

Structures Related to Jasmonic Acid and Their Effect on Lettuce Seedling Growth

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Thirty-eight homologs of jasmonic acid and related compounds were prepared and tested as growth inhibitors of lettuce seedlings. The data suggest

that 2-octyl- and 2-methylcyclohexyl homologs of dihydrojasmonic acid are the most potent inhibitors.

A recent study of Aldridge et al. (1971) revealed that jasmonic acid is a plant-growth inhibitor. The objective of the work reported in this paper was to study the effects of various modified and closely related structures of jasmonic acid on growth inhibition of lettuce seedlings.

We tested compounds of the general structures II, VI, VII, and IX, the last one having a cyclohexanone moiety instead of the cyclopentanone ring which is characteristic of jasmonic acid. Furthermore, a series of monosubstituted cyclopentenones (I, III, and IV) and cyclopentanones V, which are intermediates in the jasmonic acid derivatives synthesis, were also tested.

EXPERIMENTAL SECTION

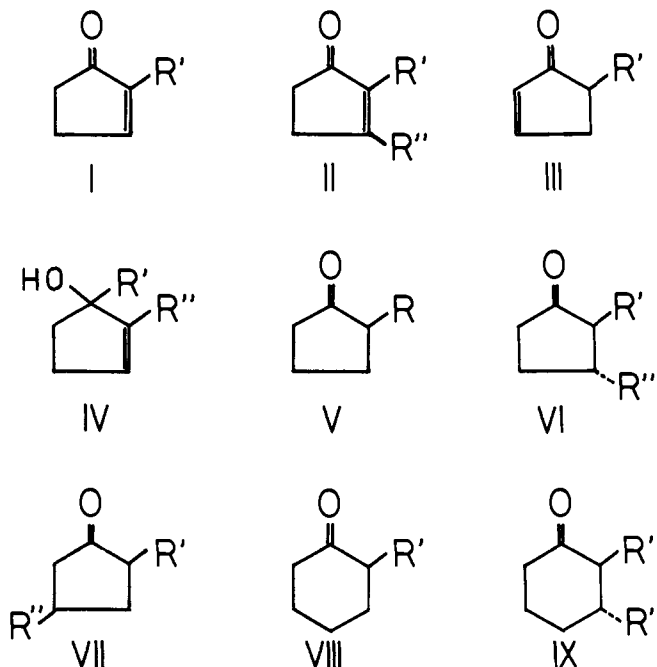
Test Procedure. The samples were dissolved in acetone to give a 10^{-2} M concentration. A 10- μ l aliquot of each sample was added to 140 μ l of water in a 10-ml beaker to give the test concentration of 6.7×10^{-4} . A filter paper disk was placed at the bottom of each beaker and 10 lettuce seeds (cv. Grand Rapids) were placed on the paper. There was one replicate beaker per test. Germination and radicle length of the germinated seedlings were recorded after 48 to 72 hr in a $22 \pm 2^\circ$ room with low intensity fluorescent light (50 ft-c "Cool White" (General Electric Co.) at seed level). Radicle length was measured by scale, visually, to the nearest millimeter. Percent inhibition of elongation was determined as follows: $100 \times (\text{radicle length, control} - \text{radicle length, test}) / \text{radicle length, control}$. Percent germination figures are the averages of the two beakers. Analyses of variance were performed on the radicle length data; in Table I only least significant differences at the 5% level are indicated.

RESULTS AND DISCUSSION

The data of Table I indicate that the cyclohexane homologs such as IXi are more potent inhibitors of lettuce radicle growth and germination than the corresponding cyclopentanes such as VIi. Some compounds (Vm', Vh', IXj'), although not preventing germination, were found to be strong inhibitors of radicle elongation. Commonly, compounds influenced germination and radicle elongation differently, suggesting that two different systems are involved for controlling the two processes. These results will guide further larger scale experiments on growth inhibition in crop and ornamental species.

Syntheses. The structures of 38 compounds studied in this work (Table I) are shown under the general formulas I to IX. The literature references are for synthetic routes used to prepare the corresponding compounds.

Methyl 2-Oxocyclopent-5-enyl-1-acetate (Ia) (Ravid et al., 1975) (bp $74-76^\circ$ (0.4 mm); yield, 35%); ir (liquid) 1732, 1705, 1636, 1435, 1260, 1079 cm^{-1} ; NMR (CCl_4) δ 1.58-2.76 (4 H, m), 3.11 (2 H, m), 3.64 (3 H, s), 7.47 (1 H,



m). Anal. Calcd for $\text{C}_8\text{H}_{10}\text{O}_3$: C, 62.34; H, 6.49. Found: C, 62.30; H, 6.71.

2-Pentylcyclopent-2-en-1-one (Ib) (Ravid and Ikan, 1974a) (bp 60° (0.2 mm); yield, 78%); ir (liquid) 1700, 1633, 1445, 1253, 1198, 1050, 1000 cm^{-1} ; NMR (CDCl_3) δ 0.85 (3 H, t), 1.08-1.63 (6 H, m), 1.88-2.72 (6 H, m), 7.06 (1 H, m). Anal. Calcd for $\text{C}_{10}\text{H}_{16}\text{O}$: C, 78.90; H, 10.59. Found: C, 78.76; H, 10.60.

2-Octylcyclopent-2-en-1-one (Ic) (Ravid and Ikan, 1975b) (bp 94° (0.5 mm); yield, 76%); ir (liquid) 1705, 1632, 1465, 1345, 1200, 1000, 788 cm^{-1} ; NMR (CDCl_3) δ 0.85 (3 H, t), 1.02-1.59 (12 H, m), 1.86-2.67 (6 H, m), 7.13 (1 H, m). Anal. Calcd for $\text{C}_{13}\text{H}_{22}\text{O}$: C, 80.35; H, 11.41. Found: C, 80.32; H, 11.42.

Methyl 2-Pentyl-3-oxo-1-cyclopentenylacetate (IId) (Ravid and Ikan, 1974a) (bp $118-119^\circ$ (0.4 mm); yield, 87%); ir (liquid) 1740, 1705, 1645, 1435, 1175 cm^{-1} ; uv $\lambda_{\text{max}}^{\text{EtOH}}$ 237 nm (ϵ 9200); NMR (CCl_4) δ 0.83 (3 H, t), 1.15-1.41 (8 H, m), 2.01-2.80 (4 H, m), 3.35 (2 H, s), 3.68 (3 H, s). Anal. Calcd for $\text{C}_{13}\text{H}_{20}\text{O}_3$: C, 69.64; H, 8.93. Found: C, 69.73; H, 9.20.

2-Octyl-3-methylcyclopent-2-en-1-one (IIe) (Ravid and Ikan, 1974a) (bp 130° (0.2 mm); yield, 64%); ir (liquid) 1705, 1647, 1465, 1387, 1180, 1073, 805, 755 cm^{-1} ; NMR (CCl_4) δ 0.82 (3 H, t), 1.00-1.53 (12 H, m), 1.98 (3 H, s), 1.98-2.52 (6 H, m).

2-Pentyl-2-carbethoxycyclopent-4-en-1-one (IIIIf) (Ravid and Ikan, 1974b) (bp $86-88^\circ$ (0.6 mm); yield, 51%); ir (liquid) 1745, 1712, 1595, 1470, 1344, 1258, 1240, 1186 cm^{-1} ; NMR (CDCl_3) δ 0.67-1.04 (3 H, t), 1.11-2.05 (11 H, m), 2.36-3.52 (2 H, m), 4.14 (2 H, q), 6.11 (1 H, m), 7.74 (1 H, m); uv $\lambda_{\text{max}}^{\text{EtOH}}$ 223 nm (ϵ 7700). Anal. Calcd for $\text{C}_{13}\text{H}_{20}\text{O}_3$: C, 69.64; H, 8.93. Found: C, 69.71; H, 9.02.

Methyl 2-Pentylcyclopent-2-en-1-olacetate (IVg)

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Table I. Structures and Growth Inhibition Data

No.	R'	R''	% inhibition	% germination	Radicle length, mm ^a
Control				100	29
Ia	CH ₂ COOCH ₃		95	10	0.5
Ib	(CH ₂) ₄ CH ₃		65	100	10
Ic	(CH ₂) ₇ CH ₃		75	100	7
IIId	(CH ₂) ₄ CH ₃	CH ₂ COOCH ₃		60	7
IIe	(CH ₂) ₇ CH ₃	CH ₃	73	100	8
IIIIf	(CH ₂) ₄ CH ₃		56	100	13
	COOC ₂ H ₅				
IVg	CH ₂ COOCH ₃	(CH ₂) ₄ CH ₃	55	100	13
Vh	CH ₂ COOCH ₃		98	70	1
Vi	(CH ₂) ₄ CH ₃		66	100	10
Vj	(CH ₂) ₆ CH ₃		70	100	9
Vk	(CH ₂) ₇ CH ₃		66	100	10
VI	CH ₂ C≡CCH ₂ CH ₃		65	100	10
Vm	CH ₃		89	100	3
	COOC ₂ H ₅				
Vn	(CH ₂) ₃ CH ₃		15	100	24
	COOC ₂ H ₅				
Vo	(CH ₂) ₄ CH ₃		61	100	11
	COOC ₂ H ₅				
Vp	(CH ₂) ₆ CH ₃		60	100	12
	COOC ₂ H ₅				
Vq	(CH ₂) ₇ CH ₃		53	100	14
	COOC ₂ H ₅				
Vr	CH ₂ C≡CCH ₂ CH ₃		74	100	8
	COOC ₂ H ₅				
Vs	CH ₂ CH ₂ COOC ₂ H ₅		23	100	22
	COOC ₂ H ₅				
VIIt	CH ₃	CH ₂ COOH		50	12
VIU	CH ₃	CH ₂ COOCH ₃		30	12
VIv	CH ₃	CH(COOCH ₃) ₂	42	100	17
VIw	(CH ₂) ₄ CH ₃	CH ₃	47	100	15
VIx	(CH ₂) ₇ CH ₃	CH ₃	57	100	12
VIy	(CH ₂) ₄ CH ₃	CH ₂ COOH		50	5
VIz	(CH ₂) ₄ CH ₃	CH ₂ COOCH ₃		70	2
VIa'	CH ₂ C≡CCH ₂ CH ₃	CH ₂ COOCH ₃		40	6
VIb'	(CH ₂) ₇ CH ₃	CH ₂ COOH		0	
VIc'	(CH ₂) ₇ CH ₃	CH ₂ COOCH ₃		20	6
VIId'	(CH ₂) ₇ CH ₃	CH(COOCH ₃) ₂	65	100	10
VIIf'	(CH ₂) ₄ CH ₃				
	COOC ₂ H ₅	CH(COOCH ₃) ₂	46	100	16
VIIIf'	(CH ₂) ₄ CH ₃	CH ₂ COOH	63	100	11
VIIg'	(CH ₂) ₂ CH ₃	CH ₂ COOCH ₃	16	100	24
VIIIh'	(CH ₂) ₄ CH ₃		75	100	7
	COOC ₂ H ₅				
IXi'	CH ₃	CH ₂ COOH		0	
IXj'	CH ₃	CH ₂ COOCH ₃		10	5
IXk'	CH ₃	(CH ₂) ₄ CH ₃	56	100	13
IXl'	CH ₃	CH(COOCH ₃) ₂	26	100	21

^a LSD, 0.01, 4 mm; 0.05, 3 mm.

(Ravid and Ikan, 1974a) (bp 97° (0.4 mm); yield, 82%); ir (liquid) 3500, 1740, 1440, 1203 cm⁻¹; NMR (CCl₄) δ 0.93 (3 H, t), 1.13–1.50 (8 H, m), 1.7–2.24 (4 H, m), 2.42 (2 H, s), 2.52 (2 H, s), 3.31 (1 H, s), 3.69 (3 H, s), 5.42 (1 H, m). Anal. Calcd for C₁₃H₂₂O₃: C, 69.03; H, 9.74. Found: C, 69.10; H, 9.47.

Methyl 2-Oxocyclopentyl-1-acetate (Vh) (Ravid et al., 1975) (bp 80–81° (0.6 mm); yield, 36.5%); ir (liquid) 1737, 1725, 1437, 1263 cm⁻¹; NMR (CCl₄) δ 1.46–2.90 (9 H, m), 3.65 (3 H, s). Anal. Calcd for C₈H₁₂O₃: C, 61.54; H, 7.69. Found: C, 61.59; H, 7.66.

2-Pentylcyclopentan-1-one (Vi) (Ravid and Ikan,

1974a) (bp 60–62° (0.5 mm)): ir (liquid) 1738, 1470, 1466, 1410, 1155, 929 cm^{-1} ; NMR (CDCl_3) δ 0.82 (3 H, t), 1.03–1.50 (8 H, m), 1.66–2.41 (7 H, m). Anal. Calcd for $\text{C}_{10}\text{H}_{18}\text{O}$: C, 77.92; H, 11.69. Found: C, 78.08; H, 11.77.

2-Heptylcyclopentan-1-one (Vj) (Ravid and Ikan, 1974a) (bp 91–93° (0.9 mm); 75%): ir (liquid) 1740, 1469, 1154 cm^{-1} ; NMR (CCl_4) δ 0.85 (3 H, t), 1.05–1.40 (12 H, m), 1.70–2.35 (7 H, m). Anal. Calcd for $\text{C}_{12}\text{H}_{22}\text{O}$: C, 79.06; H, 12.16. Found: C, 79.50; H, 12.13.

2-Octylcyclopentan-1-one (Vk) (Ravid and Ikan, 1975b) (bp 120° (4 mm); yield, 69%): ir (liquid) 1745, 1468, 1155 cm^{-1} ; NMR (CDCl_3) δ 0.88 (3 H, t), 1.09–1.42 (14 H, m), 1.67–2.28 (7 H, m). Anal. Calcd for $\text{C}_{13}\text{H}_{24}\text{O}$: C, 79.53; H, 12.32. Found: C, 79.73; H, 12.33.

2-Pentynylcyclopentan-1-one (Vl) (Ravid and Ikan, 1975a) (bp 66–68° (0.5 mm); yield, 69%): ir (liquid) 3464, 1740, 1640, 1455, 1157 cm^{-1} ; NMR (CCl_4) δ 1.07 (3 H, t), 1.50–1.90 (11 H, m); semicarbazone, mp 172–176°. Anal. Calcd for $\text{C}_{11}\text{H}_{17}\text{N}_3\text{O}$: C, 63.74; H, 8.27; N, 20.27. Found: C, 63.96; H, 7.83; N, 20.44.

2-Methyl-2-carbethoxycyclopentan-1-one (Vm) (Ravid and Ikan, 1974a) (bp 57° (0.3 mm); yield, 81%); ir (liquid) 1750, 1727, 1455 cm^{-1} ; NMR (CDCl_3) δ 1.18 (3 H, t), 1.22 (3 H, s), 1.66–2.11 (4 H, m), 2.13–2.63 (2 H, m), 4.08 (2 H, q). Anal. Calcd for $\text{C}_9\text{H}_{14}\text{O}_3$: C, 63.51; H, 8.29. Found: C, 63.87; H, 8.17.

2-Butyl-2-carbethoxycyclopentan-1-one (Vn) (Ravid and Ikan, 1975b) (bp 93–95° (0.7 mm); yield, 88%): ir (liquid) 1760, 1730; NMR (CCl_4) δ 0.88 (3 H, t), 1.30 (3 H, t), 1.6–2.8 (12 H, m), 4.35 (2 H, q). Anal. Calcd for $\text{C}_{12}\text{H}_{20}\text{O}_3$: C, 67.89; H, 9.50. Found: C, 67.93; H, 9.35.

2-Pentyl-2-carbethoxycyclopentan-1-one (Vo) (Ravid and Ikan, 1974a) (bp 100° (0.1 mm)): ir (liquid) 1755, 1730, 1630, 1463, 1230, 1150, 1030 cm^{-1} ; NMR (CDCl_3) δ 0.85 (3 H, t), 1.10–2.66 (17 H, m), 4.04 (2 H, q). Anal. Calcd for $\text{C}_{13}\text{H}_{22}\text{O}_3$: C, 68.99; H, 9.80. Found: C, 68.90; H, 9.65.

2-Heptyl-2-carbethoxycyclopentan-1-one (Vp) (Ravid and Ikan, 1975b) (bp 111° (0.6 mm); yield, 90%): ir (liquid) 1756, 1728 cm^{-1} ; NMR (CDCl_3) δ 0.85 (6 H, t), 1.10–1.38 (10 H, m), 1.58–2.63 (8 H, m), 4.08 (2 H, q). Anal. Calcd for $\text{C}_{15}\text{H}_{26}\text{O}$: C, 70.83; H, 10.30. Found: C, 70.80; H, 10.33.

2-Octyl-2-carbethoxycyclopentan-1-one (Vq) (Ravid and Ikan, 1975b) (bp 141° (3 mm); yield, 76%); ir (liquid) 1755, 1725, 1630, 1468, 1385, 1230, 1030 cm^{-1} ; NMR (CDCl_3) δ 0.83 (3 H, t), 1.28 (3 H, t), 2.0–2.7 (20 H, m), 4.1 (2 H, q). Anal. Calcd for $\text{C}_{16}\text{H}_{28}\text{O}_3$: C, 71.60; H, 10.52. Found: C, 71.58; H, 10.61.

2-(2'-Pentynyl)-2-carbethoxycyclopentan-1-one (Vr) (Ravid and Ikan, 1974a) (bp 120–121° (2 mm); yield, 75%): ir (liquid) 3470, 2240, 1760, 1730, 1450, 1325, 1230, 1155, 1030 cm^{-1} ; NMR (CCl_4) δ 1.16 (6 H, m), 1.78–2.46 (8 H, m), 2.59 (2 H, t), 4.10 (2 H, q). Anal. Calcd for $\text{C}_{13}\text{H}_{18}\text{O}$: C, 70.24; H, 8.16. Found: C, 70.07; H, 8.18.

Ethyl 2-(2-Carbethoxyethyl)cyclopentan-1-one-2-carboxylate (Vs) (Ravid and Ikan, 1975b) (bp 139–142° (1.5 mm); yield, 79%): ir (liquid) 1750, 1720 cm^{-1} ; NMR (CCl_4) δ 1.26 (6 H, t), 1.71–3.0 (19 H, m), 4.32 (4 H, m). Anal. Calcd for $\text{C}_{13}\text{H}_{20}\text{O}_5$: C, 60.92; H, 7.87. Found: C, 60.68; H, 7.80.

2-Methyl-3-oxocyclopentylacetic Acid (VIt) (Ravid and Ikan, 1974a) (bp 167° (0.2 mm); yield, 90%): ir (liquid) 3030–3080, 1735, 1717, 1410, 1165 cm^{-1} ; NMR (CCl_4) δ 1.08 (3 H, d), 1.50–2.90 (8 H, m), 9.3 (1 H, s). Anal. Calcd for $\text{C}_8\text{H}_{12}\text{O}_3$: C, 61.52; H, 7.74. Found: C, 61.56; H, 7.85.

Methyl (2-Methyl-3-oxocyclopentyl)acetate (VIu) (Ravid and Ikan, 1974a) (bp 136–138° (0.2 mm)): ir (liquid) 1740, 1440, 1330, 1240, 1200, 1160 cm^{-1} ; NMR (CCl_4) δ 1.03 (3 H, d), 1.4–2.6 (8 H, m), 3.63 (3 H, s). Anal. Calcd for $\text{C}_9\text{H}_{14}\text{O}_3$: C, 63.51; H, 8.29. Found: C, 63.44; H, 8.47.

2-Methyl-3-dimethylmalonylcyclopentan-1-one

(VIv) (Ravid and Ikan, 1974a) (bp 88–90° (0.2 mm); yield, 66%): ir (liquid) 1740, 1435, 1264, 1235, 1150 cm^{-1} ; NMR (CCl_4) δ 1.04 (3 H, d), 1.90–2.40 (6 H, m), 3.37 (1 H, d), 3.70 (6 H, s). Anal. Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_5$: C, 57.89; H, 7.07. Found: C, 57.86; H, 7.16.

2-Pentyl-3-methylcyclopentan-1-one (VIw) (Ravid and Ikan, 1974a) (yield, 68%): ir (liquid) 1735, 1460, 1380, 1155, 790 cm^{-1} ; NMR (CDCl_3) δ 0.63–0.98 (6 H, m), 1.00–1.70 (8 H, m), 1.82–2.63 (6 H, m). Anal. Calcd for $\text{C}_{11}\text{H}_{20}\text{O}$: C, 78.57; H, 11.98. Found: C, 78.55; H, 11.60.

2-Octyl-3-methylcyclopentan-1-one (VIx) (Ravid and Ikan, 1974a) (bp 88° (0.6 mm); yield, 77%): ir (liquid) 1740, 1460, 1380, 1155 cm^{-1} ; NMR (CDCl_3) δ 0.88 (6 H, m), 1.01–1.58 (14 H, m), 1.83–2.45 (6 H, m). Anal. Calcd for $\text{C}_{15}\text{H}_{26}\text{O}$: C, 81.02; H, 11.79. Found: C, 81.01; H, 11.85.

2-Pentyl-3-oxocyclopentylacetic Acid (Dihydrojasmonic Acid) (VIy) (Ravid and Ikan, 1974a) (bp 168–170° (0.3 mm)): ir (liquid) 3070–3020, 1740, 1712, 1465, 1410, 1165 cm^{-1} ; NMR (CCl_4) δ 0.85 (3 H, t), 1.05–1.65 (8 H, m), 1.84–2.74 (8 H, m), 11.2 (1 H, s). Anal. Calcd for $\text{C}_{12}\text{H}_{20}\text{O}_3$: C, 67.89; H, 9.50. Found: C, 68.08; H, 9.31.

Methyl (2-Pentyl-3-oxocyclopentyl)acetate (Methyl Dihydrojasmonate) (VIz) (Ravid and Ikan, 1974a) (bp 105–107° (0.2 mm)): ir (liquid) 1740, 1440, 1269, 1170 cm^{-1} ; NMR (CCl_4) δ 0.85 (3 H, t), 1.01–1.58 (8 H, m), 1.82–2.51 (8 H, m), 3.55 (3 H, s). Anal. Calcd for $\text{C}_{13}\text{H}_{22}\text{O}_3$: C, 68.99; H, 9.80. Found: C, 68.72; H, 9.60.

Methyl (2-Pentynyl)-3-oxocyclopentylacetate (VIa') (Ravid and Ikan, 1974a) (bp 170–172° (0.2 mm)): ir (liquid) 1740, 1438, 1322, 1245, 1200, 1163 cm^{-1} ; NMR (CCl_4) δ 1.09 (3 H, t), 1.7–2.8 (12 H, m), 3.65 (3 H, m). Anal. Calcd for $\text{C}_{13}\text{H}_{18}\text{O}_3$: C, 70.24; H, 8.16. Found: C, 69.85; H, 8.15.

3-Octyl-3-oxocyclopentylacetic Acid (VIb') (Ravid and Ikan, 1974a) (bp 210° (4 mm); yield, 92%): ir (liquid) 3050–3080, 1740, 1710, 1465, 1410, 1160 cm^{-1} ; NMR (CCl_4) δ 0.83 (3 H, t), 0.96–1.54 (14 H, m), 1.92–2.59 (8 H, m), 11.2 (1 H, s). Anal. Calcd for $\text{C}_{15}\text{H}_{26}\text{O}_3$: C, 70.83; H, 10.30. Found: C, 70.64; H, 10.11.

Methyl (2-Octyl-3-oxocyclopentyl)acetate (VIc') (Ravid and Ikan, 1974a) (bp 143° (0.4 mm); yield, 83%): ir (liquid) 1740, 1465, 1440, 1260, 1200, 1165 cm^{-1} ; NMR (CCl_4) δ 0.85 (3 H, t), 1.03–1.51 (14 H, m), 1.91–2.51 (8 H, m), 3.60 (3 H, s). Anal. Calcd for $\text{C}_{16}\text{H}_{28}\text{O}_3$: C, 71.60; H, 10.52. Found: C, 71.68; H, 10.49.

2-Octyl-3-dimethylmalonylcyclopentan-1-one (VI d') (Ravid and Ikan, 1974a) (bp 179° (2 mm); yield, 71%): ir (liquid) 1735, 1435, 1150 cm^{-1} ; NMR (CCl_4) δ 0.85 (3 H, t), 1.02–1.56 (14 H, m), 1.82–2.35 (6 H, m). Anal. Calcd for $\text{C}_{18}\text{H}_{30}\text{O}_5$: C, 66.23; H, 9.26. Found: C, 66.81; H, 9.29.

2-Carbethoxy-2-pentyl-4-dimethylmalonylcyclopentan-1-one (VIe') (Ravid and Ikan, 1974b) (bp 168–170° (0.9 mm); yield, 99%): ir (liquid) 1756, 1734, 1437, 1239, 1198, 1155, 1112, 1025 cm^{-1} ; NMR (CCl_4) δ 0.87 (3 H, t), 1.06–1.4 (11 H, m), 1.7–2.53 (5 H, m), 3.63 (1 H, d), 3.7 (6 H, s), 4.12 (2 H, q). Anal. Calcd for $\text{C}_{18}\text{H}_{28}\text{O}_7$: C, 60.67; H, 7.86. Found: C, 60.33; H, 7.55.

2-Pentyl-3-oxocyclopentyl-1-acetic Acid (VIIf') (Ravid and Ikan, 1974b) (bp 140–142° (0.2 mm); yield, 57%): ir (liquid) 3300–3100, 1738, 1710, 1455, 1405, 1163 cm^{-1} ; NMR (CCl_4) δ 0.89 (3 H, t), 1.0–1.48 (8 H, m), 1.69–2.65 (8 H, m), 11.52 (1 H, s). Anal. Calcd for $\text{C}_{12}\text{H}_{20}\text{O}_3$: C, 67.93; H, 9.43. Found: C, 68.15; H, 9.60.

Methyl 3-Pentyl-4-oxocyclopentyl-1-acetate (VIIf') (Ravid and Ikan, 1974b) (bp 102–104° (0.3 mm); yield, 89%): ir (liquid) 1745, 1735, 1440, 1381, 1340, 1202, 1161 cm^{-1} ; NMR (CCl_4) δ 0.89 (3 H, t), 1.08–1.47 (8 H, m), 1.65–2.55 (8 H, m), 3.58 (3 H, s). Anal. Calcd for $\text{C}_{13}\text{H}_{22}\text{O}_3$: C, 69.10; H, 9.74. Found: C, 69.03; H, 9.73.

2-Carbethoxy-2-pentylcyclohexan-1-one (VIIf') (Ravid and Ikan, 1974a) (bp 125° (1.5 mm); yield, 87%): ir (liquid) 1736, 1719; NMR (CCl_4) δ 0.87 (3 H, t), 1.21 (3 H, t), 1.45–1.88 (8 H, m), 1.98–2.57 (8 H, m), 4.11 (2 H, q).

Anal. Calcd for $C_{14}H_{24}O_3$: C, 69.96; H, 10.07. Found: C, 69.48; H, 9.72.

2-Methyl-3-oxocyclohexylacetic Acid (IXi') (Ravid and Ikan, 1974a) (bp 175° (0.2 mm); yield, 89%); ir (liquid) 3050–3100, 1710, 1410, 1310, 1220, 1170 cm^{-1} ; NMR (CCl_4) δ 1.04 (3 H, d), 1.33–2.75 (1.0 H, m), 9.0 (1 H, s). Anal. Calcd for $C_9H_{14}O_3$: C, 63.51; H, 8.29. Found: C, 63.27; H, 7.96.

Methyl (2-Methyl-3-oxocyclohexyl)acetate (IXj') (Ravid and Ikan, 1974a) (bp 145–147° (0.2 mm)); ir (liquid) 1735, 1710, 1440, 1345, 1320, 1260, 1225, 1165 cm^{-1} ; NMR (CCl_4) δ 1.03 (3 H, d), 1.3–2.6 (10 H, m), 3.56 (3 H, s); semicarbazone, mp 175–177°. Anal. Calcd for $C_{11}H_{19}N_3O_3$: C, 54.76; H, 7.94; N, 17.41. Found: C, 54.63; H, 8.08; N, 17.09.

2-Methyl-3-pentylcyclohexan-1-one (IXk') (Ravid and Ikan, 1974a) (bp 85° (0.2 mm); yield, 63%); ir (liquid) 1710, 1460, 1379, 1145, 955 cm^{-1} ; NMR (CCl_4) δ 0.92 (6 H, m), 1.08–1.72 (10 H, m), 1.92–2.26 (6 H, m); semicarbazone,

mp 159–160°. Anal. Calcd for $C_{13}H_{25}N_3O$: C, 65.23; H, 10.53; N, 17.55. Found: C, 65.20; H, 10.34; N, 17.87.

2-Methyl-3-dimethylmalonylcyclohexan-1-one (IXl') (Ravid and Ikan, 1974a) (bp 112–114° (0.3 mm); yield, 78%); ir (liquid) 1735, 1712, 1440, 1230, 1160, 1010 cm^{-1} ; NMR (CCl_4) δ 1.05 (3 H, d), 1.50–2.59 (8 H, m), 3.55 (1 H, d), 3.65 (6 H, s). Anal. Calcd for $C_{12}H_{18}O_5$: C, 59.49; H, 7.49. Found: C, 59.70; H, 7.00.

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Mode of Action of 2-Hydroxycyclohexyl Quaternary Ammonium Plant Regulators

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A direct correlation between enzyme inhibition and plant growth retardation has been demonstrated for 10 *n*-alkyl derivatives of 2-hydroxycyclohexyldimethylammonium bromide. Enzyme inhibition data were obtained using both butyrylcholinesterase from human blood serum and acetylcholinesterase isolated from mung bean (*Phaseolus aureus*). Growth retardant activity was determined for alfalfa (*Medicago sativa* L., Hairy Peruvian), cucumber seed radicles (*Cucumis sativus* L., Marketer), and grapefruit seed radicles (*Citrus paradisi* Macf., Duncan). Maximum serum butyrylcholinesterase inhibition oc-

curred when the alkyl chain attached to nitrogen had 12 carbons while the maximum for bean acetylcholinesterase inhibition occurred at a chain length of 14 carbons. The three growth tests showed maximum activities for those compounds in which the *n*-alkyl group had 11 to 13 carbons. The inhibition of bean root cholinesterase was competitive and reversible. These correlations between growth regulation and enzyme inhibition suggest that these quaternary ammonium derivatives may act on an enzyme-mediated step essential to plant growth.

There is evidence that certain quaternary ammonium growth regulators retard plant growth by blocking GA biosynthesis (Lang, 1970). Fall and West (1971) purified Kaurene synthetase from cell-free extracts of the fungus *Fusarium moniliforme* L. and showed inhibition of the enzyme by Amo-1618, Phosfon D, Phosfon S, and several quaternary ammonium derivatives of (+)-limonene. Riov and Jaffe (1973a) recently reported the isolation of a cholinesterase (ChE) from mung bean (*Phaseolus aureus*) roots and its irreversible, noncompetitive inhibition by Amo-1618 (Riov and Jaffe, 1973b). They also have shown an excellent correlation between bean ChE inhibition and retardation of the growth of secondary bean roots for a number of plant growth regulators (Riov and Jaffe, 1973c). A correlation has been reported between growth retardant activity and serum ChE inhibition for a series of quaternary ammonium derivatives of (+)-limonene (Newhall, 1969, 1971).

We have studied the correlation between both human blood serum ChE and bean root ChE inhibition and growth retardation for a new series of ten plant growth regulators

derived from 2-dimethylamino-1-cyclohexanol (Newhall, 1974).

MATERIALS AND METHODS

Compound Preparation. The synthesis and characterization of the ten quaternary ammonium derivatives used in this study have been reported (Newhall, 1974).

Sources of Enzymes. Human blood serum diluted 1 to 10 was used as a source of serum ChE. Mung bean ChE was isolated from roots of 12-day-old light-grown seedlings as previously described (Riov and Jaffe, 1973a).

Enzyme Assays. Serum ChE inhibition was determined using standard Warburg manometric techniques (Newhall, 1969). Bean root ChE inhibition was measured photometrically using a modification of the method of Ellman et al. (1961) (Riov and Jaffe, 1973a).

Growth Tests. Three bioassays were used to determine the regulant activities of the ten test compounds. The most sensitive test was based on the radicle growth of cucumber Marketer seed at concentrations of the test compound between 0.5 mM and 20 μ M. This bioassay procedure, as well as a second test based on the growth response of Hairy Peruvian alfalfa seedlings, has been described previously (Newhall, 1969, 1971). In the third growth test, grapefruit seeds, after removal of both seed coats, were placed in Petri dishes on Whatman No. 1 paper wetted with various con-

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