] Scheme 1B.

Thus fucoxanthin acetate (*13*, prepared from fucoxanthin (*12*, Scheme 3) when treated with phosphorus oxychloride gave the mixed anhydro-products (*14a, b*) judged by visible-, IR-, NMR-, and mass spectra. Absorption in the IR region at 1920 and 2170 cm^{-1} were assigned to the allenic group in *14a* and the acetylenic group in *14b*, respectively. No absorption due to terminal methylene was observed in the IR- or NMR spectra of the mixed products (*14a, b*). Separation of *14a* and *14b* was not effected by TLC, but achieved by circular kieselguhr paper chromatography on the micro scale. The visible spectrum in hexane solution of the tentatively identified acetylenic *14b* showed less fine-structure and had absorption maximum at 1 nm longer wavelength than that of the tentatively allenic *14a*. The acetylenic product (*14b*) may previously have been overlooked.[7]

Likewise peridinin acetate (*6*) on similar treatment with phosphorus oxychloride gave the allenic anhydro-peridinin acetate (*15a*) and the acetylenic pyrrhoxanthin acetate (*15b*). Anhydro-peridinin acetate (*15a*) had absorption maximum in visible light at 1.5 nm longer wavelength than that of peridinin (*1*) in hexane solution, but exhibited the same spectral fine structure, whereas pyrrhoxanthin acetate (*15b*) had less fine structure and absorption maximum at 3 nm longer wavelength than that of peridinin (*1*). No absorption characteristic of terminal methylene was observed. Pyrrhoxanthin acetate (*15b*) was inseparable by co-



Scheme 3.



Scheme 4.

chromatography from authentic *15b* [6] on circular kieselguhr paper.

Peridinin (*1*) gave in the same reaction three main products [8] by TLC (*16*, *17*, and *18*, Scheme 4), each considered to represent mixtures. Product *16* had molecular ion at *m/e* 630.3109 (calculated 630.3112 for $C_{39}H_{47}O_5{}^{35}Cl$) in addition to ions at *m/e* 199.0883 (calculated 199.0890 for $C_{11}H_{16}O^{35}Cl$) and 201.0865 (calculated 201.0860 for $C_{11}H_{16}O^{35}Cl$), compatible with pyrylium ions [9] revealing that the 3′-hydroxy group was substituted by chlorine. Product *17* had molecular ion at *m/e* 594 and a fragment ion at *m/e* 163, demonstrating that the 3′-hydroxy group had been eliminated as water. Products *16* and *17* were each mixtures containing both the allenic (*16a*, *17a*) and acetylenic (*16b*, *17b*) end group as dicussed above for the dehydration of fucoxanthin acetate (*13*). Product *18* exhibited molecular ions at *m/e* 648 (*18a*) and 612 (*18b*). Fragment ions at *m/e* 223, 212, and 197 indicated that the allenic end group was intact.[5,10] Product *18* thus represented a mixture of products where the 3′-hydroxy group partly was substituted by chlorine (*18a*) and partly eliminated as water (*18b*).

In conclusion further evidence for the conversion of the allenic (I) to acetylenic end groups in carotenoids is here presented, in chloroformic hydrogen chloride as well as in phosphorus oxychloride/pyridine.

Under both conditions stable, chlorinated products were also observed. Without mass spectrometry such halogenated carotenoids would not be identified.

The facile dehydration and chlorine substitution of the secondary hydroxy group in peridinin (*1*) in phosphorus oxychloride/pyridine was unexpected.

EXPERIMENTAL

Materials and methods were as described elsewere.[11]

Acid treatment of allenic carotenoids

Peridinin (*1*, 15.7 mg, available from a previous study [6]) was kept in 0.02 M HCl–$CHCl_3$ (100 ml) for 4 h at room temp. The mixture was diluted with petroleum ether, the organic extract washed with water, solvents removed, and the residue dried under vacuum. Chromatography on kieselgel G (25 % acetone in petroleum ether = 25 % APE) gave several bands. The four major products (*2–5*, representing 36 % of starting material) were further investigated.

Product *2*, yield 0.08 mg (1 %), had R_F = 0.75 (Schleicher and Schüll paper No. 287 = SS287, 5 % APE); λ_{max}(hexane) *430.5* and 458.5 nm (the main maximum is given in italics); *m/e* 510.2531 (M, 48 %, calc. 510.2537 for $C_{31}H_{39}O_4{}^{35}Cl$), 474 (M–36, 17 %), 439 (8 %), 383 (11 %), 257 (12 %), 236 (16 %), 211 (10 %), 207 (13 %), 183 (23 %), 57 (100 %) and no *m/e* 181.

Product *3*, yield 1.2 mg (22 %), had R_F= 0.41 (broad, SS287, 5 % APE); λ_{max}(hexane) *437.5* and 464 nm; *m/e* 552.3237 (M?, 3 %, calc. 552.3240 for $C_{37}H_{44}O_4$) and 181 (53 %); ν_{max} (KBr) 3425 (OH), 3012–2870 (CH), 2170 (very weak, –C≡C–), 1730 (C=O), 1640, 1530, 1453 (CH_2), 1366 (CH_3), 1241, 1164, 1100, 1038 (C–O), 988 and *697* (*trans* –CH=CH–) and 783 cm^{-1}.

Product *4*, yield 4.0 mg (71 %), had R_F= 0.18 (broad, SS287, 5 % APE); λ_{max}(hexane) *435* and 462.5 nm; *m/e* 648.3216 (M, 46 %, calc. 648.3218 for $C_{39}H_{49}O_4{}^{35}Cl$), 612 (M–36, 29 %), 588 (M–60, 0.9 %), 570 (M–78, 1.0 %), 568 (M–80, 1.9 %), 556 (M–92, 2.2 %), 552 (M–60–36, 10 %), 460 (M–92–60–36, 8.2 %), 234 (58 %) and 181 (100 %); δ ($CDCl_3$) 0.93 (imp.), 1.07, 1.17, 1.21, 1.27 (imp.), 1.35, 1.67, 1.70, 1.83, 2.09 and 2.21. Product *4* was crystallized from acetone-petroleum ether, yield 1.8 mg; λ_{max} (hexane) 323, *435.5* and 462.5 nm; ν_{max}(KBr) 3420 (OH), 3013–2870 (CH), 2170 (weak, acetylene), 1740 (C=O), 1629, 1598, 1531, 1446 (CH_2), 1386, 1367, 1352 (CH_3), 1243, 1214, 1180, 1145, 1100, 1040 (C–O), 987, 974, 947, 908, 864, 837, 801, 782 (Cl?), 729 and 665 cm^{-1}.

Product *5*, yield 0.34 mg (6 %), had R_F= 0.78 (SS287, 20 % APE); λ_{max}(hexane) *436* and 459.5 nm; *m/e* 648 (M, 3.3 %), 612 (M–36, 2.5 %), 570 (M–78, 3.4 %), 552 (M–60–36, 3.5 %), 430 (70 %), 412 (34 %) and 181 (70 %).

Peridinin acetate (*6*, 1.5 mg) treated as above gave after chromatography on kieselgel G several products; the two major ones *7* and *8* were further investigated.

Product *7*, yield 0.12 mg (8 % of starting material) had λ_{max}(acetone) *440* and (458) nm; *m/e* 630 (M, 1.8 %, ^{37}Cl isotope peak at *m/e* 632), 594 (M–36, 13 %), 223 (18 %), 216 (12 %) and 181 (24 %).

Product *8*, yield 1.07 mg (70 % of starting material) had λ_{max}(acetone) *437.5* and (456) nm; *m/e* 690 (M, 22 %, ^{37}Cl isotope peak at *m/e* 692, 654 (M–36, 13 %), 630 (M–60, 0.8 %), 612 (M–78, 1.3 %), 610 (M–80, 2.0 %), 598 (M–92, 3.0 %), 594 (M–60–36, 9.8 %), 502 (7.5 %), 303 (5.3 %), 223 (22 %), 216 (30 %) and 163 (43 %).

Dinochrome acetate (*9*, 0.22 mg) treated as above for 2 h gave after chromatography on kieselgel G one main product (*10*, representing 70 % of reaction mixture); λ_{max}(acetone) 407, *428* and 454.5 nm; *m/e* 702 (M, 3.2 %, ^{37}Cl isotope at *m/e* 704), 666 (M–36, 3.7 %), 622 (M–80, 4.3 %, ^{37}Cl isotope at *m/e* 624), 223 (8.1 %) and 183 (11 %). Co-chromatography with diadinochrome diacetate (*11*) gave no separation on SS288 paper (R_F= 0.65, 10 % APE).

$POCl_3$/pyridine treatment of allenic carotenoids

Fucoxanthin acetate (*13*, 34.3 mg prepared from fucoxanthin (*12*) treated with $POCl_3$ (20 drops) in dry pyridine (5 ml) for 6 h at 40°C gave recovered fucoxanthin acetate (*13*, 1.3 mg, 4 % of starting material) and dehydrated fucoxanthin acetate (*14a, b*, 18.0 mg, 53 % of starting material). The mixed products *14a, b* had λ_{max}(acetone) *446* and 466 nm; ν_{max}(KBr) 3420 (H_2O), 3030 2958, 2920 and 2860 (CH), 2167 (–C≡C–), 1912 (>C=C=C<), 1735 (C=O), 1658, 1609, 1575, 1530, 1468 and 1452 (CH_2), 1364 (CH_3), 1242, 1200, 1154, 1130, 1030, (C–O), 968 (*trans* –CH=CH–), 919, 891, 836 (>C=CH–), 805, 735, 658 and 645 cm^{-1}; δ($CDCl_3$, for numbering see fucoxanthin acetate (*13*) in Scheme 3) 0.90 and 0.93 (imp.), 0.98 s (CH_3–1), 1.07 s (CH_3–1), 1.13, 1.17, 1.19 and 1.22 (CH_3–5,1′, 1′), 1.26 (imp.), 1.77 (CH_3–5′ in *14a*?), 1.85 (CH_3–9′ in *14a*?), 1.97 (CH_3–9 and CH_3–5′ in *14b*?), 1.99, 2.01, 2.04 and 2.06 (CH_3–9 in *14b*?, CH_3–13,13′ and CH_3– in OAc), 2.61 d(H–7, J=18 Hz), 3.71 (H–7, J= 18 Hz), 4.23 (H–4, J=6 Hz), *ca.* 4.89 (H–3) and 5.56 (H–3 in *14a*); *m/e* 682 (M, 16 %), 664 (M–18, 0.9 %), 638 (M–44, 0.1 %), 622 (M–60, 11 %), 604 (M–78, 4.1 %), 590 (M–92, 2.2 %) and 43 (100 %).

The mixed products (*14a, b*) gave three zones on paper chromatography (SS287, 2 % APE): Unassigned: R_F= 0.41 (5 %); λ_{max} (hexane) 263, 329, (425), *446.5* and 475 nm; % III/II = 28;[12] *14a* (tentatively): R_F= 0.38 (55 %); λ_{max}(hexane) 263, 329,427, *448.5* and 477.5 nm; % III/II = 35 [12] and *14b* (tentatively) R_F= 0.29 (40 %); λ_{max}(hexane) 277, 340, *449.5* and 477 nm; % III/II = 9.[12]

Peridinin acetate (*6*, 4.6 mg) treated with $POCl_3$ in dry pyridine as above gave after purification by TLC recovered peridinin acetate (*6*, 1.8 mg, 38 % of starting material) and dehydrated peridinin acetate (*15a, b*, 1.5 mg, 32 % of starting material). The mixed product *15a, b*, had λ_{max} (acetone) *459.5* and (475) nm; λ_{max} (KBr) 3020, 2958, 2960 and 2855 (CH), 2167 (–C≡C–), 1908 (>C=C=C<), 1754 and 1739 (C=O), 1640, 1524, 1449 (CH_2), 1364 (CH_3), 1243, 1181, 1166, 1126, 1032 (C–O), 985 (*trans* –CH=CH–), 943, 905, 819 (>C=CH–), 795, 768, 726 and 643 cm^{-1}; *m/e* 654 (M, 20 %), 594 (M–60, 24 %), 579 (M–75, 2.3 %), 574 (M–80, 0.6 %), 562 (M–92, 1.5 %), 478 (9.6 %), 443 (1.2 %), 431 (1.5 %), 343 (2.2 %), 285 (4.3 %) and 223 (19 %). Two zones were obtained by paper chromatography (SS287, 5 % APE): Anhydro-peridinin acetate (*15b*, tentatively); R_F= 0.50 (60 %); λ_{max} (hexane) 327, *456* and 486.5 nm: % D_B/D_{II} = 17;[12] % III/II = 72 [12] and pyrrhoxanthin acetate (*15a*, tentatively); R_F= 0.41 (40 %); λ_{max} (hexane) *458.5* and 488 nm; % D_B/D_{II}= 12,[12] % III/II = 44.[12] These were not inter-convertible by iodine catalyzed stereomutation.

Peridinin (1, 21.8 mg) treated as above gave 9.5 mg (44 %) recovery. Chromatography on kieselgel G ($CHCl_3$) gave three major products: *16*, *17* and *18* numbered from the solvent front.[8]

Product *16a*, *b*, yield 0.28 mg (4 %), had λ_{max} (hexane) *457* and 487 nm; *m/e* 630.3109 (M, 30 %, calc. 630.3112 for $C_{39}H_{47}O_5{}^{35}Cl$), 594 (M − 36, 0.3 %), 570 (M − 60, 40 %, ^{37}Cl isotope peak at *m/e* 572), 534 (M − 60 − 36, 10 %), 373 (14 %), 223 (20 %), 201.0865 (12 %, calc. 201.0860 for $C_{11}H_{16}O^{37}Cl$), 199.0883 (34 %, calc. 199.0890 for $C_{11}H_{16}O^{35}Cl$) and 183 (14 %). Product *16* gave two zones by paper chromatography (SS287, 5 % APE): *16a*; R_F = 0.77 (60 %); λ_{max}(hexane) 326, *458* and 488 nm; % III/II = 75,[12] % D_B/D_{II} = 22 [12] and *16b*; R_F = 0.64 (40 %; λ_{max} (hexane) (335), *461* and 490 nm; % III/II [12] = 28; % D_B/D_{II} [12] = 16.

Product *17a*, *b*, yield 2.5 mg (35 %), had λ_{max} (hexane) *455* and 484 nm; ν_{max} (KBr) 3022 − 2855 (CH), 2167 (−C≡C−), 1912 (>C=C=C<), 1740 (C=O), 1638, 1570, 1460 (CH_2), 1374 and 1360 (CH_3), 1240, 1180, 1144, 1124, 1074, 1047, 1023, 986, 944, 905, 870, 818, 769, 718, and 634 cm^{-1}; *m/e* 594 (M, 11 %), 534 (26 %) and 163 (26 %) and no *m/e* 181. Product *17a*, *b*, gave two zones by paper chromatography (SS287, 10 % APE): *17a*: R_F = 0.77 (60 %); λ_{max} (hexane) (307), 320.5, 334.5, *455* and 484.5 nm; % III/II = 72, [12] % D_B/D_{II} = 37 and *17b*: R_F = 0.64 (40 %); λ_{max} (hexane) (307), 320, 335.5, *458* and 487 nm; % III/II = 41; % D_B/D_{II} = 26.

Product *18a*, *b*, yield 4.0 mg (59 %), had λ_{max} (hexane) *455* and 484.5 nm; ν_{max} (KBr) 3400 (OH), 3022 − 2855 (CH), 1928 (allene), 1730 (C=O), 1640, 1520, 1455 (CH_2), 1366 (CH_3), 1247, 1182, 1162, 1124, 1071, 1025, 984, 956, 924, 903, 859, 820, 768, 718, and 633 cm^{-1}; *m/e* 648 (M_1, 5.1 %, ^{37}Cl isotope peak at *m/e* 650, 612 (M_2, 16 %), 594 (M_1 − 36, M_2 − 18, 50 %), 570 (M_1 − 60, 44 %), 534 (M_1 − 60 − 36, 28 %), 520 (M_2 − 92, 73 %), 223 (32 %), 212 (50 %), 201 (18 %), 199 (28 %), 197 (99 %), and 163 (100 %) and no *m/e* 181.

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