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Note

Oxidation of α-D-glucoisosaccharinic acid by nitric acid

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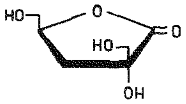
The waste liquors from alkaline pulping contain significant quantities of aliphatic hydroxy acids formed from wood polysaccharides[1]. One of the main base-catalysed degradation products of cellulose and glucomannans is 3-deoxy-2-*C*-hydroxymethyl-D-pentonic acid (glucoisosaccharinic acid). In connection with our studies of the utilisation of this acid, it was of interest to separate and identify, by g.l.c.–m.s., the products formed by oxidising the primary hydroxyl groups of the corresponding 3-deoxy-2-*C*-hydroxymethyl-D-*erythro*-pentono-1,4-lactone (**1**, α-D-glucoisosaccharino-1,4-lactone) to carboxylic groups. Nitric acid was used as the oxidant.

The structure of **1** had been earlier confirmed by oxidation with nitric acid[2] which gave, after decarboxylation, *meso*-dihydroxyglutaric acid and its optically active isomer. The reaction was also applied in later studies aimed at identification of the products of alkaline degradation of alginates and guaran[3,4]. In a recent study, one of the products of alkaline degradation of xylan, namely xyloisosaccharinic acid, was subjected to a similar oxidation[5].

In the mixture of products obtained in this work, carboxylic acid derivatives



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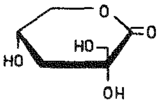

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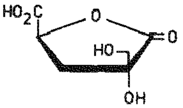

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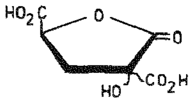

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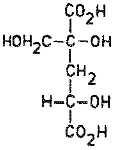
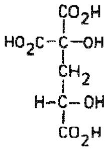


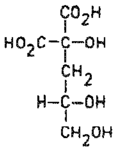
$$\begin{array}{c} \mathrm{CO_2H} \\ | \\ \mathrm{HOH_2C-C-OH} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CO_2H} \end{array}$$

6



$$\begin{array}{c} \mathrm{CO_2H} \\ | \\ \mathrm{HO_2C-C-OH} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CO_2H} \end{array}$$

7



$$\begin{array}{c} \mathrm{CO_2H} \\ | \\ \mathrm{HO_2C-C-OH} \\ | \\ \mathrm{CH_2} \\ | \\ \mathrm{H-C-OH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

8

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(**3**–**7**) containing six carbon atoms, together with several degradation products, were detected by g.l.c. after trimethylsilylation (Table I). Oxidation of glucoisosaccharinic acid by nitric acid produces a carboxylic group at C-2′, so that the asymmetry of C-2 disappears. Thus, in **7**, only the penultimate carbon atom (C-5) is asymmetric. However, in the most abundant oxidation products identified (diastereomers **4** and **5**), C-2 was chiral due to the lactonisation of **7**. In addition to these tribasic acid derivatives (~60% of the total products identified), small proportions of the dicarboxylic acid derivatives **3** and **6** were also present. The tricarboxylic acid derivative **7** has been also isolated after the oxidative alkaline degradation of pectic acid[6], whereas **6** is a major dicarboxylic acid obtained from alginates and pectic acid on treatment with alkali[3,7].

Besides the most common lactone structure for **1**, the isomeric 1,5-lactone **2** was also detected in this study. The samples taken during the course of the oxidation indicated that its concentration was already significant in the early stage of the reaction.

Identification of the trimethylsilylated acid derivatives **6** and **7** was based on published mass spectra[6,7].

The most characteristic ion peaks in the (practically identical) mass spectra of the trimethylsilylated derivatives **4** and **5**, formed *via* lactonisation (–CO_2H (C-1) and –OH at C-4) from **7** were at *m/z* 391 $[M^{+\cdot} - CH_3]$ and *m/z* 362 $[M^{+\cdot} - CO_2]$ (a McLafferty type rearrangement[8]). The intense peaks with *m/z* 273 [391 –

TABLE I

PRODUCTS IDENTIFIED AFTER THE OXIDATION OF α-D-GLUCOISOSACCHARINIC ACID BY NITRIC ACID[a]

Product[b]	*Percentage*	*Retention time*[c]
Lactic acid	0.2	0.221
Glycolic acid	5.3	0.228
Oxalic acid	17.7	0.260
Glyceric acid	0.3	0.472
C-Methyltartronic acid	0.3	0.493
Hydroxytartronic acid	2.5	0.584
Deoxytetraric acid	0.6	0.604
C-Hydroxymethyltartronic acid	1.2	0.667
Threaric acid	2.5	0.722
GISA 1,4-lactone (**1**)	+	0.747
DHPA 1,4-lactone (**3**)	1.2	0.778
GISA 1,5-lactone (**2**)	3.9	0.789
CDPA 1,4-lactone (**4** & **5**)	19.6 & 28.2	0.817 & 0.830
DHPA (**6**)	0.2	0.942
CDPA (**7**)	11.0	0.969
Unidentified	5.3	—

[a] Percentage of the total compounds analysed. The values represent an average value from two oxidations. [b] GISA, glucoisosaccharinic acid; DHPA, 3-deoxy-2-*C*-hydroxymethylpentaric acid; CDPA, 2-*C*-carboxy-3-deoxypentaric acid. [c] G.l.c. retention of Me_3Si derivatives relative to the D-mannono-1,4-lactone derivative.

HCO_2SiMe_3], 257 [362 − CH_3 − $HOSiMe_3$], and 245 [362 − CO_2SiMe_3] were also indicative of the corresponding structures. The elution order of these diastereomers in g.l.c. is not known, although the peak pair could readily be recognised.

The alternative lactonisation (–CO_2H (C-5) and –OH at C-2) of **7** gives a structure in which the carboxylic acid groups are attached to the same carbon atom. However, it is obvious that the spectrum of this derivative after trimethylsilylation would be somewhat different from those noted above.

The mass spectra corresponding to the small g.l.c. peaks that appeared in the same region were indicative of the trimethylsilylated lactones originating from dibasic acids. The most abundant was assumed to correspond to the trimethylsilylated derivative of **3** (formed from **6**), although it could not be resolved completely by g.l.c.

The presence of these lactone derivatives was further confirmed by opening their ring structures with alkali before g.l.c. analysis. This resulted in a corresponding increase in the proportions of the acyclic derivatives **6** and **8** [*C*-(2,3-dihydroxypropyl)tartronic acid[9]; retention time, 0.931].

In the mass spectrum of the trimethylsilylated derivative of **1**, there was a prominent peak at *m/z* 245 [M^{+} − CH_2O − CH_2OSiMe_3]. However, this type of fragmentation was not possible for the trimethylsilylated derivative of **2** and, therefore, its spectrum showed a significant peak at *m/z* 259 [M^{+} − CH_2O − $OSiMe_3$]. The peak at *m/z* 321 [M^{+} − 57] could be derived from the 1,5-lactone structure by a ring-fission mechanism.

Interpretations of the mass spectra for other compounds were based on published data[7,10–16]. For the identification of D-threaric acid, the corresponding retention time data[17] were also used.

EXPERIMENTAL

Oxidation, g.l.c., and g.l.c.–m.s. — The calcium salt of **1** (1.51 g, prepared from lactose[18]) was oxidised with conc. nitric acid (72%) to dicarboxylic and tricarboxylic derivatives[4]. A sample (1.37 g) of the resulting white syrup was trimethylsilylated[9] for g.l.c. To eliminate peaks of acid lactones in g.l.c., a portion of the reaction mixture was also treated with weakly acidic cation-exchange resin (NH_4^+) to convert the acids into their corresponding ammonium salts before trimethylsilylation[9].

Non-volatile carboxylic acids and lactones were analysed by g.l.c.–m.s. as previously described[5]. The following carboxylic acid derivatives containing six carbon atoms were identified (as their trimethylsilylated derivatives, see Table I).

3-Deoxy-2-*C*-hydroxymethyl-D-*erythro*-pentono-1,4-lactone (**1**, α-D-glucoisosaccharino-1,4-lactone; prepared for g.l.c.–m.s. from its calcium salt by using a cation-exchange resin). Mass spectrum: *m/z* 378 (3% M^{+}), 363 (4), 348 (74), 273 (10), 245 (22), 231 (15), 217 (31), 203 (9), 171 (11), 155 (14), 147 (51), 133 (16), 129 (44), 117 (32), 103 (29), 75 (18), 73 (100).

3-Deoxy-2-*C*-hydroxymethyl-D-*erythro*-pentono-1,5-lactone (**2**, α-D-glucoisosaccharino-1,5-lactone). Mass spectrum: *m/z* 378 (18%, $\mathrm{M}^{\dagger}$), 363 (4), 348 (24), 321 (14), 305 (8), 273 (4), 259 (34), 233 (22), 231 (25), 217 (20), 215 (13), 147 (72), 133 (14), 129 (47), 117 (58), 103 (14), 101 (11), 75 (14), 73 (100).

The 1,4-lactone of 3-deoxy-2-*C*-hydroxymethyl-D-*erythro*-pentaric acid (**3**). Mass spectrum: *m/z* 377 (11%), 362 (4), 349 (11), 348 (9), 321 (8), 305 (6), 287 (21), 259 (22), 233 (13), 231 (19), 217 (11), 215 (10), 169 (9), 147 (74), 133 (16), 129 (39), 117 (49), 103 (15), 75 (15), 73 (100). Because of the low content of this compound in the sample, only a tentative spectrum was obtained.

The 1,4-lactone of (2*R*,4*S*)- and (2*S*,4*S*)-2-*C*-carboxy-3-deoxy-D-*glycero*-pentaric acid (**4** and **5**). Mass spectrum: *m/z* 391 (28%), 362 (15), 273 (39), 257 (16), 245 (19), 219 (27), 217 (34), 201 (13), 147 (85), 133 (15), 131 (111), 75 (18), 73 (100).

3-Deoxy-2-*C*-hydroxymethyl-D-*erythro*-pentaric acid (**6**). Mass spectrum: *m/z* 539 (3%), 437 (4), 361 (12), 347 (22), 331 (4), 305 (6), 292 (11), 257 (29), 221 (11), 217 (9), 191 (11), 147 (80), 133 (11), 117 (6), 103 (6), 75 (13), 73 (100).

2-*C*-Carboxy-3-deoxy-D-*glycero*-pentaric acid (**7**). Mass spectrum: *m/z* 553 (5%), 451 (6), 435 (5), 361 (34), 305 (24), 292 (40), 221 (14), 217 (16), 147 (87), 133 (11), 73 (100).

The molar response factors in g.l.c. for the reaction products were calculated[19,20] in relation to that of D-mannono-1,4-lactone (added as the internal standard). The values used for glycolic acid, oxalic acid, lactic acid, glyceric acid, *C*-methyltartronic acid, hydroxytartronic acid, deoxytetraric acid, *C*-hydroxymethyltartronic acid, threaric acid, glucoisosaccharinic acid lactone, deoxy-*C*-hydroxymethylpentaric acid lactone, *C*-carboxydeoxypentaric acid lactone, deoxy-*C*-hydroxymethylpentaric acid, and *C*-carboxydeoxypentaric acid were 0.42, 0.37, 0.47, 0.58, 0.65, 0.75, 0.65, 0.82, 0.81, 0.84, 0.80, 0.75, 1.11, and 1.06, respectively.

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