

Tobacco Smoke Chemistry. 4. A Mass Spectral Study of Alkyl 3-Hydroxy-4-pyrones

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3-Hydroxy-4-pyrone and a series of C-alkylated 3-hydroxy-4-pyrones have been synthesized and their behaviour under electron impact investigated. The fragmentation pathways were elucidated with the aid of accurate mass measurements, metastable ion analysis and deuterium labelling. All compounds examined gave a detectable molecular ion which undergoes a retro Diels–Alder type process accompanied by hydrogen transfer to give characteristic ions, which in many cases allow differentiation of positional isomers. Loss of carbon monoxide is encountered from several ions, but to any substantial extent from the molecular ions only in the cases of 3-hydroxy-4-pyrone and 5-hydroxy-2-methyl-4-pyrone. Instead, the more general fragmentation routes involve extrusion of a hydrogen or an alkyl radical from the molecular ion prior to the elimination of carbon monoxide. When the alkyl substituent in 2-alkyl-3-hydroxy- or 2-alkyl-5-hydroxy-4-pyrone has three or more consecutive carbons the molecular ion loses an alkene fragment by a McLafferty type of reaction. The even mass ions formed by this process constitute the base peak in most spectra of this type. Another rearrangement reaction giving even mass ions after loss of an alkene fragment occurs when the alkyl substituent in the 2-alkyl-3-hydroxy-4-pyrones is branched at the α -carbon. Moreover, γ -bond cleavage of the alkyl side chain vicinal to the hydroxy group becomes important due to anchimeric assistance by the hydroxy group.

Maltol¹ (3-hydroxy-2-methyl-4-pyrone), known since 1862, is found in many plant species^{1–3} e.g. larch bark, fern leaves, pine needles and foodstuffs such as roasted coffee, cocoa and bread crust. Common to the foodstuffs mentioned is a roasting process and most synthetic methods for making maltol employ heat treatment of carbohydrates.⁴ Maltol is a widely used flavouring agent^{2,5} because of its sweet odour. The presence of maltol in cigarette smoke condensate, CSC, was first reported by Elmenhorst⁶ in 1971. Other studies have confirmed this finding and added a number of other 3-hydroxy-4-pyrone derivatives to the known CSC components.⁷

Mass spectra of some 3-hydroxy-4-pyrones have been published,^{8,9} but no mechanistic studies of their mass spectral behaviour have been reported. In our on-going study of CSC we found, in addition to maltol and the other previously described 3-hydroxy-4-pyrones, a number of constituents, the mass spectra of which suggested that they contain a 3-hydroxy-4-pyrone moiety. Since most of them are present in very small amounts and gas chromatography with mass spectrometric detection constitutes the only convenient way to detect and identify them, we undertook the present study to establish the fragmentation patterns of

3-hydroxy-4-pyrones under electron impact (EI), the aim being to elucidate the structures of our unidentified CSC constituents from their mass spectra.

To accomplish this we prepared a set of 2-alkyl-3-hydroxy- and 2-alkyl-5-hydroxy-4-pyrones (R = methyl, ethyl, propyl and butyl) and some dialkyl-3-hydroxy-4-pyrones (R = methyl and/or ethyl). Since our initial study of their fragmentation under EI did not agree with an interpretation of the mass spectrum of 3-hydroxy-2-isopropyl-4-pyrone published earlier⁹ we also prepared 2-isopropyl-, 2-(1,1,1,3,3,3-²H₆)isopropyl-, 2-isobutyl- and 2-(*sec*-butyl)-3-hydroxy-4-pyrone. The compounds examined in this study are listed in Table 1.

The identification of CSC compounds, based on the results of this study, will be discussed in a separate paper in this series.

Results

Preparation of the reference compounds. 3-Hydroxy-2-methyl-4-pyrone and 2-ethyl-3-hydroxy-4-pyrone are commercially available. The other pyrones were prepared by one of the following three methods.

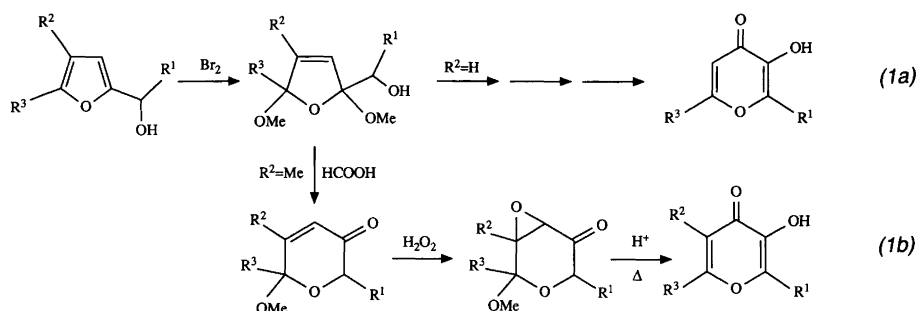


Table 1. Compounds examined in this study. Substituent numbering refers to eqn. (1ab).

Compound No.	R ¹	R ²	R ³	Synthetic method
1	H	H	H	1a
2	H	H	Me	2
3	H	H	Et	2
4	H	H	Pr	2
5	H	H	Bu	2
6	Me	H	H	Com
7	C ² H ₃	H	H	1a
8	Et	H	H	Com
9	Pr	H	H	1a
10	<i>iso</i> -Pr	H	H	1a
11	(C ² H ₃) ₂ CH	H	H	1a
12	Bu	H	H	1a
13	<i>sec</i> -Bu	H	H	1a
14	<i>iso</i> -Bu	H	H	1a
15	Me	H	Me	1a
16	Me	Me	H	1b
17	Et	H	Me	1a
18	Me	H	Et	1a
19	Me	Me	Me	1b

Method 1a. 3-Hydroxy-4-pyrone (**1**) and its 2-alkyl derivatives (**7** and **9–14**) were prepared by means of a one-pot procedure¹⁰ including bromine oxidation of a suitably substituted 2-(1-hydroxyalkyl)furan in methanol, acid-catalysed ring expansion to give the six-membered ring and a second bromine oxidation step followed by hydrolysis/elimination (eqn. 1a). We found that yields dropped drastically on going from maltol and its ethyl homologue to higher straight-chain homologues, branched isomers and disubstituted counterparts, but no attempts were made to optimize the yields. The starting materials were prepared either by reduction of an alkyl 2-furyl ketone or by a Grignard reaction between 2-furaldehyde and an alkylmagnesium halide. The 2,6-dialkyl-3-hydroxy-4-pyrones (**15**, **17** and **18**) were synthesized by the same oxidative ring expansion reaction but starting with a suitable 5-alkyl-2-(1-hydroxyalkyl)furan. These were obtained either by acylation of 2-alkylfurans followed by reduction or by a Grignard reaction using commercially available 5-methyl-2-furaldehyde and an alkylmagnesium halide.

Method 1b. This one-pot procedure failed, however, when attempts were made to prepare the 3-hydroxy-4-pyrone derivatives **16** and **19**, which have a methyl group in the

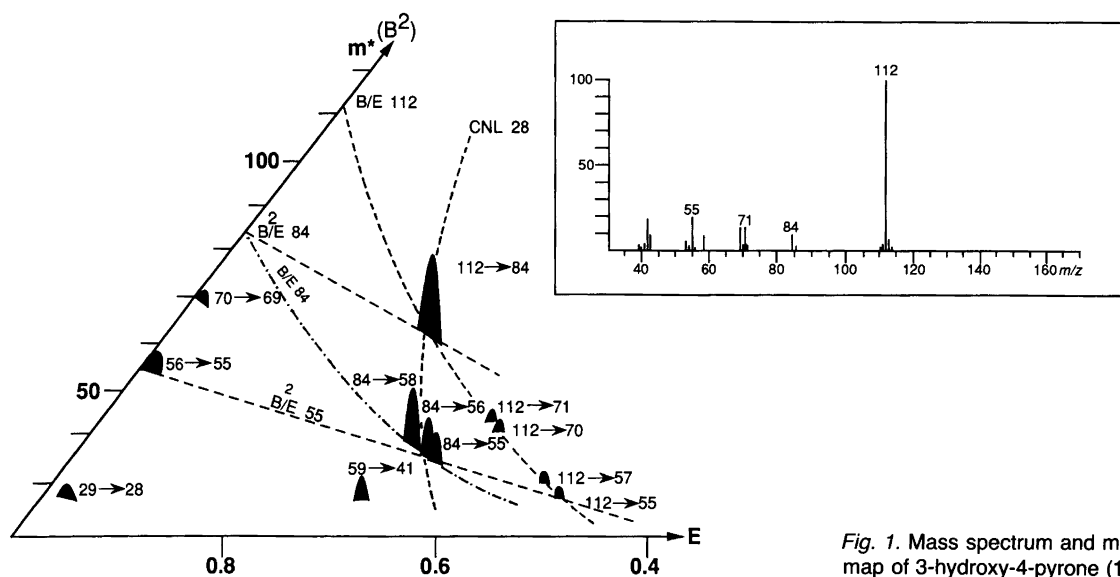


Fig. 1. Mass spectrum and metastable map of 3-hydroxy-4-pyrone (**1**).

Table 2. Selected ions from the electron impact spectra (70 eV) of alkyl substituted PMAs. Intensities are given as a percentage of the total ion current (m/z 39 to $M+1$) and obtained from low-resolution mass spectra, using the high-resolution results to determine the ratios between ions of the same nominal mass. Ions with intensities less than 1% of base peak are set to 0. Numbering of the compounds refers to Table 1.

m/z	Formula	1	2	3	4	5	6	8	9	10	12	13	14	15	16	17	18	19	
168	C ₉ H ₁₂ O ₃					14					1.4	2.0	4.5						
167	C ₉ H ₁₁ O ₃										0.4	0.5	1.0						
154	C ₈ H ₁₀ O ₃				21				6.1	7.0						24	18	32	
153	C ₈ H ₉ O ₃				0.4	0.2			2.1	2.8	2.6	14	13						
140	C ₇ H ₈ O ₃			19				16			0.8	12		24	19				
139	C ₇ H ₇ O ₃			1.7	2.4	1.9		10	18	27	11	18		0.4	0.5	7.0	4.3	4.1	
137	C ₇ H ₅ O ₃							0.2	0.6	0.7	0.6	1.1	1.0						
126	C ₇ H ₁₀ O ₂																0.5	1.2	
126	C ₆ H ₆ O ₃		34		7.5	21	31	0.4	22	10	36	6.8	30				0.5		
125	C ₇ H ₉ O ₂										0.6						0.6	2.0	4.2
125	C ₆ H ₅ O ₃		1.4	1.8	6.1	2.2	0.4	3.9	5.3	0.6	3.8	0.9	6.2	3.2	0.5	0.2			
113	C ₆ H ₉ O ₂				0.3														
112	C ₆ H ₈ O ₂			0.9										0.9	0.8				
112	C ₅ H ₄ O ₃	42				0.3		0.5	0.3										
111	C ₆ H ₇ O ₂			1.3		0.7			0.7	3.0		3.3		3.1	4.2	4.0	4.4	5.8	
111	C ₅ H ₃ O ₃				0.3		0.6	1.0		0.5	0.5								
99	C ₅ H ₇ O ₂			0.6													4.1	2.6	
98	C ₅ H ₆ O ₂		2.5	0.8	1.1	1.0	0.5	0.3			0.5			0.3	0.2				
97	C ₆ H ₉ O										0.5	0.8						0.7	
97	C ₅ H ₅ O ₂		1.1	6.3	9.5	4.9	4.1	4.6	5.9	0.5	3.8	1.2	4.6	2.7	1.1	0.2	1.2		
87	C ₃ H ₃ O ₃		0.4	0.7	0.7	1.4													
86	C ₃ H ₂ O ₃	0.8																	
85	C ₄ H ₅ O ₂		1.3											10	4.7	8.4			
84	C ₅ H ₈ O			0.8											0.3				
84	C ₄ H ₄ O ₂	3.8	0.6	0.2	1.1	1.0		0.5	0.4						0.5				
83	C ₅ H ₇ O			3.9	0.6	0.6		0.4	1.2	6.1		0.4			2.3		2.8	7.4	
71	C ₃ H ₃ O ₂	5.9					14	6.1	4.5	4.9	5.0	4.1	5.1				0.3		
70	C ₄ H ₆ O				0.4	1.0							0.5	0.3	0.3				
70	C ₃ H ₂ O ₂	1.7	1.6	0.5			0.7	0.6		0.5	0.6			0.2	0.2				
69	C ₅ H ₉				2.4							1.2	0.5						
69	C ₄ H ₅ O		7.0	0.9	2.4	4.2	1.1	4.8	0.4	0.9	0.5	1.2	0.9	6.1	5.9	4.2	1.7	0.4	
69	C ₃ HO ₂	5.7	4.2	5.6			1.6	0.7	0.9	0.9	1.0			0.7					
58	C ₂ H ₂ O ₂	3.3	5.4	2.5	1.8	1.7													
57	C ₃ H ₅ O			3.9	0.3	0.2	0.6	0.8			0.6	0.6	0.5		0.9	2.0	1.7		
56	C ₄ H ₈			1.3		0.2									0.4		0.2	0.5	
56	C ₃ H ₄ O	1.7	0.3				1.7				0.6	0.4	0.7	0.4	2.0		0.3		
55	C ₄ H ₇			4.8	0.8	1.8			1.1	4.0	1.0				1.0	0.2	2.0	2.0	
55	C ₃ H ₃ O	8.2	0.9	1.8	1.5	1.4	8.3	2.5	2.5	1.3	2.6	2.5	2.5	2.4	4.5	1.0	3.1	1.4	

5-position. It was therefore necessary to isolate the intermediates after the first bromine oxidation step. Acidic rearrangement and oxidation with hydrogen peroxide^{11,12} gave, after treatment with acid, the desired compounds (eqn. 1b). The starting materials were made from 3-furoic acid derivatives by a multistep synthesis including acetylation and conversion of the carboxylic acid function into a methyl group.

Method 2. A different strategy was used for the synthesis of 2-alkyl-5-hydroxy-4-pyrones (2–5). 5-Hydroxy-2-hydroxy-methyl-4-pyrone (kojic acid) is commercially available and was converted into 5-hydroxy-2-methyl-4-pyrone (2) by treatment with thionyl chloride and reduction of the resulting primary halide with zinc in acetic acid.¹³ Higher homologues were obtained by protection of the 5-hydroxy group of kojic acid followed by oxidation of the primary

hydroxy group to the corresponding aldehyde. Reactions between this aldehyde and zinc-modified Grignard reagents gave hydroxyalkylpyrones, which upon treatment with thionyl chloride and subsequent reduction with zinc gave, after removal of the protecting group, the desired alkylpyrones (3–5).

Mass spectrometric methods. The mass spectrometric fragmentation routes for ions derived from compounds 1–19 were determined from a study of metastable transitions occurring in the first field-free region of the double focusing mass spectrometer. In our instrument, which has a Nier–Johnson geometry, these metastable transitions can be observed by the metastable mapping technique,¹⁴ i.e. the apparent masses m^* (measured m/z) are plotted against the electrostatic analyser voltages and ion intensities to give a three-dimensional contour map from which both parent

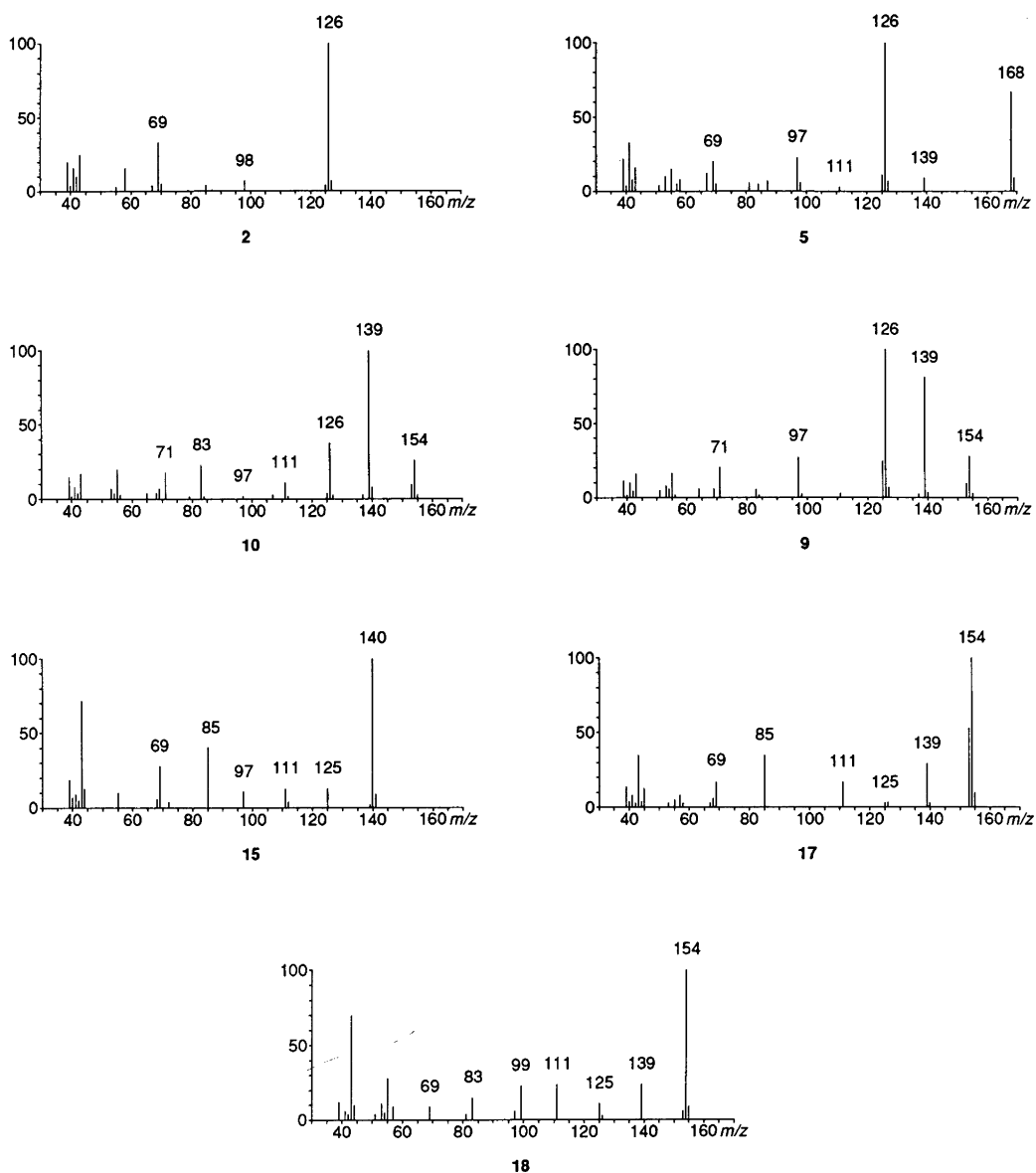


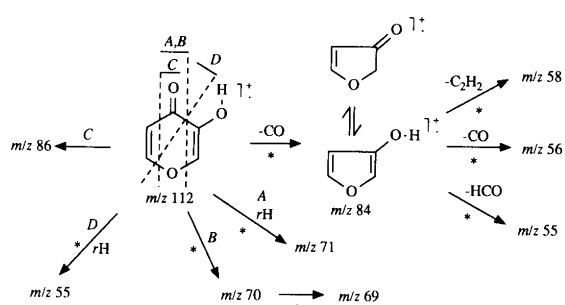
Fig. 2. Mass spectra of 5-hydroxy-2-methyl-4-pyrone (**2**), 2-butyl-5-hydroxy-4-pyrone (**5**), 3-hydroxy-2-isopropyl-4-pyrone (**10**), 3-hydroxy-2-propyl-4-pyrone (**9**), 3-hydroxy-2,6-dimethyl-4-pyrone (**15**), 2-ethyl-3-hydroxy-6-methyl-4-pyrone (**17**) and 6-ethyl-3-hydroxy-2-methyl-4-pyrone (**18**).

and daughter ion masses can be calculated. Fig. 1 shows the metastable map of 3-hydroxy-4-pyrone as recorded by this technique.

Since this is a rather time consuming technique it was only applied to certain selected compounds (**1**, **2**, **6**, **8**, **9** and **15**). Computer-generated linked scans; B/E -scans, B^2/E -scans and neutral loss scans were used on selected ions to confirm fragmentation routes for the rest of the compounds.

To further confirm postulated fragmentation routes, low resolution mass spectra were recorded for all compounds after exchange of the hydroxy hydrogen for deuterium. The exchange was accomplished by dissolution of a small amount of the compound in ($^2\text{H}_4$)methanol in the direct-inlet sample tube. After 5 min the probe was inserted into

the ion source, the solvent evaporated and the mass spectrum recorded. Several of the fragmentation routes proposed below were confirmed by distinct transitions observed in either the metastable maps or the B/E , B^2/E or constant neutral loss experiments and these are indicated with asterisks in the Schemes. The fragment ions of importance for the discussion are displayed in Table 2, which gives their compositions and abundances in the low resolution mass spectra as a percentage of the total ion current (m/z 39 to $M + 1$). The abundances of ions having the same nominal mass but different elemental compositions were estimated from their intensities in the high resolution mass spectra. The low resolution mass spectra of the compounds used as examples in the discussion below are shown in Fig. 2.



Scheme 1. Proposed routes to some of the fragment ions of 3-hydroxy-4-pyrone (**1**).

Discussion

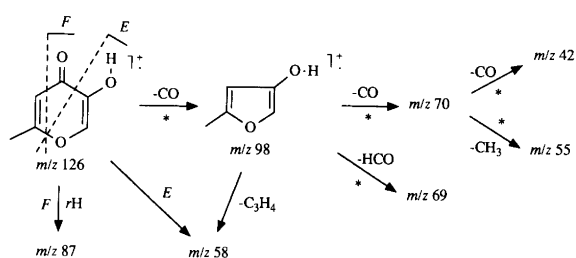
To facilitate the subsequent discussion of the fragmentation pathways and their dependence on the position of the alkyl substituents, the compounds will be referred to as alkyl-substituted pyromeconic acids (3-hydroxy-4-pyrone)s, PMAs. Thus 3-hydroxy-2-methyl-4-pyrone (maltol) will be designated 2-methyl-PMA and 5-hydroxy-2-methyl-4-pyrone (allomaltol) 6-methyl-PMA.

All the PMAs examined in this study exhibit a molecular ion which constitutes the base peak in the spectra of compounds **1–4**, **6–8** and **15–19**. The high abundance of the molecular ion indicates a high stability of the 3-hydroxy-4-pyrone system under EI conditions, and PMA (**1**) gives a relatively simple mass spectrum with only a few fragment peaks (Fig. 1). The elemental composition of the m/z 84 ion (Table 2) indicates that this ion is formed by loss of carbon monoxide from the molecular ion, a reaction confirmed by a prominent peak in the metastable map (Fig. 1). Since loss of carbon monoxide from the molecular ion of 4-pyrone has been observed by several authors^{15,16} and there is evidence for a furyl radical cation structure of the ion formed in this reaction,¹⁷ a 3-hydroxyfuryl radical cation structure or a corresponding keto-form may be assigned to the m/z 84 ion (Scheme 1). In agreement with the behaviour of furyl radical cations, further fragmentations of the m/z 84 species include loss of ethyne, carbon monoxide or a formyl radical leading to m/z 58, 56 and 55 ions.

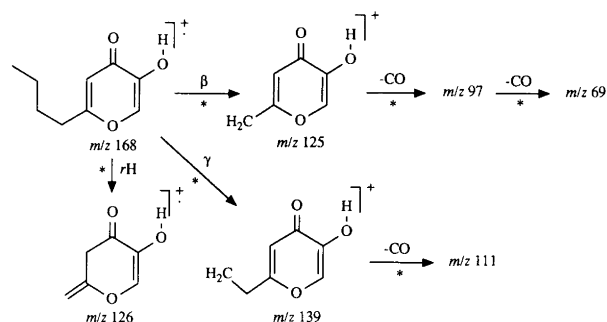
The metastable map of **1** (Fig. 1) also shows two minor peaks for the transitions $M^{+\cdot}$ to m/z 71 (A) and $M^{+\cdot}$ to m/z 70 (B), with the compositions $C_3H_3O_2$ and $C_3H_2O_2$. The latter of these extrudes a hydrogen radical to give the m/z 69 ion. When the hydroxy hydrogen in **1** was exchanged for deuterium, the ion from cleavage B retained its original m/z value, while the ion from cleavage A was shifted to m/z 72. Thus, the retro Diels–Alder type cleavage, A, involves transfer of the hydroxy hydrogen to the charged species (Scheme 1; rH designates a hydrogen rearrangement). Cleavage C of $M^{+\cdot}$ generates the m/z 86 ion by loss of ethyne, without any observable metastable transition. As shown by a small peak in the metastable map, $M^{+\cdot}$ also gives rise to an m/z 55 (C_3H_3O) ion, apparently through cleavage D in Scheme 1.

6-Alkyl-PMAs. This set includes the four monoalkyl substituted compounds, 6-methyl- (**2**), 6-ethyl- (**3**), 6-propyl- (**4**) and 6-butyl-PMA (**5**) and their mass spectra can be rationalized in much the same way as that of **1**. A cleavage, which corresponds to route A in Scheme 1, gives m/z 85, 99 and 113 ions from compounds **2**, **3** and **4**, respectively. The ions formed by the retro Diels–Alder cleavages B and C in Scheme 1 are of low abundance, especially in the cases of the higher homologues, and are therefore less useful. Similarly, ions derived from cleavage D (m/z 69, 83 etc.) are of little value for structural elucidation purposes, notably because ions with the same composition can arise by many different routes (cf. Schemes 2–6). Diagnostically important ions are found at m/z 58 ($C_2H_2O_2$) and m/z 87 ($C_3H_3O_3$). Of all compounds examined, these two ions are encountered only in the spectra of PMAs in which a hydrogen in the 2-position is present (i.e. **2–5**) and probably arise by cleavages E and F of the pyrone ring as shown for compound **2** in Scheme 2.

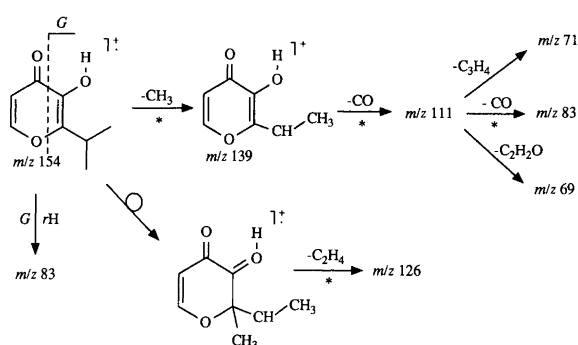
Accurate mass measurement (Table 2) and the metastable mass measurement reveal that the m/z 98 ion is derived from $M^{+\cdot}$ of 6-methyl-PMA (**2**) by loss of carbon monoxide and decomposes further as shown in Scheme 2. Direct loss of carbon monoxide from the molecular ion constitutes only a minor route in the fragmentation of compounds **3–5**. Instead, bond cleavage reactions in the alkyl side chain are more important and occur prior to the loss of carbon



Scheme 2. Proposed routes to some of the fragment ions of 5-hydroxy-2-methyl-4-pyrone (**2**).



Scheme 3. Proposed routes to some of the fragment ions of 2-butyl-5-hydroxy-4-pyrone (**5**).

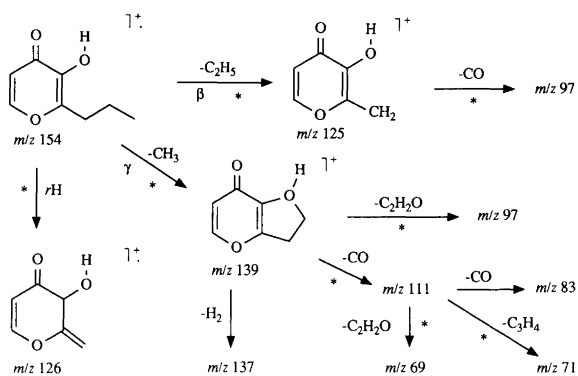


Scheme 4. Proposed routes to some of the fragment ions of 3-hydroxy-2-isopropyl-4-pyrone (**10**).

monoxide. Hence, a major fragmentation route is cleavage of the bond β to the pyrone ring generating the m/z 125 ($\text{C}_6\text{H}_5\text{O}_3$) ion, which extrudes carbon monoxide to give the m/z 97 ($\text{C}_5\text{H}_5\text{O}_2$) ion. This is exemplified for **5** in Scheme 3 and is also observed as a minor route in the metastable map of **2**. The corresponding γ -bond cleavage leading to the m/z 139 ($\text{C}_7\text{H}_7\text{O}_3$) ion followed by loss of carbon monoxide to the m/z 111 ($\text{C}_6\text{H}_7\text{O}_2$) ion is also observed in the spectra of **3–5**. However, the prevailing fragmentation here is the β -bond cleavage followed by extrusion of carbon monoxide. As revealed by B/E -scans and accurate mass measurements, the resulting m/z 97 ion undergoes further loss of carbon monoxide to give the m/z 69 ($\text{C}_4\text{H}_5\text{O}$) ion.

The m/z 126 ion, which constitutes the base peak in the mass spectrum of the 6-butyl-PMA (**5**) has the composition $\text{C}_6\text{H}_6\text{O}_3$ and is, as shown by B/E -scans, derived from $M^{+\cdot}$ (Scheme 3). It is thus formed by a McLafferty reaction and is also present in the spectrum of 6-propyl-PMA (**4**).

2-Alkyl-PMAs. Representatives of this group included here are the compounds which have C_1 – C_4 straight (**6, 8, 9, 12**) or branched (**10, 13, 14**) alkyl side chains, and the labelled derivatives 2-($^2\text{H}_3$)methyl- and 2-($^2\text{H}_6$)isopropyl-PMA (**7** and **11**). Cleavage *A* (Scheme 1) leads to the m/z 71 ($\text{C}_3\text{H}_3\text{O}_2$) ion, which is abundant in the spectra of all 2-alkyl-PMAs. In the spectra of the side-chain-labelled

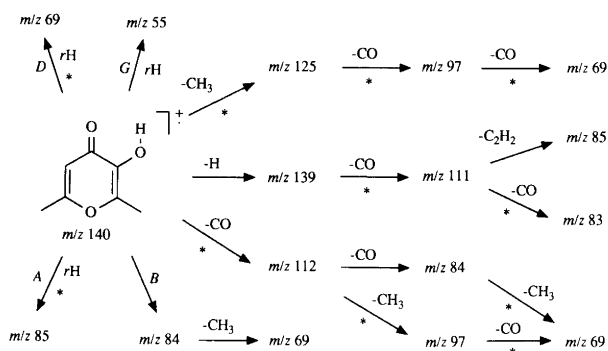


Scheme 5. Proposed routes to some of the fragment ions of 3-hydroxy-2-propyl-4-pyrone (**9**).

compounds **7** and **11** about 40% of the m/z 71 ion is shifted to m/z 72. Moreover, mass spectra of the other compounds (**6, 8–10** and **12–14**) with the 3-hydroxy hydrogen exchanged for deuterium show that deuterium is incorporated into this ion to an extent ranging from 50 to 60%. Thus, the itinerant hydrogen can be derived either from the hydroxy group or from the alkyl side chain. The same retro Diels–Alder type cleavage of the 4-pyrone ring resulting in charge retention by the fragment comprising the C-2 and C-3 carbons is also observed, i.e. cleavage *G* in Scheme 4. Although this is only a minor fragmentation route for the PMAs having a straight alkyl side chain, it is important for those in which the alkyl side chain is branched at the α -carbon, i.e. compounds **10** and **13**, which furnish abundant m/z 83 ($\text{C}_5\text{H}_5\text{O}$) and m/z 97 ($\text{C}_6\text{H}_6\text{O}$) ions, respectively. In the spectrum of 2-($^2\text{H}_6$)isopropyl-PMA (**11**), this fragment appears at m/z 89 and therefore must contain the ($^2\text{H}_6$)isopropyl group. Moreover the B/E scan reveals that $M^{+\cdot}$ of **11** yields the m/z 89 ion directly and that this m/z 89 ion decomposes further by loss of carbon monoxide to the m/z 61 ion.

While loss of carbon monoxide from $M^{+\cdot}$ of the 6-methyl-PMA (**2**) is a major fragmentation route it is only a minor one in the case of 2-methyl-PMA (**6**). In the case of **6**, it gives rise to the m/z 98 ion which is further degraded to the m/z 80, 70 and 52 ions. Cleavage of the bond β to the pyrone ring in $M^{+\cdot}$ of the compounds **6, 8, 9, 12** and **14**, which involves loss of a hydrogen or an alkyl radical, yields the m/z 125 ($\text{C}_6\text{H}_5\text{O}_3$) ion. This ion decomposes further by loss of carbon monoxide to the m/z 97 ($\text{C}_5\text{H}_5\text{O}_2$) ion, a reaction displaying a strong metastable transition. Major peaks in the B/E scan also reveal loss of C_2H_2 (C_2D_2 in the case of **7**) and of carbon monoxide from the m/z 97 ion to furnish the m/z 71 and 69 ions. As expected, the α -carbon branched compounds furnish even more prominent β -cleavage ions. Thus, in the case of compound **10**, the most abundant ion occurs at m/z 139, which in turn, by loss of carbon monoxide, gives the m/z 111 ion (Scheme 4). In the spectrum of ($^2\text{H}_6$)isopropyl-PMA (**11**) the corresponding ions appear at m/z 142 and 114. A B/E scan from m/z 114 shows major peaks for transitions to m/z 86, 72 and 71. Similarly, the most abundant ion derived from compound **13** occurs at m/z 139 and extrudes carbon monoxide to give the m/z 111 ion.

In contrast with the 6-alkyl-PMAs **3–5**, the 2-alkyl isomers **8, 9** and **12** yield an ion (m/z 139) formed by cleavage of the bond γ to the pyrone ring; which is much more abundant than that (m/z 125) derived from the β -cleavage. It seems, therefore, that the γ -bond cleavage occurs with anchimeric assistance of the hydroxy group at C-3 to yield the m/z 139 ion by cyclization. We have,¹⁸ in an earlier study, reported such a cyclization reaction in the EI fragmentation of some 3-alkyl-2-hydroxy-2-cyclopentenones. The compounds that contain a branched alkyl chain (**10, 13** and **14**) exhibit the corresponding ion at m/z 153. The further fragmentation of these bicyclic ions seems to include an aromatization reaction that furnishes an m/z 137



Scheme 6. Proposed routes to some of the fragment ions of 3-hydroxy-2,6-dimethyl-4-pyrone (**15**).

($C_7H_5O_3$) ion through loss of either a hydrogen and a methyl group or two hydrogens from the α - and β -carbons.

The base peak in the spectra of compounds **9**, **12** and **14** is due to the m/z 126 ion formed by a McLafferty reaction similar to that proposed for the 6-alkyl-PMAs **4** and **5** (Scheme 3), which is shown for **9** in Scheme 5. In the spectrum of the 2-(*sec*-butyl)-PMA (**13**) this ion, as expected, appears at m/z 140, and, in addition, there is another abundant ion of even mass at m/z 126 ($C_6H_6O_3$), the formation of which requires loss of C_3H_6 from $M^{+\cdot}$. Furthermore, the 2-isopropyl-PMA (**10**) gives a prominent ion at m/z 126. Originally this ion was assumed to be formed by loss of carbon monoxide from the $M^{+\cdot}$ of compound **10**,⁹ but our accurate mass measurements showed it to have the composition $C_6H_6O_3$ which contradicts such an interpretation. A *B/E* scan from $M^{+\cdot}$ of compound **10** confirmed that the m/z 126 ion is derived from $M^{+\cdot}$, which requires loss of ethene. Hence, the molecular ions of compounds **10** and **13** must undergo a rearrangement of the alkyl group before this elimination can occur. Support for such a rearrangement is also found in the spectrum of the deuterium labelled 2-isopropyl-PMA (**11**), where the corresponding ion appears at m/z 129 and, thus, must have been formed by loss of C_2HD_3 . A rearrangement that accounts for these observations is presented in Scheme 4. It should be noted that the spectrum of 2-ethyl-PMA (**8**) contains a weak peak at m/z 112 ($C_5H_4O_3$, Table 2), which could arise by the same type of rearrangement, but now involving a hydrogen instead of a methyl group.

Di- and tri-alkylated PMAs. The five compounds in which two or more alkyl groups are attached to the pyrone ring examined here are 2,6-dimethyl- (**15**), 2,5-dimethyl- (**16**), 2-ethyl-6-methyl- (**17**), 6-ethyl-2-methyl- (**18**) and 2,5,6-trimethyl-PMA (**19**). The spectra of these compounds nicely confirm the fragmentation pathways postulated for the monoalkylated compounds. In addition, they clarify the effect that substituents at different positions on the pyrone ring have on the fragmentation pathways. Of the PMAs having only methyl substituents, (**15**, **16** and **19**), those substituted in the 2- and 6-positions show a more abundant ($M-CH_3$)⁺ ion than either of the monomethyl-PMAs (**2**

and **6**). The remainder of the prominent ions seem to arise by the routes considered important for the monoalkyl-PMAs. Major pathways to the most prominent ions in the spectrum of 2,6-dimethyl-PMA (**15**) are outlined in Scheme 6.

It is obvious that the routes starting either with loss of carbon monoxide or β -cleavage, as discussed for the mono-substituted derivatives, are still valid. The aforementioned route starting with extrusion of a methyl group is also available for compounds **2** and **6** but of minor importance. Of the ring cleavages discussed, *A*, *D* and *G* lead, as is the case for the 2-monosubstituted PMAs, to the most prominent ions, while cleavage *B* only gives rise to minor peaks.

The importance of the substituent in the 2-position can also be seen by comparison of the spectra of 2-ethyl-6-methyl-PMA (**17**) and 6-ethyl-2-methyl-PMA (**18**) in Fig. 2. The spectrum of **18** shows a mixture of fragment ions derived from routes starting with β -cleavage of each alkyl group. Though it is, in general, much easier to lose a methyl radical than a hydrogen radical under EI conditions, the β -cleavage of the substituent in the 2-position is favoured. The ions corresponding to cleavages *A*, *D* and *G* now appear at m/z 99, 83 and 55, respectively.

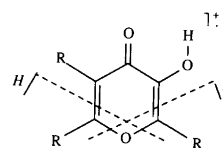
The fragment ions in the spectrum of **17** is to a large extent determined by the ethyl substituent in the 2-position. Thus, the bicyclic m/z 153 ion, the m/z 139 ion from β -cleavage of the ethyl group (cf. Scheme 5) and the m/z 126 ($C_6H_6O_3$) ion (cf. Scheme 4) are present. Also ions corresponding to cleavages *A*, *D* and *G* are encountered and appear at m/z 85, 69 and 69, respectively.

Conclusions

Of the several ring cleavages (*A*–*G* in Schemes 1, 2 and 4) discussed, the diagnostically most important ones for differentiating positional isomers are *A* and *E*. As long as the PMA derivatives carry an alkyl substituent in the 2-position, the ion corresponding to cleavage *A* is present in a detectable amount. Although ions of the same composition have been shown to arise by another route (Schemes 4 and 5) we have made no attempt to evaluate their relative importance, since the information contained in these ions is the same as in those derived from cleavage *A*.

Cleavage *E* gives an m/z 58 ($C_2H_2O_2$) ion if the PMAs have a hydrogen in the 2-position. As discussed for cleavage *A*, this ion can also be derived by another route (Scheme 1), but it discloses the same information.

These two cleavages together with the molecular weight reveal the presence of a substituent in the 2-position, and



Scheme 7. Proposed fragment ions.

also whether there are any substituents in the 5- and/or 6-position.

Inspection of the mass spectra derived from the alkyl-PMAs suggests the presence of ions formally derived from cleavages *H* and *I*, shown in Scheme 7. Although there is no metastable evidence for these cleavages, it is noteworthy that all mass spectra of compounds in which a methyl substituent is present in the 2- or 6-position, exhibit a prominent (among the three most intense) m/z 43 ion, which on $^2\text{H}_3$ -labelling (**7**) is shifted to m/z 46. Similarly, compounds possessing an ethyl group in the 2- or 6-position display a m/z 57 ion of enhanced intensity.

With the information now at hand it is possible to elucidate the structures of most alkyl-PMAs of reasonable molecular weight from their mass spectra.

Experimental

General methods. ^1H NMR spectra were recorded on a Varian XL300 spectrometer in CDCl_3 with TMS as an internal standard. Coupling constants are given in Hz.

High-resolution mass measurements and metastable map experiments were carried out by means of a Kratos MS50 mass spectrometer interfaced to a Data General Nova 3 computer operated by DS-55 data processing software. Mass spectrometric conditions were: acceleration voltage 8 kV, electron energy 70 eV, electron beam 500 μA , source temperature 250 °C. The accurate mass measurements were obtained by computer-controlled repetitive scanning at 10 s decade⁻¹ of the double-focusing instrument tuned to a resolution of 10000 with perfluorokerosene as an internal standard. The metastable map experiments were performed by means of a Fluke model 4275A programmable power supply for the electrostatic analyser reference voltage.¹⁴

Low-resolution mass spectra and first field-free region metastable ion linked scan spectra were obtained by means of a Kratos MS25RFA mass spectrometer interfaced to a Data General Eclipse 280 computer operated by DS90 software and connected to a Carlo Erba Mega series 5160 GC equipped with a 60 m Supelcowax 10 fused silica capillary column. Mass spectrometric conditions were: acceleration voltage 4 kV, electron energy 70 eV, electron beam 250 μA , source temperature 250 °C. The scan rate was 1 s decade⁻¹ for both low-resolution acquisition and linked-scan experiments. The computer controlled *B/E*-, *B²/E*- and constant neutral loss scanning capability is a part of the MS25RFA-DS90 system. Low resolution mass spectra were obtained by introducing the sample via a GC column into the ion source. An averaged mass spectrum was calculated from five consecutive spectra taken across the GC peak. The abundances of the individual ions in the averaged spectrum were calculated as a percentage of the total ion current (m/z 39 to $M+1$). Accurate mass measurements were made after introduction of the sample via a direct-inlet probe under high-resolution conditions, by determina-

tion of the elemental composition of each ion in the recorded spectrum.

Solvents used were of HPLC grade, or better, and chemicals were of analytical grade and used as purchased. Separations and purifications were carried out by column chromatography either traditionally or as flash chromatography. Merck Kieselgel 60 (230–400 mesh) served as the stationary phase and solvent mixtures were tailored to each individual separation. TLC was performed on Merck DC-Alufolien Kieselgel 60, and 1 M ferric chloride in 1 M hydrochloric acid was employed for selective detection of 3-hydroxy-4-pyrones.

Melting points, uncorrected, were measured on a Leitz Wetzlar Heizstativ apparatus. Elemental compositions were determined from high resolution mass spectra and were, for all molecular ions, within a 11 ppm range from the expected. Low-resolution mass spectral data are given as a percentage of the base peak, unless otherwise stated.

The pyrones were synthesized by one of three general methods, as follows.

Method 1a. Since the same reaction sequence was used for the preparation of **1** and all its 2-alkyl and 2,6-dialkyl derivatives, experimental details are given for one example (**9**) only.

3-Hydroxy-4-pyrone (1) was prepared from furfuryl alcohol. Crystals from hexane, had m.p. 112–115 °C (lit.¹⁹ 113–115.5 °C). MS m/z (%): 112 (100, M^+), 55 (19), 42 (17), 71 (14), 69 (13), 84 (9), 43 (9), 58 (8), 70 (4), 41 (4). ^1H NMR δ 7.88 (s), 7.80 (d, $J = 5.4$), 6.50 (d, $J = 5.4$). Integrals of the three groups were equal.

3-Hydroxy-2-methyl-4-pyrone (6) is commercial. MS m/z (%): 126 (100, M^+), 71 (45), 43 (36), 55 (27), 97 (13), 42 (10), 69 (9), 127 (8), 52 (6). ^1H NMR δ 7.71 (d, $J = 5.7$, 1 H), 6.42 (d, $J = 5.7$, 1 H), 2.37 (s, 3 H).

3-Hydroxy-2-($^2\text{H}_3$)methyl-4-pyrone (7) was prepared in 20% yield from (2,2,2- $^2\text{H}_3$)-1-(2-furyl)ethanol, made from ($^2\text{H}_3$)methylmagnesium iodide and 2-furaldehyde in a Grignard reaction. MS m/z (%): 129 (100, M^+), 71 (43), 46 (43), 72 (23), 128 (23), 55 (19), 54 (18), 45 (17), 99 (15), 130 (14). ^1H NMR δ 7.71 (d, $J = 5.5$), 6.42 (d, $J = 5.5$). Integrals were equal.

2-Ethyl-3-hydroxy-4-pyrone (8) is commercial. MS m/z (%): 140 (100, M^+), 139 (63), 71 (37), 69 (30), 97 (29), 125 (24), 43 (17), 39 (16), 41 (16), 55 (15). ^1H NMR δ 7.74 (d, $J = 5.5$, 1 H), 6.42 (d, $J = 5.5$, 1 H), 2.75 (q, $J = 7.6$, 2 H), 1.25 (t, $J = 7.6$, 3 H).

3-Hydroxy-2-propyl-4-pyrone (9). To a mixture, at 0 °C, of bromine (0.6 ml) and sodium acetate (1 g) in methanol (10 ml) was slowly added a solution of 1-(2-furyl)-1-butanol (1.35 g) in methanol (10 ml). After 1.5 h the ice-bath was removed, bromine (0.6 ml) and water (20 ml) were added

and the reaction mixture kept at room temperature for 2 h. The solvents were removed, 50% hydrobromic acid (20 ml) was added and the mixture heated at 90°C for 2 h. After being cooled, the mixture was extracted with dichloromethane (3×15 ml). The organic phase was dried over sodium sulfate and the solvent evaporated. The crude product was purified by column chromatography to give 450 mg, 29%, of the title compound. Crystals from isopropyl acetate–hexane, m.p. 73–76°C (lit.¹⁹ 82–83°C). MS *m/z* (%): 126 (100), 139 (81), 154 (28, *M*⁺), 97 (27), 125 (24), 71 (21), 43 (21), 55 (16), 39 (12), 153 (9). ¹H NMR δ 7.74 (d, *J* = 5.5, 1 H), 6.43 (d, *J* = 5.5, 1 H), 2.70 (t, *J* = 7.5, 2 H), 1.72 (sextet, *J* = 7.5, 2 H), 0.99 (t, *J* = 7.5, 3 H).

3-Hydroxy-2-isopropyl-4-pyrone (10) was prepared from 1-(2-furyl)-2-methyl-1-propanol in 10% yield. Crystals from hexane, m.p. 63–65°C (lit.⁹ 70–72.5°C). MS *m/z* (%): 139 (100), 126 (38), 154 (26, *M*⁺), 83 (23), 55 (20), 71 (18), 43 (17), 39 (15), 111 (11), 140 (8). ¹H NMR δ 7.76 (d, *J* = 5.5, 1 H), 6.42 (d, *J* = 5.5, 1 H), 3.34 (septet, *J* = 7.0, 1 H), 1.26 (d, *J* = 7.0, 6 H).

3-Hydroxy-2-(²H₆)isopropyl-4-pyrone (11). (²H₆)Acetone was reduced with lithium aluminium hydride in diethyl ether. The ether was evaporated, a small amount of water added carefully under nitrogen and the (²H₆)-2-propanol formed was distilled off through a short column. Phosphorus tribromide and (²H₆)-2-propanol were heated and the (²H₆)-2-propyl bromide distilled off when formed. The bromide was converted into the corresponding Grignard reagent and reacted with 2-furaldehyde to give 1-(2-furyl)-2-methyl-(²H₆)-1-propanol. This was treated with bromine as described above to give the title compound. MS *m/z* (%): 142 (100), 129 (33), 160 (33, *M*⁺), 89 (27), 71 (16), 114 (15), 61 (13), 143 (13), 72 (10), 42 (10). ¹H NMR δ 7.78 (d, *J* = 5.5), 6.45 (d, *J* = 5.5), 3.3 (br, s). Integrals of the groups were equal.

2-Butyl-3-hydroxy-4-pyrone (12) was prepared from 1-(2-furyl)-1-pentanol in 15% yield. Crystals from hexane, m.p. 47–52°C (lit.¹⁹ 55–56°C). MS *m/z* (%): 126 (100), 139 (31), 71 (14), 97 (12), 43 (11), 125 (11), 41 (11), 39 (8), 153 (7), 55 (10), 168 (4, *M*⁺). ¹H NMR δ 7.73 (d, *J* = 5.6, 1 H), 6.42 (d, *J* = 5.6, 1 H), 2.72 (dd, *J* = 7.3 and 7.8, 2 H), 1.67 (m, 2 H), 1.4 (m, 2 H), 0.95 (t, *J* = 7.3, 3 H).

2-(sec-Butyl)-3-hydroxy-4-pyrone (13) was prepared from 1-(2-furyl)-2-methyl-1-butanol in 10% yield. MS *m/z* (%): 139 (100), 153 (76), 140 (67), 126 (37), 71 (22), 41 (21), 111 (18), 43 (17), 55 (13), 69 (13), 168 (11, *M*⁺). ¹H NMR δ 7.76 (d, *J* = 5.5, 1 H), 6.42 (d, *J* = 5.5, 1 H), 3.11 (d, *J* = 8.4 of quintets, *J* = 7.0, 1 H), 1.69 and 1.61 (AB system with *J*_{AB} = –13.5 further coupled with a methyl group, *J* = 7.4 and with a methine proton with *J* = 8.5 and 6.4, respectively, 2 H), 1.24 (d, *J* = 7.0, 3 H), 0.88 (t, *J* = 7.4, 3 H).

3-Hydroxy-2-isobutyl-4-pyrone (14) was prepared from 1-(2-furyl)-3-methyl-1-butanol in 13% yield. Crystals from hexane, m.p. 88–92°C (lit.¹⁹ 89–89.5°C). MS *m/z* (%): 126 (100), 153 (44), 125 (20), 43 (17), 71 (17), 97 (15), 168 (15, *M*⁺), 41 (13), 55 (8), 39 (8). ¹H NMR δ 7.38 (d, *J* = 5.5, 1 H), 6.43 (d, *J* = 5.5, 1 H), 2.59 (d, *J* = 7.3, 2 H), 2.10 (m, 1 H), 0.98 (d, *J* = 6.7, 3 H).

3-Hydroxy-2,6-dimethyl-4-pyrone (15) was prepared from 1-(5-methyl-2-furyl)ethanol in 21% yield. Crystals from hexane–dichloromethane, m.p. 155–157°C (sealed tube) (lit.²⁰ 161–162°C). MS *m/z* (%): 140 (100, *M*⁺), 43 (72), 85 (41), 69 (28), 39 (19), 125 (13), 111 (13), 44 (13), 97 (11), 55 (10). ¹H NMR δ 6.21 (s, 1 H), 2.34 (s, 3 H), 2.29 (s, 3 H).

2-Ethyl-3-hydroxy-6-methyl-4-pyrone (17) was prepared from 1-(5-methyl-2-furyl)-1-propanol. Crystals from hexane, m.p. 104–107°C. MS *m/z* (%): 154 (100, *M*⁺), 153 (53), 85 (35), 43 (35), 139 (29), 69 (17), 111 (17), 39 (14), 155 (10), 41 (8). ¹H NMR δ 6.20 (s, 1 H), 2.72 (q, *J* = 7.5, 2 H), 2.30 (s, 3 H), 1.25 (t, *J* = 7.5, 3 H).

6-Ethyl-3-hydroxy-2-methyl-4-pyrone (18) was prepared from 1-(5-ethyl-2-furyl)ethanol. Crystals from isopropyl acetate–hexane, m.p. 93–96°C. MS *m/z* (%): 154 (100, *M*⁺), 43 (70), 55 (28), 111 (24), 139 (24), 99 (23), 83 (15), 39 (14), 53 (12), 44 (10). ¹H NMR δ 6.21 (s, 1 H), 2.56 (t, *J* = 7.5, 2 H), 2.34 (s, 3 H), 1.22 (t, *J* = 7.5, 3 H).

Method 1b. This was used to prepare the pyrones **16** and **19**.

1-(4-Methyl-2-furyl)ethanol. 3-Furoic acid was reduced with lithium aluminium hydride to 3-furyl-methanol. This was heated in acetic anhydride at 70°C with a catalytic amount of zinc chloride for 24 h to form 4-acetoxymethyl-2-acetylfuran together with the isomeric 3-acetoxymethyl-2-acetylfuran. Separation of these by column chromatography and hydrolysis (1:1 dioxane–1 M sodium hydroxide) gave 2-acetyl-4-hydroxymethylfuran. The hydroxy group was replaced by chlorine by treatment with thionyl chloride in dichloromethane at room temperature for 3 h. Treatment of this chloride with lithium aluminium hydride in boiling tetrahydrofuran overnight gave the title compound.

3-Hydroxy-2,5-dimethyl-4-pyrone (16). 1-(4-Methyl-2-furyl)ethanol (350 mg) was dissolved in diethyl ether (25 ml) and methanol (15 ml) and cooled to –35°C. Bromine (0.16 ml), dissolved in methanol (10 ml), was added slowly. The mixture was stirred for 15 min at –15°C and neutralized with triethylamine. To remove residual bromine, sodium sulfite was added. The solvents were evaporated and the residue triturated in ether, filtered, and the solvent evaporated. The residue was dissolved in methanol (4 ml) and poured into a mixture of formic acid (40 ml) and methanol (2 ml). After 15 min the mixture was

diluted with dichloromethane, washed with water and aqueous sodium hydrogencarbonate and dried and the solvent evaporated. Purification by column chromatography gave 70 mg 2,6-dihydro-6-methoxy-2,5-dimethyl-3-pyrone. This was dissolved in 2-propanol (1 ml) and water (1 ml). An excess of hydrogen peroxide (30%) was added slowly together with 1 M sodium hydroxide to keep the mixture weakly alkaline. The mixture was kept below 5°C for 1 h. Dilution with water and extraction with dichloromethane gave an epoxide¹² which, after evaporation of the solvents, was heated with 2 M sulfuric acid for 2 h. Work-up gave the desired product in low yield. Crystals from hexane, m.p. 95–98°C. MS m/z (%): 140 (100, M^{+}), 43 (62), 39 (31), 69 (31), 55 (29), 66 (29), 85 (25), 111 (22), 56 (13), 41 (11). ¹H NMR δ 7.64 (q, $J = 1.2$, 1 H), 2.35 (s, 3 H), 1.99 (d, $J = 1.2$, 3 H).

1-(4,5-Dimethyl-2-furyl)ethanol. Methyl 2-methyl-3-furoate was reduced with lithium aluminium hydride in tetrahydrofuran to 2-methyl-3-furylmethanol in almost quantitative yield. This was dissolved in acetic anhydride and a small amount of zinc chloride was added every 12 h until the starting material was almost consumed (3–5 days). Some 10% of the theoretical amount of 3-acetoxymethyl-5-acetyl-2-methylfuran was obtained after column chromatography. Hydrolysis in 1:1 dioxane–1 M sodium hydroxide gave 5-acetyl-3-hydroxymethyl-2-methylfuran. Treatment with thionyl chloride followed by lithium aluminium hydride as described above for 1-(4-methyl-2-furyl)ethanol gave the title compound.

3-Hydroxy-2,5,6-trimethyl-4-pyrone (19) was prepared from 1-(4,5-dimethyl-2-furyl)ethanol as described for **16** above in low yield. MS m/z (%): 154 (100, M^{+}), 43 (35), 83 (23), 111 (18), 139 (13), 125 (13), 55 (11), 155 (9), 99 (8), 39 (6). ¹H NMR δ 2.34 (s), 2.32 (s), 2.01 (s). The integrals were equal.

Method 2. This was used to prepare the 2-alkyl-5-hydroxy-4-pyrones (**2–5**).

5-Hydroxy-2-methyl-4-pyrone (2) was prepared from 5-hydroxy-2-hydroxymethyl-4-pyrone (kojic acid) by chlorination and reduction¹³ in 62% yield. Crystals from ethyl acetate m.p. 151–153°C (lit.⁸ 153–154°C). MS m/z (%): 126 (100, M^{+}), 69 (33), 43 (25), 39 (20), 58 (16), 41 (14), 98 (7), 85 (4), 67 (4), 55 (3). ¹H NMR δ 7.80 (s, 1 H), 6.29 (s, 1 H), 2.31 (s, 3 H).

2-Formyl-5-methoxy-4-pyrone. Kojic acid was treated with dimethyl sulfate¹³ to give 2-hydroxymethyl-5-methoxy-4-pyrone in 70% yield. The alcohol (1.54 g) was oxidized with pyridinium chlorochromate (1.4 g) in boiling dichloromethane (40 ml) for 3 h. After being cooled the reaction mixture was filtered and the solution purified by column chromatography. After evaporation 820 mg (50%) of alde-

hyde was isolated and recrystallized from ethyl acetate. M.p. 188–192°C (lit.²¹ 202°C).

2-(1-Hydroxyethyl)-5-methoxy-4-pyrone. The Grignard reagent made from methyl iodide (570 mg) and magnesium (96 mg) was stirred with anhydrous zinc chloride (540 mg) at room temperature for 1 h. Freshly distilled ethyl acetate (20 ml) was added and the mixture was purged with nitrogen at room temperature to allow some of the ether to evaporate. 2-Formyl-5-methoxy-4-pyrone (360 mg) was dissolved in hot ethyl acetate and added to the organozinc reagent. The mixture was heated to 60°C and the remaining ether removed by nitrogen-purging. Water (10 ml) and 1 M hydrochloric acid (5 ml) were added, the phases separated, and the aqueous phase extracted with ethyl acetate (6×15 ml). The combined organic phase was dried over sodium sulfate and the solvent evaporated. Column chromatography gave 284 mg of a crude product. Crystallization from ethyl acetate gave the title compound. M.p. 92–95°C. ¹H NMR δ 7.55 (s, 1 H), 6.51 (s, 1 H), 4.65 (quintet, $J = 7$, 1 H), 3.75 (s, 3 H), 3.45 (d, $J = 7$, 1 H), 1.5 (d, $J = 7$, 3 H).

2-Ethyl-5-methoxy-4-pyrone. 2-(1-Hydroxyethyl)-5-methoxy-4-pyrone was dissolved in dichloromethane and treated with an excess of thionyl chloride at room temperature over night. After evaporation of the solvent and thionyl chloride, the residue was dissolved in glacial acetic acid, an excess of zinc powder and a catalytic amount of sulfuric acid were added, and the mixture was heated at 60°C for 30 min. After the reaction mixture had been cooled, the salts were filtered off and the filtrate diluted with dichloromethane, washed with water and aqueous sodium hydroxide (1 M) to remove acetic acid, dried and the solvent evaporated. The crude product was chromatographed and then crystallized from hexane to give some 10% of the theoretical amount of desired compound. M.p. 80–82°C. ¹H NMR δ 7.58 (s, 1 H), 6.29 (t, $J = 0.7$, 1 H), 3.81 (s, 3 H), 2.6 (d, $J = 0.7$ of q, $J = 7.6$, 2 H), 1.08 (t, $J = 7.6$, 3 H).

5-Methoxy-2-propyl- and 2-butyl-5-methoxy-4-pyrone were prepared in the same way as described above for the 2-ethyl homologue starting with Grignard reagents prepared from ethyl bromide and propyl iodide, respectively. Intermediates were not isolated and overall yields were comparable.

2-Ethyl-5-hydroxy-4-pyrone (3) was prepared from 2-ethyl-5-methoxy-4-pyrone, which was boiled for 2 h in 50% hydrobromic acid, in 25% yield. Crystals from hexane, m.p. 97–102°C. MS m/z (%): 140 (100, M^{+}), 55 (35), 69 (34), 97 (33), 39 (26), 43 (24), 41 (23), 83 (21), 57 (21), 53 (16). ¹H NMR δ 7.80 (s, 1 H), 6.29 (s, 1 H), 2.59 (q, $J = 7.5$, 2 H), 1.20 (t, $J = 7.5$, 3 H).

5-Hydroxy-2-propyl-4-pyrone (**4**) was prepared from 5-methoxy-2-propyl-4-pyrone as for **3** in 25% yield. Crystals from hexane, m.p. 80–82°C. MS m/z (%): 154 (100, M^{+}), 97 (46), 41 (41), 126 (36), 125 (29), 69 (23), 39 (23), 43 (17), 67 (14), 155 (13). $^1\text{H NMR}$ δ 7.74 (s, 1 H), 6.20 (s, 1 H), 2.52 (t, $J=7.4$, 2 H), 1.69 (sextet, $J=7.4$, 2 H), 0.98 (t, $J=7.4$, 3 H).

2-Butyl-5-hydroxy-4-pyrone (**5**) was prepared from 2-butyl-5-methoxy-4-pyrone as for **3** in 29% yield. Crystals from hexane, m.p. 57–58°C. MS m/z (%): 126 (100), 168 (67, M^{+}), 41 (33), 97 (23), 39 (22), 69 (20), 43 (16), 55 (15), 67 (12), 53 (10). $^1\text{H NMR}$ δ 7.80 (s, 1 H), 6.30 (s, 1 H), 2.55 (t, $J=7.5$, 2 H), 1.64 (m, 2 H), 1.38 (m, 2 H), 0.95 (t, $J=7.4$, 3 H).

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