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HALOGENATED ACETAMIDES, BUT-3-EN-2-OLS, AND ISOPROPANOLS FROM *ASPARAGOPSIS TAXIFORMIS* (DELILE) TREV

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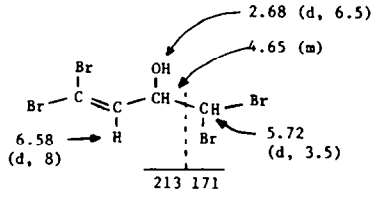
Abstract—Five dihaloacetamides, seven halogenated but-3-en-2-ols, and twenty halogenated isopropanols have been identified in the methylene chloride extract of the dried red alga *Asparagopsis taxiformis* from Hawaii. The structures of 1,1,4,4-tetrabromobut-3-en-2-ol and 1,1,1,4,4-pentabromobut-3-en-2-ol have been verified by synthesis.

The essential oil of the edible red alga *Asparagopsis taxiformis* (Delile) Trev.,[1] known as limu kohu in Hawaii, is composed of mainly bromine and iodine-containing haloforms with smaller amounts of other halogenated methanes and several halogenated ethanes, ethanols, acetaldehydes, acetones, isopropanols, propenes, 2-acetoxypropanes, epoxypropanes, acroleins and butenones.[2,3]

We have now examined the methylene chloride extract of the vacuum-dried seaweed and have isolated and identified several new halogenated compounds, all of which are directly related to the volatile constituents.[4] Only one of these compounds, 1,1,3-tribromoisopropanol (**10**), was detected in the essential oil by GC-MS.[3] After removal of the essential oil *in vacuo*, the dried seaweed was extracted with methylene chloride. The oily extract was chromatographed on silica gel and mixtures of halogenated alcohols and amides (Table 1) were eluted with ether–hexane (75:25) and ether, respectively.

From the forerun of the alcohol fraction was obtained an optically active, crystalline compound melting at 84.5–85.5°. The mass spectrum of this alcohol exhibited a small 1:4:6:4:1 molecular ion cluster at *m/e* 384, 386, 388, 390, 392 ($C_4H_4Br_4O$) and a huge 1:2:1 fragment ion cluster at *m/e* 213, 215 (base peak), 217, assigned to an oxonium ion $C_2HBr_2CH{=}\dot{O}H$. Its PMR spectrum showed three doublets at 6.58, 5.72 and 2.68 ppm, the latter signal disappearing on treatment with D_2O, and a multiplet at 4.65 ppm. These data were consistent with structure **27**.



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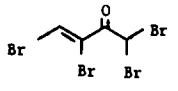
To prove the structure racemic 1,1,4,4-tetrabromobut-3-en-2-ol was synthesized by the addition of dibromomethane to 3,3-dibromoacrolein in the presence of lithium dicyclohexylamide[5] and had PMR and mass spectra and a GC retention time identical with those of the natural product.

One of the ketones in the essential oil of *A. taxiformis* was a tetrabromobutenone to which we have erroneously assigned structure **34** in a preliminary communication.[2] Its structure must be revised to **35**, since we have found that sodium borohydride reduction of this ketone leads to **27**



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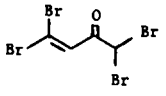

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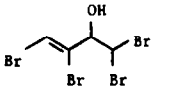

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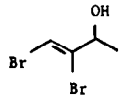

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and not to Z-1,1,3,4-tetrabromo-but-3-en-2-ol (**36**). The PMR spectrum of **36** would have shown a singlet for the C-4 proton and not a doublet with a coupling of 8 Hz. Z-3,4-Dibromobut-3-en-2-ol (**37**), for example, exhibits a sharp singlet at δ 7.00 for the C-4 proton.

Minor amounts of seven other halogenated but-3-en-2-ols (**21–26**, **28**) were detected in the alcohol fraction by GC–MS. By analogy the two olefinic halogens should be attached to C-4. Relative GC retention times for the butenols increased proportionally with their molecular weights. Molecular ion clusters, however, were not seen for all seven compounds. All of the alcohols exhibited oxonium ions (base peaks) and halomethyl ions in their mass spectra and therefore structure elucidation was straightforward. For example, **25** cleaved to give $Br_2C{=}CH{-}CH{=}\dot{O}H$ and $BrClCH^+$ whereas **26** fragmented to give $BrClC{=}CH{-}CH{=}\dot{O}H$ and Br_2CH^+. Compound **28** exhibited a 1:2:1 ion cluster at *m/e* 213, 215, 217 ($Br_2C{=}CH{-}CH{=}\dot{O}H$) and a 1:3:3:1 ion cluster at *m/e* 249, 251, 253, 255 (CBr_3^+). Furthermore natural **28** had a

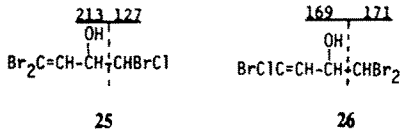
Table 1. Halogenated alcohols and amides in the methylene chloride extract of dried Hawaiian *Asparagopsis taxiformis*

Type of Compound		Structure	Est. % in Extract by Weight[a]	GC Retention Time (min)[b]	MS Fragments from α-Fission
Dihaloisopropanols	1	$Br_2CHCH(OH)CH_3$		8.3	1 Br_2CHOH^+, Br_2CH^+, CH_3CHOH^+
	2	$BrCH_2CH(OH)CH_2Br$		9.8	2 $BrCH_2^+$, $BrCH_2CHOH^+$
	3	$ClCH_2CH(OH)CH_2I$		10.1	3 ICH_2CHOH^+, $ClCH_2CHOH^+$
	4	$BrCH_2CH(OH)CH_2I$	0.01	11.4	4 ICH_2CHOH^+, $BrCH_2CHOH^+$, $BrCH_2^+$
	5	$ICH_2CH(OH)CH_2I$	0.009	13.3	5 ICH_2CHOH^+, ICH_2^+
Trihaloisopropanols	6	$BrClCHCH(OH)CH_2Cl$		10.1	6 $BrClCHCHOH^+$, $ClCH_2CHOH^+$
	7	$Cl_2CHCH(OH)CH_2Br$		10.1	7 $BrCH_2CHOH^+$, $Cl_2CHCHOH^+$
	8	$BrClCHCH(OH)CH_2Br$	0.01	11.3	8 $BrClCHCHOH^+$, $BrCH_2CHOH^+$, $BrCH_2^+$
	9	$Br_2CHCH(OH)CH_2Cl$	0.09	11.3	9 $Br_2CHCHOH^+$, Br_2CH^+, $ClCH_2CHOH^+$, $ClCH_2^+$
	10	$Br_2CHCH(OH)CH_2Br$	0.3	13.8	10 $Br_2CHCHOH^+$, Br_2CH^+, $BrCH_2CHOH^+$, $BrCH_2^+$
	11	$BrClCHCH(OH)CH_2I$	0.03	14.3	11 ICH_2CHOH^+, $BrClCHCHOH^+$, $BrClCH^+$
	12	$Br_2CHCH(OH)CH_2I$	0.03	15.8	12 $Br_2CHCHOH^+$, ICH_2CHOH^+
Tetrahaloisopropanols	13	$Cl_2CHCH(OH)CHCl_2$		11.2	13 $Cl_2CHCHOH^+$, Cl_2CH^+
	14	$BrClCHCH(OH)CHCl_2$		12.8	14 $BrClCHCHOH^+$, $BrClCH^+$, $Cl_2CHCHOH^+$, Cl_2CH^+
	15	$Br_2CHCH(OH)CHCl_2$		14.3	15 $Br_2CHCHOH^+$, $Cl_2CHCHOH^+$
	16	$Br_2CHCH(OH)CHBrCl$		15.8	16 $Br_2CHCHOH^+$, $BrClCHCHOH^+$
	17	$Br_3CCH(OH)CH_2Cl$		15.8	17 Br_3CCHOH^+, Br_3C^+, $ClCH_2CHOH^+$, $ClCH_2^+$
	18	$Br_2CHCH(OH)CHBr_2$	0.30	17.4	18 $Br_2CHCHOH^+$
	19	$Br_2CHCH(OH)CHBrI$	0.03	19.3	19 $Br_2CHCHOH^+$
	20	$Br_2CHCH(OH)CHI_2$	0.007	21.0	20 $Br_2CHCHOH^+$
1,4,4-Trihalobut-3-en-2-ols[c]	21	$Br_2C{=}CHCH(OH)CH_2Cl$	0.01	13.2	21 $Br_2C{=}CHCHOH^+$, $ClCH_2^+$
	22	$Br_2C{=}CHCH(OH)CH_2Br$	0.03	15.2	22 $Br_2C{=}CHCHOH^+$, $BrCH_2^+$
1,1,4,4-Tetrahalobut-3-en-2-ols[c]	23	$Br_2C{=}CHCH(OH)CHCl_2$		15.8	23 $Br_2C{=}CHCHOH^+$, Cl_2CH^+
	24	$Cl_2C{=}CHCH(OH)CHBr_2$		15.8	24 Br_2CH^+, $Cl_2C{=}CHCHOH^+$
	25	$Br_2C{=}CHCH(OH)CHBrCl$		17.2	25 $Br_2C{=}CHCHOH^+$, $BrClCH^+$
	26	$BrClC{=}CHCH(OH)CHBr_2$[d]	0.03	17.4	26 Br_2CH^+, $BrClC{=}CHCHOH^+$
	27	$Br_2C{=}CHCH(OH)CHBr_2$	0.6	18.8	27 $Br_2C{=}CHCHOH^+$, Br_2CH^+
1,1,1,4,4-Pentahalobut-3-en-2-ols[c]	28	$Br_2C{=}CHCH(OH)CBr_3$	0.04	21.4	28 Br_3C^+, $Br_2C{=}CHCHOH^+$
Dihaloacetamides	29	$BrClCHCONH_2$	0.2	13.7	29 $BrClCH^+$, $NH_2C{\equiv}O^+$
	30	$Br_2CHCONH_2$	0.7	14.5	30 Br_2CH^+, $NH_2C{\equiv}O^+$
	31	$ClICHCONH_2$	0.06	14.9	31 $NH_2C{\equiv}O^+$
	32	$BrICHCONH_2$	0.5	16.7	32 $NH_2C{\equiv}O^+$
	33	$I_2CHCONH_2$	0.3	19.2	33 $NH_2C{\equiv}O^+$

[a] Percentages of compounds that are less than 0.005% are not listed.

[b] Determined on a 6 ' x 1/8" stainless steel column of 3% OV-17 on 80-100 Supelcoport heated isothermally at 60° for 4 min after injection, then temperature programmed from 60° to 170° at 8° per min, and finally heated isothermally at 170° using a helium flow rate of 30 ml/min.

[c] There is no direct chemical or spectral evidence for the attachment of the two vinylic halogens in a geminal rather than in a vicinal position for compounds 21-26 and 28. By analogy with 27 the two halogens are assumed to be on C-4.



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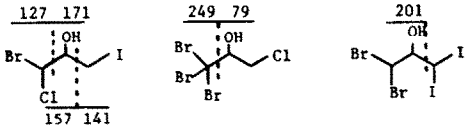
GC retention time and MS that were identical with those of synthetic **28** prepared by the addition of bromoform to 3,3-dibromoacrolein in the presence of lithium dicyclohexylamide.[5]

Twenty halogenated isopropanols were similarly identified in the alcohol fraction by GC–MS. The relative GC retention times for the isopropanols also corresponded nicely with molecular weights. The mass spectra of the iodine-containing alcohols clearly showed molecular ions, but molecular ion clusters were not observed for most of the other isopropanols. All of the alcohols underwent the expected α-fission to give oxonium ions and halomethyl ions. α-Fission was not the primary fragmentation



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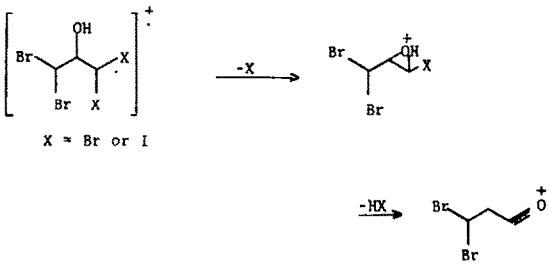
pathway in the mass spectra of **19** and **20**. The base peak was found in a 1:2:1 ion cluster at *m/e* 213, 215, 217 for **19** and **20** (successive losses of iodine and HBr or HI). Associated with this cluster was another 1:2:1 ion cluster at *m/e* 185, 187, 189 for further loss of CO. These two ion clusters had the same intensity ratios in both mass spectra and were also observed in the MS of **18**. For **18**, however, α-fission was the predominant fragmentation process. The *m/e* 213, 215, 217 ion cluster may have the structure $Br_2CHCH_2C \equiv \dot{O}$; it probably does not have the structure $Br_2C{=}CH{-}CH{=}\dot{O}H$ as there is no *m/e* 185, 187, 189 ion cluster, corresponding to the loss of CO from the oxonium ion, in the mass spectra of **27** and other 4,4-dibromobut-3-en-2-ols. Two of the major compounds (**10** and **18**) were compared directly with synthetic samples.[5]



X = Br or I

An optically inactive mixture of dihaloacetamides crystallized from the amide fraction. GC–MS analysis showed that it was primarily a mixture of **30**, **32** and **33** with smaller amounts of **29** and **31**. Each of the dihaloacetamides exhibited a molecular ion cluster in the MS and a huge *m/e* 44 peak for $NH_2C\equiv\dot{O}$. The PMR spectrum of the mixture in acetone-d_6 showed sharp singlets at δ 5.66, 6.09, 6.16, 6.26 and 6.30 for the CH protons of **33**, **32**, **30**, **31** and **29**, respectively, and several broad multiplets from 6.5 to 7.5 ppm for the amide protons of the various compounds. In DMSO-d_6 the amide signals were sharper and found in the 7.5–8.0 ppm region. The PMR spectrum of synthetic **30** in acetone-d_6 showed the methine proton at δ 6.16 (δ 6.26 in DMSO-d_6) and the amide protons at δ 7.0 and 7.4 (δ 7.62 and 7.86 in DMSO-d_6). By comparison the PMR spectrum of dichloroacetamide in DMSO-d_6 showed the methine proton at δ 6.34 and the amide protons at 7.71 and 7.89 ppm.

EXPERIMENTAL

PMR and CMR spectra were obtained on a Varian XL-100 spectrometer equipped with a Digilab Fourier transform system. Single frequency off-resonance decoupled CMR spectra were determined with the proton decoupler at δ 14. Chemical shifts are reported in δ units (ppm) relative to TMS (δ = 0) as an internal standard. GC–MS was carried out with a Hewlett-Packard 5700 Gas Chromatograph coupled through a double-stage jet separator to a JEOL JMS-01SG-2 double focusing mass spectrometer operating at 70 eV.

Isolation. After removal of the essential oil *in vacuo*,[5] dried plants of *A. taxiformis* (286 g) were extracted with methylene chloride. Evaporation of the solvent afforded 6.5 g (2.4%) of oil which was chromatographed on a 1 m × 2.5 cm column of silica gel. The chromatogram was developed initially with hexane and then with mixtures of hexane–ether.

One of the fractions (190 mg) eluted with 75:25 hexane/ether was rechromatographed on a 120 × 10 mm column of silica gel G (Brinkmann) with the same solvent system. A crystalline substance (70 mg) was obtained which upon recrystallization from pentane gave 26 mg of 1,1,4,4-tetrabromobut-3-en-2-ol (**27**) as colorless needles: m.p. 84.5–85.5°; $[\alpha]_D^{25} = +7.9°$ (CH_2Cl_2, c = 2.61); IR (CH_2Cl_2) 3540 (s), 3380 (m), 1610 (m), 1450 (w), 1185 (w), 1130 (w), 1010 (s) cm^{-1}; UV (EtOH) λ_{max} 212.5 nm (ϵ = 8400); PMR ($CDCl_3$) δ 2.68 (bd, J = 6.5 Hz, OH, disappears on addition of D_2O), 4.65 (m, C-2H, signal becomes dd, J = 3.5 and 8.0 Hz, on addition of D_2O), 5.72 (d, J = 3.5 Hz, C-1 H), 6.58 (d, J = 8.0 Hz, C-3 H); CMR ($CDCl_3$) δ 47.2 (d, C-1), 76.7 (d, C-2), 96.2 (s, C-4), 135.3 (d, C-3); MS *m/e* (rel. intensity) 384, 386, 388, 390, 392 (1:4:6:4:1 ion cluster < 1%), 213 (56), 215 (100), 217 (50), 171 (6), 173 (9), 175 (5), 105 (19), 107 (17). The mother liquor was evaporated to give 43 mg of yellow oil which was mainly a mixture of **27** and 1,1,3,3-tetrabromo-2-propanol [PMR ($CDCl_3$) δ 3.25 (bd, J = 5 Hz, OH), 4.23 (m, C-2 CH), 5.93 (d, J = 5 Hz, C-1 and C-3 CH)] with smaller amounts of other halogenated 3-buten-2-ols and isopropanols. Analysis of the mixture by GC–MS revealed the presence of the following compounds: 1,1,3,3-*tetrachloro*-2-*propanol* (**13**), < 1% retention time 11.2 min, *m/e* (rel. intensity) no M^+ ion cluster, 113 (100), 115 (68), 117 (7), 83 (23), 85 (20), 87 (6); 1-*bromo*-1,3,3-*trichloro*-2-*propanol* (**14**), < 1%, 12.8 min, no M^+ ion cluster, 157 (56), 159 (65), 161 (20), 127 (16), 129 (13), 131 (6), 113 (100), 115 (67), 117 (7) 83 (24), 85 (18), 87 (6); 1,1,3-*tribromo*-2-*propanol* (**10**), < 10%, 13.8 min, 294 (0.1), 296 (0.3), 298 (0.3), 300 (0.1), 201 (6), 203 (7), 205 (4), 171 (4), 173 (7), 175 (4), 123 (100), 125 (94), 93 (17), 95 (16); 1,1-*dibromo*-3,3-*dichloro*-2-*propanol* (**15**), < 1%, 14.3 min, no M^+ ion cluster, 201 (52), 203 (95), 205 (49), 113 (100), 115 (67), 117 (14); 1-*bromo*-1-*chloro*-3-*iodo*-2-*propanol* (**11**), 4%, 14.3 min, 298 (5), 300 (5), 302 (3), 171 (100), 157 (72), 159 (82), 161 (24), 127 (48), 129 (50), 131 (14); 4,4-*dichloro*-1,1-*dibromobut*-3-*en*-2-*ol* (**24**), < 1%, 15.8 min, no M^+ ion cluster, 171(2), 173 (6), 175 (2), 125 (100), 127 (62), 129 (16); 4,4-*dibromo*-1,1-*dichlorobut*-3-*en*-2-*ol* (**23**), < 1%, 15.8 min, no M^+ ion cluster, 213 (65), 215 (100), 217 (60), 83 (40), 85 (70), 87 (15); 1,1-*dibromo*-3-*iodo*-2-*propanol* (**12**), 5%, 15.8 min, 342, 344, 346 (0.6:1.0:0.5 ion cluster, < 1%), 201 (49), 203 (89), 205 (45), 171 (100); 1,1,1-*tribromo*-3-*chloro*-2-*propanol* (**17**), < 1%, 15.8 min, no M^+ ion cluster, 279 (3), 281 (5), 283 (5), 285 (2), 249 (5), 251 (8), 253 (6), 255 (4), 79 (> 100), 81 (> 100), 49 (11), 51 (5); 1,1,3-*tribromo*-3-*chloro*-2-*propanol* (**16**), < 1%, 15.8 min, no M^+ ion cluster, 201 (55), 203 (96), 205 (47), 157 (80), 159 (100), 161 (28); 1,1,4-*tribromo*-4-*chlorobut*-3-*en*-2-*ol* (**26**), 5%, 17.4 min, 340, 342, 344, 346, 348 (0.5:0.7:1:0.6:0.1 ion cluster, < 1%), 169 (76), 171 (100), 173 (34), 175 (6); 1,1,3,3-*tetrabromo*-2-*propanol* (**18**), 43%, 17.4 min, 372, 374, 376, 378, 380 (1:4:6:4:1 cluster, < 1%), 213 (4), 215 (7), 217 (4), 201 (53), 203 (100), 205 (48), 185 (4), 187 (7), 189 (4); 1,1,4,4-*tetrabromobut*-3-*en*-2-*ol* (**27**), 31%, 18.8 min; 1,1,3-

tribromo-3-iodo-2-propanol (**19**), 5%, 19.3 min, 420, 422, 424, 426 (1:3:3:1 ion cluster < 1%), 293 (8), 295 (15), 297 (15), 299 (8), 213 (55), 215 (100), 217 (50), 201 (12), 203 (20), 205 (10), 185 (49), 187 (79), 189 (40); 1,1-*dibromo-3,3-diiodo-2-propanol* (**20**), 1%, 21.0 min, 468, 470, 472 (1:2:1 ion cluster, < 1%), 341 (11), 343 (17), 345 (11), 213 (52), 215 (100), 217 (48), 201 (26), 203 (38), 205 (25), 185 (20), 187 (33), 189 (20), 127 (43); 1,1,1,4,4-*pentabromobut-3-en-2-ol* (**28**), 6%, 21.4 min, 472, 474, 476, 478, 480, 482 (0.1:0.6:1.0:0.9:0.5:0.2 ion cluster, < 1%), 275 (2), 277 (3), 279 (3), 281 (2), 249 (1), 251 (2), 253 (2), 255 (1), 213 (61), 215 (100), 217 (47).

The next fraction eluted from the silica gel column with 75.25 hexane/ether was an oil (310 mg). Rechromatography on silica gel G with 60:40 hexane/methylene chloride yielded 30 mg of oil containing mostly **10** [PMR ($CDCl_3$) δ 3.30 (d, J = 5 Hz, OH), 3.66 (d, J = 5 Hz, C-3 CH_2), 4.15 (m, C-2 H), 5.40 (d, J = 4 Hz, C-1 H) and 1,1-*dibromo-3-chloro-2-propanol* (**9**) [PMR ($CDCl_3$) δ 3.30 (bd, OH), 3.76 (d, J = 5 Hz, C-3 CH_2), 4.15 (m, C-2 H), 5.40 (d, J = 4 Hz, C-1 H) plus small amounts of other halogenated isopropanols and 3-buten-2-ols. Analysis of the mixture by GC–MS showed the presence of the following compounds: 1,1-*dibromo-2-propanol* (**1**), < 1%, retention time 8.3 min, *m/e* (rel. Intensity) 216, 218, 220 (1:2:1 ion cluster, < 1%), 201 (9), 203 (13), 205 (10), 171 (4), 173 (20), 175 (13), 45 (> 100); 1,3-*dibromo-2-propanol* (**2**), < 1%, 9.8 min, 216 (3), 218(4), 220 (3), 123 (97), 125 (100), 93 (11), 95 (9); 1-*bromo-1,3-dichloro-2-propanol* (**6**), < 1%, 10.1 min, no M^+ ion cluster, 157 (8), 159 (10), 161 (3), 79 (100), 81 (32); 1-*bromo-3,3-dichloro-2-propanol* (**7**), < 1%, 10.1 min, no M^+ ion cluster, 123 (100), 125 (95), 113 (8), 115 (6), 117 (2); 1-*chloro-3-iodo-2-propanol* (**3**), < 1%, 10.1 min, 220, 222 (1:0.3 ion cluster, < 1%), 171 (3), 79 (100), 81 (32); 1,3-*dibromo-1-chloro-2-propanol* (**8**), 3%, 11.3 min, no M^+ ion cluster, 157 (11), 159 (14), 161 (4), 123 (> 100), 125 (> 100), 93 (39), 95 (37); 1,1-*dibromo-3-chloro-2-propanol* (**9**), 20%, 11.3 min, 250, 252, 254, 256 (0.5:1.0:0.7:0.3 ion cluster, < 1%), 201 (7), 203 (14), 205 (7), 171 (3), 173 (6), 175 (3), 79 (100), 81 (40), 49 (10), 51 (3); 1-*bromo-3-iodo-2-propanol* (**4**), 3%, 11.4 min, 264 (12), 266 (11), 171 (45), 123 (> 100), 125 (> 100), 93 (39), 95 (36); 1,1,3-*tribromo-2-propanol* (**10**), 55%, 13.1 min; 4,4-*dibromo-1-chlorobut-3-en-2-ol* (**21**), 3%, 13.2 min, 262, 264, 266, 268, (0.6:1:0.8:0.4 ion cluster, < 1%), 213 (55), 215 (100), 217 (53), 49 (15), 51 (5); 1,3-*diiodo-2-propanol* (**5**), 2%, 13.3 min, 312 (35), 185 (85), 171 (100), 141 (30); 1,4,4-*tribromobut-3-en-2-ol* (**22**), 7%, 15.2 min, 306 (1), 308 (3), 310 (4), 312 (1), 213 (64), 215 (> 100), 217 (61), 93 (7), 95 (5); 1,1-*dibromo-3-iodo-2-propanol* (**12**), < 1%, 15.5 min; 1,1,4-*tribromo-4-chlorobut-3-en-2-ol* (**26**), < 1%, 16.9 min; 1,4,4-*tribromo-1-chlorobut-3-en-2-ol* (**25**), < 1%, 17.2 min, 340, 343, 344, 346, 348 (0.5:0.7:1:0.6:0.2 ion cluster, < 1%), 213 (53), 215 (100), 217 (48), 127 (4), 129 (6), 131 (2); 1,1,4,4-*tetrabromobut-3-en-2-ol* (**27**), 5%, 18.5 min.

Elution with 100% ether gave a fraction (600 mg) which was dissolved in 3 ml of methylene chloride. On standing in the cold 80 mg of a greenish solid precipitated. Recrystallization from methylene chloride gave 75 mg of an optically inactive mixture of dihaloacetamides as colorless needles. Analysis of the mixture by GC–MS showed the presence of the following dihaloacetamides; *bromochloroacetamide* (**29**), 15%, retention time 14.4 min, *m/e* (rel. intensity) 171 (9), 173 (13), 175 (3), 127 (3), 129 (5), 131 (2), 44 (> 100); *dibromoacetamide* (**30**), 51%, 14.9 min, 215 (3), 217 (6), 219 (3), 172 (2), 174 (4), 176 (2), 171 (1), 173 (2), 175 (1), 120 (2), 122 (2), 91 (2), 92 (3), 93 (3), 94 (3), 95 (2), 79 (2), 81 (2), 44 (> 100); *chloroiodoacetamide* (**31**), 5%, 15.9 min, 219 (4), 221 (1), 127 (2), 92 (7), 94 (4), 44 (> 100); *bromoiodoacetamide* (**32**), 22%, 17.4 min, 263 (26), 265 (24), 220 (35), 222 (35), 136 (55), 138 (59), 127 (24), 44 (≥ 100); *diiodoacetamide* (**33**), 6%, 19.9 min, 311 (55), 268 (20), 184 (91), 127 (37), 44 (≥ 100). The PMR spectrum of the mixture in acetone-d_6 showed singlets at δ 5.66, 6.09, 6.16, 6.26 and 6.30 for the CH protons of **33**, **32**, **31**, **30**, and **29**, respectively, and several broad multiplets for the NH_2 protons in the 6.5–7.5 ppm region (7.5–8.0 in DMSO-d_6). The next fraction eluted from the silica gel column with 100% ether (610 mg) also deposited a mixture of dihaloacetamides (30 mg) from methylene chloride; PMR and GC–MS analysis showed that it was essentially a 2:2:1 mixture of **33**, **32** and **30**, respectively.

1,1,4,4-*Tetrabromo-3-buten-2-ol* (**27**)

(a) *From 3,3-dibromoacrolein and methylene bromide.* 3,3-Dibromoacrolein (2.52 g, 10.0 mmol), methylene bromide (1.74 g, 10.0 mmol) and lithium dicyclohexylamide (3.74 g, 20.0 mmol) were reacted as described by Taguchi *et al.*[5] Workup as described below for **28** gave after vacuum sublimation (78°, 0.025 torr) 1.06 g (27%) of **27** as colorless needles, m.p. 84–85°. (Found: C, 12.2; H, 1.0. Calcd. for $C_4H_4Br_4O$: C, 12.4; H, 1.0%).

(b) *From 1,1,4,4-tetrabromobutenone.* Fraction 4 (11 mg, essentially a 2:1 mixture of **35** and 1,1,1-tribromoacetone) from chromatography of the essential oil of *A. taxiformis* on silica gel at 5°[2] was treated with 20 mg $NaBH_4$ in 1 ml EtOH at 0° for 30 min. One ml of 2N NH_4Cl followed by 20 ml water were added and the mixture was extracted with methylene chloride. The dried extract was evaporated to give **27**. The PMR spectrum was identical with that of **27** from Method (a) and signals for 1,1,1-tribromo-2-propanol were not present.

Z-3,4-Dibromobut-3-en-2-ol (**37**). Z-3,4-Dibromobutenone (0.5 g) was added to a soln of 100 mg $NaBH_4$ (excess) in EtOH (5 ml) at 0° and stirred for 10 min. Water (75 ml) was added and the soln extracted with methylene chloride (3 × 15 ml). The extracts were combined, dried ($MgSO_4$) and the solvent removed *in vacuo* to give 0.49 g (97%) of crude **37**: PMR δ 1.41 (d, J = 6.5 Hz, Me), 2.9 (bs, OH), 4.41 (q, J = 6.5 Hz, C-2 H), 7.00 (s, C-4 H).

1,1,1,4,4-*Pentabromo-3-buten-2-ol* (**28**). 3,3-Dibromoacrolein (1.07 g, 4.2 mmol) and freshly distilled bromoform (2.52 g, 5.0 mmol) were reacted with lithium dicyclohexylamide (1.73 g, 10 mmol) using the generalized procedure of Taguchi *et al.*[5] The mixture was quenched with 50 ml of 2N NH_4Cl and the organic solvents were removed *in vacuo*. The oily solid was extracted with methylene chloride (3 × 40 ml), the extracts combined, dried ($MgSO_4$) and the solvent removed *in vacuo* to give 3.16 g of dark oil. Chromatography of the oil on 1 × 1.5 cm column of silica gel with 50:50 methylene chloride/hexane followed by vacuum sublimation (85°, 0.025 torr) afforded 1.35 g (69%) of **28** as colorless needles, m.p. 94.0–95.5°; IR (Nujol) ν_{max} 3260 (s), 1630 (w), 1460 (m), 1380 (m), 1140 (m), 790 (w), 740 (m), 710 (m) cm^{-1}; UV (EtOH) λ_{max} 215 nm (ϵ = 12,000); PMR ($CDCl_3$) δ 6.64 (d, J = 8.0 Hz, C-3 H), 4.75 (dd, J = 6.0 and 8.0 Hz, C-2 H), 3.28 (d, J = 6.0 Hz, OH); CMR ($CDCl_3$) δ 133.4 (d, C-3), 97.9 (s, C-4), 83.7 (d, C-2), 48.7 (s, C-1). (Found: C, 10.6; H, 0.7. Calc. for $C_4H_3OBr_4$: C, 10.3; H, 0.7%).

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