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PREPARATION AND STRUCTURE OF AN UNUSUAL DIMERIC FURAN FROM THE ACID DECOMPOSITION OF ISOMALTOL

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ABSTRACT

Isomaltol (**1**), an enolic nonenzymic browning-product, decomposes in dilute acid to form the new red-orange colored, symmetrical dimer, (*E*)-2-[1-(3-hydroxy-2-furanyl)ethylidene]-(2*H*)-furan-3-one (**2**). Compound **2** was obtained in 20.4% yield with toluenesulfonic acid (≥3M) at 50°. The structure for **2** was assigned on the basis of spectral data (m.s., u.v., i.r., ^{13}C- and ^{1}H-n.m.r.) and conversion into its mono-*O*-acetyl derivative (**3**).

INTRODUCTION

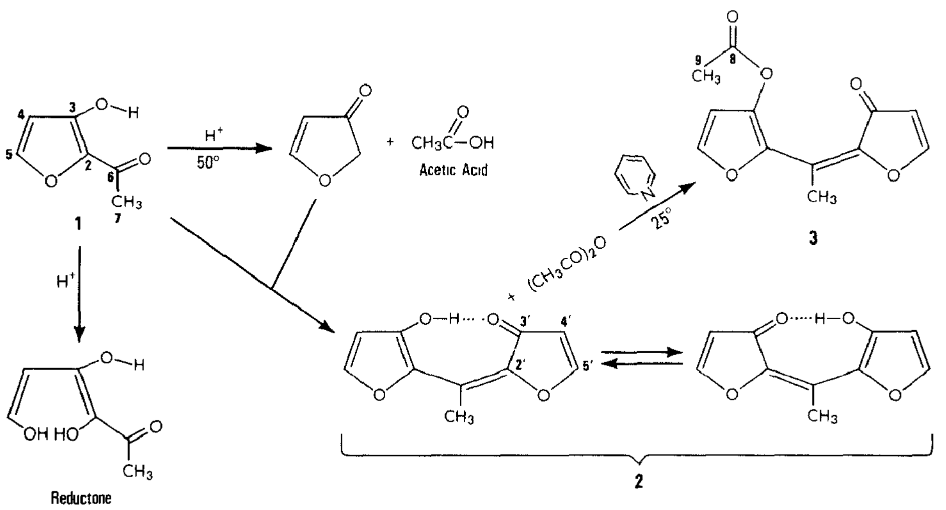
Isomaltol (3-hydroxy-2-furyl methyl ketone, **1**) is a volatile, crystalline, enolic compound first detected in trace amounts in bread and baked cereal products by its purple color-reaction with ferric chloride reagent[1–5]. Compound **1** has been prepared from isomaltol β-D-galacto[6]- and α-D-gluco[7]-pyranosides, and its structure was elucidated by Fisher and Hodge[8].

Furan compounds from carbohydrate degradation are found in foods and food-related model systems[9,10]. Compounds having two or three furan nuclei have been identified in roasted coffee beans[11], in popcorn[12,13] and in heated whey powder[14]. Ferretti *et al.*[15] reported the mass-spectral characteristics of four acyl derivatives of 2,2′-difurylmethane.

The present work demonstrates the preparation of a new red-orange colored, symmetrical furanic dimer, (*E*)-2-[1-(3-hydroxy-2-furanyl)ethylidene]-(2*H*)-furan-3-one (**2**) from acidic (≥3M) decomposition of isomaltol (**1**). Compound **2** was characterized by conversion into its mono-*O*-acetyl derivative (**3**). This work will extend our knowledge of the physicochemical properties of the nonenzymic browning product, isomaltol (**1**), found in a number of processed foods.

RESULTS AND DISCUSSION

When isomaltol (**1**) is dissolved in ≥3M acid solutions [hydrochloric, sulfuric,



Scheme 1

perchloric, phosphoric, *p*-toluenesulfonic (TsOH)], it decomposes to form a symmetrical red-orange compound (**2**) (Scheme 1).

Compound **2** was obtained in a yield of 20.4% with ≥3M TsOH at 50°, and it decomposed sharply at 123.5–124.5°. Elemental analyses and a Rast molecular-weight measurement (calc. mass 192) for compound **2** furnished the formula $C_{10}H_8O_4$, which was supported by mass spectrometry with a molecular ion M^+, *m/z* 192. The u.v. spectrum for compound **2** in dry methanol showed two maxima, 230 (ε 6544) and 275 nm (3640).

The i.r. spectrum (KBr disk) for **2** showed a broad absorption band (3480–3395 cm^{-1}) centered at 3445 cm^{-1} that indicated an enolic (C=C-OH$\rightleftarrows$HC-C=O) structure. Additional absorptions were C=O (1620 cm^{-1}, strong H-bonding), four C=C bands (1560, 1545, 1525, and 1440 cm^{-1})[6,7], and absorption bands at 3140 and 3110 cm^{-1} for HC=CH vibrations on furan-type structures[16,17]. The mono-*O*-acetyl derivative (**3**) showed strong absorption bands for an ester (1755 cm^{-1}) and carbonyl groups (1685 cm^{-1}). Compound **2** produced a dark, reddish-brown color-reaction with ferric chloride reagent, indicative of an enolic hydroxyl function.

The ^{1}H-n.m.r. spectrum for **2** showed a singlet at δ 2.50 for CH_3-C, and a singlet at δ 11.01 for an enolic OH proton. The chemical shifts (Table I) for furanic-protons (4-H_βC= and 4′-$H_{\beta'}$C=, as well as 5-H_αC= and 5′-$H_{\alpha'}$C=) for **2** are equivalent, which is consistent with a completely symmetrical structure. The chemical shifts for methyl and furanic protons of compounds **2** and **3** agreed closely with the chemical shifts and coupling constants (J = 2.0 Hz) for the small doublets given by compound **1**. Compound **3** showed four non-equivalent chemical shifts for its furanic ring protons. The non-equivalent furanic ring protons in compound **3** suggested that acetylation destroyed the symmetry present in compound **2**. The

TABLE I

^{1}H-N M.R. CHEMICAL SHIFTS AT 100 MHz

Proton	*Chemical shifts*[a]		
	Compound		
	1 $C_6H_6O_3$	**2** $C_{10}H_8O_4$[b]	**3** $C_{12}H_{10}O_5$
CH_3OCO			2.30 (s)[c]
CH_3CO	2.30 (s)[c]		
$CH_3C=$		2.50 (s)[c]	2.62 (s)[c]
4-$H_\beta C=$	6.35 (d)[d]	6.30 (d)[d]	5.93 (d)[d]
4'-$H_{\beta'}C=$		6.30 (d)	6.95 (d)
5-$H_\alpha C=$	7.68 (d)	7.90 (d)	7.54 (d)
5'-$H_{\alpha'}C=$		7.90 (d)	7.97 (d)
OH	4.60	11.00	
Solvents	Me_2SO-d_6	$CDCl_3$	$CDCl_3$

[a] In p.p.m. downfield from internal Me_4Si. [b] Coupling constant (Hz) for all small doublets, $J_{H\alpha\beta,H\alpha'\beta'}$ = ~2.0. [c] Integrated for four furanic protons. [d] Integrated for one methyl group (three protons).

TABLE II

CARBON-13 CHEMICAL SHIFTS[a] AT 90 MHz IN CHLOROFORM-*d* SOLUTIONS

Carbon	*Carbon-13 signal, p.p.m. from* Me_4Si-^{13}C		
	Compound		
	1 $C_6H_6O_3$	**2** $C_{10}H_8O_4$	**3** $C_{12}H_{10}O_5$
C-2	137.1 s	138.4 s	138.7 s
C-2'		138.4	140.1 s
C-3	157.0 s	171.1 s	140.6 s
C-3'		171.1	187.8 s
C-4	105.0 d	110.2 d	109.1 d
C-4'		110.2	110.2 d
C-5	146.22 d	157.0 d	144.0 d
C-5'		157.0	165.3 d
C-6	189.8 s	127.3 s	118.7 s
C-7	24.6 q	16.1 q	11.2 q
C-8			167.4 s
C-9			20.8 q

[a] d, Doublet; q, quartet; s, singlet.

equivalent chemical shifts ($H_{\alpha\beta}$, $H_{\alpha'\beta'}$), and coupling constants of the small doublets ($J_{H\alpha\beta,H\alpha'\beta'}$ = 2.0 Hz) for the furanic ring protons of **2** are also consistent with a condensed dimer formed from the acid decomposition of isomaltol (**1**) (Scheme 1) with H-bonded hydroxyl and carbonyl substituents at positions C-3 and C-3'.

The ^{13}C-n.m.r. spectra (Table II) of compounds **1** and **2** each exhibited six signals, all in the unsaturated region (δ >100) except for methyl proton signals at δ 24.5 in **1** and 16.1 in **2** and carbonyl carbon signals at δ 189.8 (**1**) and 171.1 (**2**). The ^{13}C-n.m.r. spectrum of **3** had twelve signals, indicating that formation of the acetate had removed the chemical-shift equivalence observed for the symmetrical dimer, **2**. The lowest-field signal at δ 187.8 is assigned to C-3′ followed by the acetate carbonyl carbon (C-8) at δ 167.4. The C-5′ resonance is assigned δ 165.3, because conjugation with the carbonyl group would cause a downfield shift. Other assignments were verified by observing the coupling patterns with an INEPT (Insensitive Nuclei Enhanced by Polarization Transfer)[18] experiment. Thus, the signals at δ 138.7 and 140.1 indicated coupling to the C-7 methyl protons and could therefore be assigned to C-2 and C-2′.

Elemental analyses and mass spectrometry furnished the formula $C_{12}H_{10}O_5$ for **3**. The high intensity of the peak at M$^+$, *m/z* 192 (base peak) for **2** suggested an aromatic system with no readily breakable bonds in the molecule[19]. The mass spectra for **2** and **3** showed the same prominent peaks, with the exception of the M$^+$ peak at *m/z* 234 for **3**. The intense peak at *m/z* 192 (rel. intensity 83%) in the spectrum for **3** is attributed to cleavage of the acetyl bond with the elimination of ketene (M$^+ \rightarrow$ *m/z* 192; metastable peak at *m/z* 157.5).

The fragmentations for compounds **2** and **3** agreed closely with the ion fragmentations for the acyl derivatives of 2,2′-difurylmethane reported by Ferretti *et al.*[15], and the fragmentations for **2** and its mono-*O*-acetyl derivative (**3**) complement the i.r., ^{13}C-, and ^{1}H-n.m.r. data.

Considering the physicochemical data, the dimeric structure (Scheme I) is most probable for compound **2** with two (2) furanic (CH=CH) rings giving identical ^{1}H-n.m.r. chemical shifts for α,α' and β,β' protons, and identical ^{13}C-n.m.r. chemical shifts for carbon-13 atoms at the same positions (Tables I and II). The ^{1}H- and ^{13}C-n.m.r. spectral data (Table I and II) show that the mono-*O*-acetyl derivative (**3**) is dissymmetric in the furanic rings.

In summary, compound **2** is a completely symmetrical dimer of isomaltol (**1**). The structure, and the presence of hydroxyl and carbonyl groups were established from spectral data for **2** and its mono-*O*-acetyl derivative (**3**).

EXPERIMENTAL

General methods. — Isomaltol (**1**) was prepared by the methods of Hodge and Nelson[6]. Reagent-grade acids were used. Melting points were recorded with a Thomas–Hoover Unimelt apparatus and are uncorrected. I.r. spectra were determined in potassium bromide pellets (1.22 mm thick containing 0.1M concentrations) with a Perkin–Elmer Model 621 spectrophotometer. The mass spectra were determined with a Nuclide 12–90 DF double-focusing spectrometer at 70 eV, and either a direct or heated inlet (150–200°) was used. Purity of the compounds was established by t.l.c., m.p., and elemental analyses. T.l.c. was conducted on 0.25 mm of EM Reagent Silica Gel G (Brinkman Instruments, Inc.) with air-dried plates. The spots were detected by spraying with 5% ethanolic sulfuric acid and charring. T.l.c. was performed with 80% (v/v) methanol–ethyl acetate for compound **2** and with 75% ethyl acetate–hexane for the acetylated compound (**3**). ^{1}H-N.m.r. spectra were recorded with a Varian Model HA-100 spectometer; chemical-shift peaks were assigned by spin-decoupling experiments, referred to internal tetramethylsilane. Products were vacuum-dried in the presence of phosphorus pentaoxide for 24–48 h at room temperature before analysis. The ^{13}C-n.m.r. spectra (natural abundance) were obtained from solutions in chloroform-*d*, which also served as the internal deuterium lock. Chemical shifts were measured as δ values in p.p.m. downfield from the internal ^{13}C signal of tetramethylsilane. The ^{13}C spectra were recorded in 5-mm tubes with a Bruker WH-300 WB Fourier-transform n.m.r. spectrometer at 75.4 MHz. Sweep widths of 221 p.p.m. with 8192 data-points were used to give chemical-shift values accurate to within ±2 Hz (±0.05 p.p.m.) A 2-μsec (~25°) pulse-width was used and the computer-data memory size (8192 addresses) set the data-acquisition time at 0.46 sec. Proton noise-decoupled, INEPT spectra were obtained to assist in signal assignments.

Microchemical analyses were performed by the Galbraith Laboratories, Inc., P.O. Box 4187, 2323 Sycamore Drive, Knoxville, TN 37921.

(E)-*2-[1-(3-Hydroxy-2-furanyl)ethylidene]-(2*H*)-furan-3-one* (**2**). — Compound **2** was obtained from decomposition of isomaltol (**1**) by dissolving **1** in $\geqslant$3M *p*-toluenesulfonic acid (40 mL) with stirring at 50°. After 1.0 h at 50°, a deep red color developed and crystals were formed in the mixture. The crystals were filtered off and washed with aliquots of $\geqslant$3M *p*-toluenesulfonic acid (50 mL). The crystals were dried at 50°; recrystallization was from aqueous ethanol (50%, v/v); yield 1.2 g (20.4%); m.p. 123.5–124.5°. Compound **2** is volatile and sublimes when heated under vacuum or dried at 50° in a vacuum; $\nu_{\max}^{\mathrm{KBr}}$ 3480–3395 cm^{-1}, centered at 3445 (C=C-OH$\rightleftarrows$C-C=O), 3140 and 3110 (furan, HC=CH), 1375 (CH_3-C), 1560, 1545, 1525, and 1440 (C=C vibrations), and 1620 cm^{-1} (carbonyl group); $\lambda_{\max}^{\mathrm{EtOH}}$ 230 (ε 6544) and 257 nm (3640); *m/z* (rel. intensity) for **2** 192 (100), 175 (48), 174 (24), 163 (10), 149 (2), 135 (16), 122 (15), 121 (13), 110 (11), 109 (18), 93 (8), 82 (7), 69 (34), 58 (27), 55 (13), 43 (74), 39 (16), 29 (5), 28 (15), 27 (13), 26 (11), 18 (84), 17 (17), and 15 (11).

Anal. Calc. for $C_{10}H_8O_4$: C, 62.50; H, 4.20. Found: C, 62.61; H, 4.17.

(E)-*2-[1-(3-*O*-Acetyl-2-furanyl)ethylidene]-(2*H*)-furan-3-one* (**3**). — Compound **2** (260 mg, 1.35 mmol) was dissolved in dry pyridine (3 mL). The red-orange colored solution was cooled to 0° in an ice bath. Acetic anhydride (0.55 g, 5.4 mmol or 4.0 mol per mol of **2**) was added at 0°. After 1.0 h, the *O*-acetyl derivative crystallized in the mixture. Ice and water were added to the crystalline mixture, which was kept for 1.0 h. The crystalline acetate was filtered and washed with cold water (50 mL), and dried over P_2O_5 under diminished pressure to give **3**; yield 289 mg (92%); crystallization was from abs. ethanol; $\nu_{\max}^{\mathrm{KBr}}$ 3158, 3112, 3092 with shoulder at 3145 (furan, HC=CH), 2968 and 2930 (CH_3-C), 1755 (CH_3OCO), and 1685 cm^{-1} (C=O). Apparently the *O*-acetyl group was lost on being kept in methanol, because compound **3** gave the same u.v. spectrum as for compound **2**; λ_{max}^{MeOH} 230 (ε 6544), 257 nm (3640); m/z (rel. intensity) for **3** 234 (11), 192 (83), 175 (100), 163 (19), 149 (2), 135 (21), 122 (21), 121 (13), 110 (9), 109 (20), 93 (5), 83 (10), 69 (17), 55 (14), 43 (50), 39 (10), 29 (2), 28 (13), 27 (13), 26 (10), 18 (29), 17 (7), and 15 (6).

Anal. Calc. for $C_{12}H_{10}O_5$: C, 61.54; H, 4.30. Found: C, 61.66; H, 4.40.

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