Experimental Section

$NaBH_4$ Reduction of 2,3-Dimethyl-5,6-bis(acetoxymethyl)-1,4-benzoquinone.—Quinone 1 (0.5 g, 1.8 mmol) was suspended in 20 ml of methanol and chilled in an ice bath. $NaBH_4$ (0.065 g, 1.8 mmol) was added in small portions to the suspension with stirring. The clear yellow solution was stirred at ice-cold temperature for another 30 min after the addition of $NaBH_4$. The methanol was evaporated to dryness under reduced pressure and room temperature to give a yellow powder. Water (20 ml) was added and the mixture was extracted three times with ether (30 ml). Ether extracts were combined, dried, and evaporated to dryness. The yellow powder was chromatographed on a column of silica gel (50 g) using EtOAc and petroleum ether (bp 38–47°) (1:4, v/v) as eluent; two major yellow fractions were obtained. The first fraction yielded 50 mg of long needles (from H_2O), mp 110°, and was identified as duroquinone (4) (lit.[4] mp 111°) by ir, nmr, and mixture melting point. The second fraction yielded 75 mg of dimer 5: mp 155.5–157.5°; ir (KBr) 1635, 1665, and 1675 cm^{-1} (-C=O); mass spectrum *m/e* 324 (M^+); uv λ_{max}^{EtOH} 259 nm (ϵ 27,000), 265 (24,000).

Anal. Calcd for $C_{20}H_{20}O_4$: C, 74.07; H, 6.17. Found: C, 73.88; H, 6.31.

$NaBH_4$ Reduction of 2,3-Dimethyl-5,6-bis(acetoxymethyl)-1,4-benzoquinone in the Presence of Morpholine.—Quinone 1 (0.25 g, 0.9 mmol) and morpholine (0.5 ml) were suspended in 10 ml of ice-cold methanol. To the suspension, $NaBH_4$ (0.035 g, 0.9 mmol) was added in small portions with stirring. After the addition, the solution was mixed for an additional 30 min. The white precipitate was collected and washed with ice-cold methanol to give 60 mg of white crystals. The filtrate was evaporated to dryness and the crude product was washed with H_2O followed by cold methanol to give another 50 mg of white crystals. Combination and recrystallization of the product from methanol yielded 100 mg (37%) of white crystals (6): mp 206° dec; ir (KBr) 3450–2700 (broad and weak, -OH···N-) and 1110 cm^{-1} (ether); nmr ($CDCl_3$) 2.71 (s, 6), 2.54 (m, 8), 3.68 (s, 4) and 3.75 ppm (m, 8).

Anal. Calcd for $C_{18}H_{28}N_2O_4$: C, 64.29; H, 8.33; N, 8.33. Found: C, 64.01; H, 8.26; N, 8.28.

$NaBH_4$ Reduction of 2,3-Dimethyl-5,6-bis(acetoxymethyl)-1,4-benzoquinone in the Presence of Aniline.—To quinone 1 (0.15 g, 0.53 mmol) in 20 ml of methanol was added an excess of aniline (0.5 ml). The solution was cooled in an ice bath and $NaBH_4$ (0.02 g, 0.53 mmol) was added in small portions. The clear solution was stirred for 10 min and the formed white precipitate was collected and washed with a small amount of methanol. Recrystallization from ethanol gave white needles of 7 (0.14 g, 76%): mp 171–173° dec; ir (KBr) 3290 (s, NH), 3200–2700 (-OH···N-), 1602, 1500, 747, and 690 cm^{-1} (monosubstituted phenyl); nmr (DMSO-d_6) 2.10 (s, 6), 4.25 (broad singlet, 4), 5.43 (broad singlet, 2), 6.88 (m, 10), 8.13 ppm (broad singlet, 3).

Anal. Calcd for $C_{22}H_{24}N_2O_2$: C, 75.85; H, 6.90; N, 8.05. Found: C, 75.73; H, 7.02; N, 7.79.

Registry No.—1, 37439-56-8; 3, 37439-57-9; 5, 37439-58-0; 6, 37439-59-1; 7, 37439-60-4; $NaBH_4$, 16940-66-2; morpholine, 110-91-8; aniline, 62-53-3.

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Hydrolysis Products of 4-Acetamido-4-hydroxy-2-butenoic Acid γ-Lactone

MICHAEL D. GROVE* AND DAVID WEISLEDER

Northern Regional Research Laboratory,[1] Peoria, Illinois 61604

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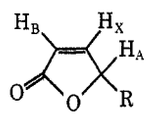
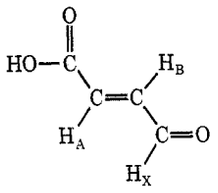
4-Acetamido-4-hydroxy-2-butenoic acid γ-lactone (**1a**) is a mycotoxin produced on laboratory media by a strain of *Fusarium tricinctum* originally isolated from tall fescue hay (*Festuca arundinaceae* Schreb.).[2] Gangrene in tails of cattle receiving **1a** provided circumstantial evidence implicating it in the problem of tall fescue toxicity.[3,4]

Our current interest in the biological activity of **1a** prompted us to examine more closely two earlier reports concerning the hydrolysis products of this mycotoxin. White[5] found that acid hydrolysis of **1a** gave a 23% yield of malealdehydic acid (*cis*-β-formylacrylic acid, **1b**) as the major four-carbon fragment isolated; alkaline hydrolysis also gave **1b**, no yield being reported. Burkhardt, *et al.*,[6] found that alkaline hydrolysis of **1a** yielded a mixture of **1b** and fumaraldehydic acid (*trans*-β-formylacrylic acid, **2**). However, their results were



1a, R = $NHCOCH_3$
b, R = OH
c, R = OCH_2CH_3



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not unambiguous since the melting point given for cis acid **1b** (127°) is the same as reported by Schroeter, *et al.*,[7] for trans acid **2**. Our investigation shows that, whereas acid hydrolysis of **1a** does indeed give **1b** as the major product, **2** predominates under alkaline conditions. Hydrolysis products were identified by direct comparison with unequivocally characterized samples of **1b** and **2**.

Compound **1b** had been prepared earlier[7] by acid hydrolysis of the corresponding ethyl pseudo ester **1c**, which was obtained by photosensitized oxygenation of furfural in ethanol.[8] We prepared **1b** more directly, albeit in lower yield (25%), by carrying out the photooxygenation of furfural in aqueous ethanol (1:1). The ethanol required to maintain the eosin sensitizer in solution leads to formation of some **1c**. The ir spectrum of **1b** exhibits a pair of carbonyl bands at 1790 and 1760 cm^{-1} characteristic of an α,β-unsaturated lactone of this type.[2] That **1b** exists as the cyclic pseudoacid and not as an open-chain aldehydic acid as its name implies was confirmed by the nmr spectrum (Table I), which shows no aldehyde proton. The three ring protons of **1b** exhibit an ABX pattern with the cis-vinyl proton coupling constant of 5.7 Hz in close agreement with that for **1a**[6] and *cis*-β-acetylacrylic acid.[9]

Compound **2** had been prepared previously by acid treatment of either **1b** or **1c** in 25 and 46% yields, re-

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TABLE I
NMR DATA OF MALEALDEHYDIC AND FUMARALDEHYDIC ACIDS

Compd	Chemical shifts, δ			Coupling constants, Hz		
	H_A	H_B	H_X	J_{AB}	J_{AX}	J_{BX}
1b[a]	6.25	6.20	7.41	1.2	1.2	5.7
2[b]	6.91	6.72	9.77	15.8	0.4	7.8

[a] In acetone-d_6. [b] In DMSO-d_6.

spectively.[7] We found that **2** can be prepared conveniently in 26% yield by treating a crude photooxygenation mixture containing **1b** and **1c** with sodium bicarbonate. No **2** was detected in the mixture by tlc before the bicarbonate was added. Likewise, treating pure **1b** with bicarbonate for 2 days gave an isomerization mixture containing **2** and **1b** in the ratio of approximately 3:2. The three C protons of **2** exhibit an ABX pattern with coupling constants near those reported for *trans*-crotonaldehyde.[10] The typically large trans-vinyl proton coupling constant of 15.8 Hz in **2** is also near that found for *trans*-β-acetylacrylic acid.[9]

Since an initial attempt to hydrolyze **1a** with 0.1 *N* HCl at room temperature resulted in less than 50% hydrolysis, the compound was hydrolyzed with refluxing 2 *N* HCl by the method of White.[5] Purification of the ethyl acetate extractables by adsorption chromatography gave, as the major product, 28% of crystalline **1b**, plus less than 2% of **2**. Identity of the hydrolysis products from **1a** was established by ir, tlc, and melting point.

Alkaline hydrolysis of **1a** was carried out at room temperature with 0.1 *N* NaOH according to the procedure of Burkhardt, *et al.*[6] In view of the ease of bicarbonate-induced ring opening and concomitant isomerization of **1b** to **2**, the expected product in this reaction was again **2**. Indeed, examination of the ether extract from the acidified reaction mixture by ir and tlc showed **2** as the major product, plus a minor amount of **1b**. Thus, contrary to implications of earlier reports,[5,6] formation of **2** from **1a** is favored under alkaline conditions. Silica gel chromatography of the ether extractables afforded a 24% yield of **2**, plus less than 1.5% **1b**. The low yield of **2** is not due to loss of significant amounts of material on the silica, but rather to formation of considerable polymeric material during hydrolysis.

Experimental Section

Melting points were determined on a Fisher-Johns block and are uncorrected. The following spectrometers were used: ir, Perkin-Elmer 337 ($CHCl_3$); uv, Beckman DK-2A (EtOH); nmr, Varian HA-100 with TMS as an internal standard.[11] Thin layer chromatograms were run on silica gel G coated plates.

Malealdehydic Acid (1b).—Oxygen was passed into an irradiated mixture of 100 g of furfural and 2.0 g of eosin (yellowish) in 1400 ml of H_2O–EtOH (1:1) for 4 days. Light was provided by a circular arrangement of 26 20-W cool-white fluorescent lamps; wavelengths shorter than 460 nm were filtered out by an aqueous solution of 1.25 *M* $CaCl_2$.[12] After most of the solvent was removed, the solution was diluted with H_2O and filtered to remove eosin. The filtrate was washed with CCl_4 and extracted thoroughly with ethyl acetate. After the ethyl acetate extract was dried (Na_2SO_4), the solvent was removed; the residual oil crystallized upon refrigeration. The crystals were washed with benzene and recrystallized from $CHCl_3$–benzene to give 25.8 g (25%) of **1b**: mp 53–56°; additional recrystallizations raised the melting point to 54.5–56.5° (lit.[7] mp 58–59°); tlc R_f 0.44 [$CHCl_3$–acetone–acetic acid (85:10:5), sprayed with 3% ceric sulfate in 3 *N* H_2SO_4, and heated at 120°]; ir 3580 (OH), 1790, 1760 (C=O), 1115, 1003 cm^{-1}; uv max 202 nm (ε 6870); phenylhydrazone[8] mp 159–161°, tlc R_f 0.48 [hexane–ether–acetic acid (47:50:2), I_2 vapor].

Fumaraldehydic Acid (2).—The reaction was carried out as described for **1b**. Two-thirds of the solvent was removed, 126 g of $NaHCO_3$ was added, and the mixture was kept at room temperature for 3 days. The solution was acidified to pH 1.5 with 10 *N* HCl, washed with CCl_4, and extracted thoroughly with ethyl acetate. The crystalline residue, obtained by drying (Na_2SO_4) and removal of the ethyl acetate solvent, was passed through 600 g of silica gel (70–325 mesh). Elution of the column with acetone–$CHCl_3$ (1:4), concentration of the fractions containing **2**, and recrystallization from acetone–$CHCl_3$ gave 26.8 g (26%) of **2**: mp 125–126°; additional recrystallizations raised the melting point to 126.5–127° (lit.[7] mp 127°); tlc R_f 0.55 [$CHCl_3$–acetone–acetic acid (85:10:5), sprayed with 3% ceric sulfate in 3 *N* H_2SO_4, and heated at 120°]; ir 3510 (OH), 1740, 1700 (C=O), 1100, 978 cm^{-1}; uv max 216 nm (ε 11,000); phenylhydrazone[8] mp 159.5–161°, mixture melting point with **1b** phenylhydrazone 146–151°, tlc R_f 0.33 (hexane–ether–acetic acid, 47:50:2).

Isomerization of Malealdehydic Acid (1b).—A solution of 1.0 g of **1b** and 2.1 g of $NaHCO_3$ in 20 ml of H_2O was kept at 20° for 2 days. The solution was acidified to pH 1 with 4 *N* HCl and extracted with ethyl acetate. The extract was dried (Na_2SO_4) and concentrated, leaving 780 mg of residue. Examination of the ir carbonyl region of the residue showed compound **2** and starting **1b** in approximately a 3:2 ratio.

Acid Hydrolysis of 4-Acetamido-4-hydroxy-2-butenoic Acid γ-Lactone (1a).—A solution of 1.0 g of **1a** (obtained by synthesis[8]) in 40 ml of 2 *N* HCl was refluxed for 3 hr, cooled, and extracted with ethyl acetate. The ethyl acetate extract was dried (Na_2SO_4), and the solvent was removed. Chromatography of the residue on 25 g of silica gel ($CHCl_3$ eluent) plus crystallization from $CHCl_3$–benzene gave 202 mg (28%) of **1b**, mp 53.5–56.5°. Ir analysis of the carbonyl region of the mother liquor indicated less than 10 mg (2%) of **2**.

Alkaline Hydrolysis of 4-Acetamido-4-hydroxy-2-butenoic Acid γ-Lactone (1a).—A solution of 1.0 g of **1a** in 78 ml of 0.1 *N* NaOH was kept at room temperature for 16 hr. The solution was acidified to pH 1.5 with 1 *N* HCl and extracted with ether. After the ether extract was dried (Na_2SO_4), the solvent was removed. The residue (410 mg) was examined by ir and tlc and chromatographed on 25 g of silica gel [acetone–$CHCl_3$ (5:95) eluent]. Recrystallization from $CHCl_3$ gave 169 mg (24%) of **2**, mp 126.5–127.5°. Subsequent column fractions were combined and by ir analysis contained less than 9 mg (1.5%) of **1b**.

Registry No.—**1a**, 16275-44-8; **1b**, 14032-66-7; **2**, 4437-06-3; furfural, 98-01-1.

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"Dimers" from the Reaction of Propargyl Halides with Organometallic Reagents

ROGER S. MACOMBER

Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221

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In connection with another study, we had occasion to prepare di-*tert*-butylacetylene (**1**). Its synthesis was first described by Hennion and Banigan,[1] then

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