Gibberellins A_{60}, A_{61}, and A_{62}: Partial Syntheses and Natural Occurrence

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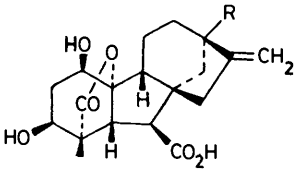
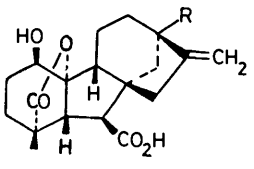
ent-1α,10,13-Trihydroxy-20-norgibberell-16-ene-7,19-dioic acid 19,10-lactone (gibberellin A_{60}) and *ent*-1α,10-dihydroxy-20-norgibberell-16-ene-7,19-dioic acid 19,10-lactone (gibberellin A_{61}) have been prepared from gibberellin A_3 and gibberellin A_7, respectively, and shown to be identical with two gibberellins previously detected by g.l.c.–mass spectrometry in developing grains of *Triticum aestivum*. *ent*-1α,10-Dihydroxy-20-norgibberella-2,16-diene-7,19-dioic acid 19,10-lactone (gibberellin A_{62}) has also been prepared from gibberellin A_7 and shown to be present in the grain of *T. aestivum*. Gibberellins A_{61} and A_{62} have also been detected in immature seed of *Pyrus malus*. Attempts to prepare a fourth putative gibberellin, detected in *T. aestivum*, were not successful.

THE 1β-hydroxygibberellins GA_{54} (1b) and GA_{55} (1a) have recently been identified[1] in developing grain of *Triticum aestivum* (wheat). In the same extract several other presumptive 1β-hydroxy-GAs were detected[1] by g.l.c.–mass spectrometry. The mass spectrometric fragmentations (discussed later) of the methyl ester trimethylsilyl ether derivatives of three of these components indicated the structures (2a), (2b), and (3b). Confirmation of the structures (2a) and (2b) by partial synthesis is now reported; attempts to prepare compound (3b) have been unsuccessful. In addition, the partial synthesis of compound (4b) is described and its occurrence in wheat grain and in seed of *Pyrus malus* (apple) has been established by g.l.c.–mass spectrometry. GA numbers are allocated[2] to these new gibberellins as follows: GA_{60} (2a), GA_{61} (2b), and GA_{62} (4b).



(1) a; R = OH
b; R = H



(2) a; R = OH
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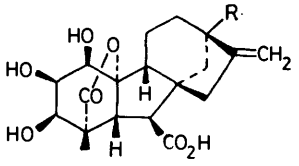

(3) a; R = OH
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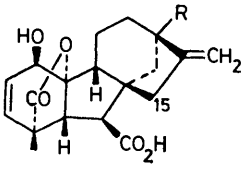


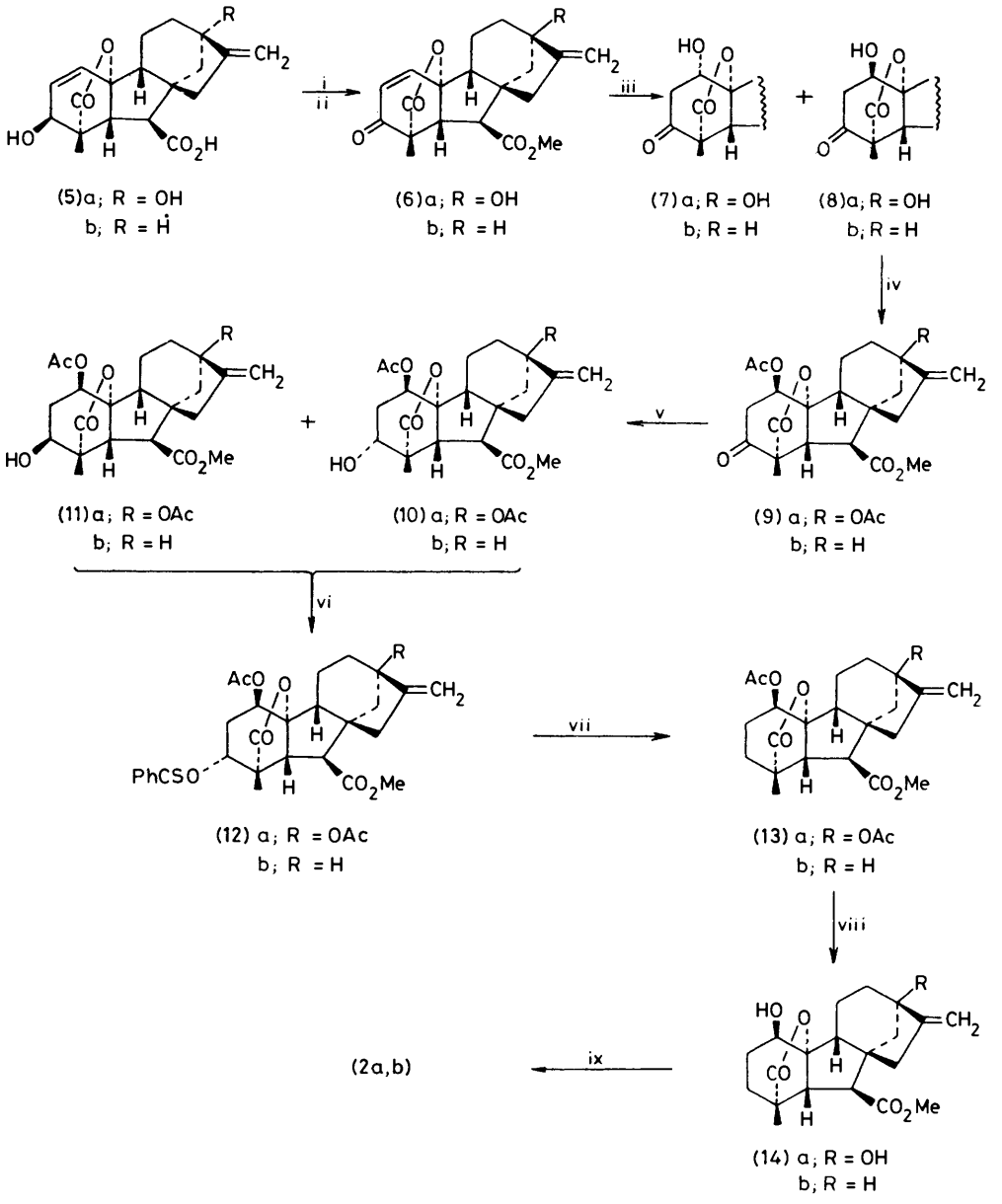
(4) a; R = OH
b; R = H

Gibberellin A_{60} (2a) (*Scheme* 1).—As previously described,[1] GA_3 (5a) was converted into the 1α- and 1β-alcohols (7a) and (8a) by hydration of the intermediate enone (6a).

In an exploratory attempt to deoxygenate the ketone (8a) by reduction of the corresponding *p*-tolylsulphonylhydrazone,[3] analysis of the derivatised product by g.l.c.–mass spectrometry indicated the presence of the methyl ester of the 2,3-olefin (4a) (33%), the methyl ester of GA_{55} (1a) (15%), unchanged ketone (8a) (5%), traces of the methyl ester of GA_{60} (2a), and traces of the 16,17-dihydro-derivatives of these products. The 2,3-olefin (4a) is probably formed by thermal decomposition of the *p*-tolylsulphonylhydrazone of the ketone (8a) during g.l.c. The formation of the methyl ester of (2a), albeit in low yield, supported the assigned structure for the putative GA in wheat grain and the following preparative route from the ketone (8a) was devised.

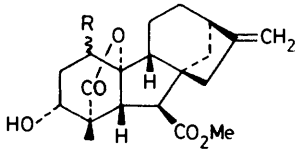
The 1-hydroxy-group in the ketone (8a) was protected by acetylation. Gurvich *et al.*[4] reported that attempted acetylation of (8a), under unspecified conditions, resulted in dehydration to the enone (6a). In our hands, the same result was obtained using acetic anhydride and pyridine. However, with acetic anhydride and toluene-*p*-sulphonic acid the diacetate (9a) was formed in 95% yield. Treatment of the diacetate (9a) with sodium borohydride in ethanol at room temperature brought about some reduction of the acetate functions and gave a mixture of the methyl esters of GA_{55} (1a) and its 3α-hydroxy-epimer, plus their 13-acetates. Hydrogenolysis of secondary acetates by sodium borohydride has been observed before.[5] This problem was overcome by using sodium trimethoxyborohydride at −10 °C, and the 3α- and 3β-alcohols (10a) and (11a) were obtained in 94% yield in the ratio 2 : 1 (by n.m.r.). The stereochemistry of these epimers was deduced from the n.m.r. spectra, the 3β-alcohol (11a) showing the lower field signal (δ 3.57 *versus* 3.06) for the 5-proton.

Thiobenzoylation[6] of the mixture of the 3-alcohols (10a) and (11a) gave the 3α-thiobenzoate (12a); the 3β-alcohol (11a) did not react and was recovered together with some unchanged 3α-alcohol (10a) in the ratio 2 : 1 (by n.m.r.). Two further cycles of thiobenzoylation and recovery gave the pure 3β-alcohol (11a). Alkaline hydrolysis of the 3β-alcohol (11a) provides an alternative[1] preparation of GA_{55} (1a). The 3α-thiobenzoate (12a) was reduced with bis(tri-n-butylstannyl) oxide and polymethylhydrosiloxane[7] to give the diacetate (13a) and a minor amount of the 3α-alcohol (10a). Mild hydrolysis of the diacetate (13a) with potassium carbonate in methanol gave GA_{60} methyl ester (14a), which was hydrolysed with potassium hydroxide in aqueous methanol to give GA_{60} (2a). The methyl ester trimethylsilyl ether of GA_{60} was identical (g.l.c.–mass spectro-

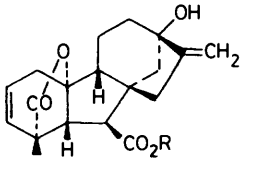


SCHEME 1 *Reagents:* i, CH_2N_2; ii, MnO_2; iii, 2M-HCl, tetrahydrofuran; iv, Ac_2O,*p*-$MeC_6H_4SO_3H$; v, $NaBH(OMe_3)$ at −10 °C; vi, $C_6H_5C(Cl)=\overset{+}{N}Me_2Cl^-$, H_2S; vii, Bu^n_3SnH; viii, K_2CO_3–MeOH; ix, KOH–MeOH–H_2O

metry) with one of the putative gibberellins, previously detected [1] in grain of wheat.



(15) R = β-OH
(16) R = α-OH



(17) R = Me
(18) R = H

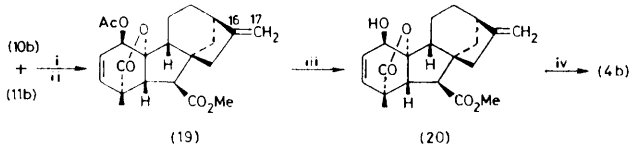
Gibberellin A_{61} (2b) (*Scheme* 1).—Starting from GA_7 (5b), the route was analogous to that used for GA_{60} (2a). Methylation of GA_7 (5b), containing 15% GA_4, then oxidation with manganese dioxide, gave the enone (6b). Treatment of the enone (6b) with acid using the method of Adam and Hung [8] gave a complex mixture which g.l.c.–mass spectrometry of the trimethylsilyl derivative showed to contain mainly the 1β-alcohol (8b) together with small amounts of unchanged enone (6b), the 1α-alcohol (7b), and products from hydration of the 16,17-double bond. This mixture could not be separated by droplet counter-current chromatography [1,9] but, by careful column chromatography on silica gel, the required 1β-alcohol (8b) and the unchanged enone (6b) were obtained pure together with mixed fractions of the 1-epimeric alcohols (7b) and (8b). Reduction of a mixture (3 : 1) of the 1α- and 1β-alcohols (7b) and (8b)

with sodium borohydride gave 3-*epi*-GA_{54} methyl ester (15) and 3-*epi*-GA_{16} methyl ester (16) as the major products. This result is in agreement with the analogous reduction [1] of the 1α- and 1β-alcohols (7a) and (8a), which gave predominantly the 3α-alcohols.

Attempted deoxygenation of the 1β-hydroxy-3-ketone (8b) by reduction of the corresponding *p*-tolylsulphonylhydrazone [3] gave, as in the case of the 13-hydroxy-analogue (8a), a complex mixture in which the 1β,3α-diol (15) (36%), the 1β-hydroxy-2,3-olefin (20) (Scheme 2) (7%) and the corresponding 16,17-dihydro-derivatives of these products (15 and 42%, respectively) were detected by g.l.c.–mass spectrometry.

The synthesis of GA_{61} (2b) from the 1β-hydroxy-3-one (8b) was completed (Scheme 1) as for GA_{60} (2a). In the acylation of the 1β-alcohol (8b) with acetic anhydride and toluene-*p*-sulphonic acid, it was necessary to dry the reagents rigorously otherwise a substantial amount of the isomeric 15-ene was formed. The presence of a catalytic amount of pyridine in the acetylation reaction, or p.l.c. of the 1β-acetate (9b) on silica gel, resulted in dehydration to the enone (6b).

Reduction of the 1β-acetate (9b) with sodium trimethoxyborohydride at −10 °C gave a mixture (3 : 2) of the 3α- and 3β-alcohols (10b) and (11b). Thiobenzoylation of this mixture of 3-alcohols gave the 3α-thiobenzoate (12b), and some (20%) unchanged 3α-alcohol (10b) and unchanged 3β-alcohol (11b). Reduction of the thiobenzoate (12b) with tri-n-butylstannane yielded the 1β-acetate (13b) which, on mild hydrolysis, gave GA_{61} methyl ester (14b) and, on more vigorous hydrolysis, gave GA_{61} (2b). The methyl ester trimethylsilyl ether of GA_{61} (2b) was identical (by g.l.c.–mass spectrometry) with that of one of the putative gibberellins, detected [1] in the grain of wheat and in extracts of immature seed of apple, supplied by Professor F. G. Dennis.

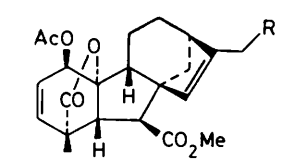


SCHEME 2 *Reagents:* i, $POBr_3$–C_5H_5N; ii, DBU; iii, K_2CO_3–MeOH; iv, KOH–H_2O–MeOH

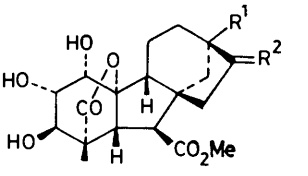
Gibberellin A_{62} (4b) (*Scheme* 2).—The mixture of 3α- and 3β-alcohols (10b) and (11b) recovered from the thiobenzoylation of this mixture of alcohols *en route* to GA_{61} (2b), was treated with phosphoryl bromide in pyridine. The crude product was treated with 1,5-diazabicyclo-[5.4.0]undec-5-ene (DBU) to give the required 2,3-olefin (19) and a small amount of bromine-containing impurity. When the reaction was performed on a large scale, this impurity was the major product which, by n.m.r. and field desorption mass spectrometry, appeared to consist of the 17-bromo-15-ene (21) and a small amount of the 16,17-dibromide of the 2,16-ene (19). The 17-bromo-15-ene (21) is presumably formed by bromide addition to the 16,17-double bond, followed by dehydrobromination. Mass spectral analysis of the phosphoryl bromide product indicated that dehydrobromination had largely occurred at this stage.

Alkaline hydrolysis of the mixture from the phosphoryl bromide–DBU treatment of the mixture of (10b) and (11b), followed by methylation, permitted the separation of GA_{62} methyl ester (20) from the 17-hydroxy-15-ene (22). Alkaline hydrolysis of GA_{62} methyl ester (20) completed the synthesis of GA_{62} (4b), which was shown to contain *ca.* 10% of the isomeric 15-ene by g.l.c.–mass spectrometry of the methyl ester trimethylsilyl ethers and of the trimethylsilyl ester trimethylsilyl ethers. The mass spectrum of the methyl ester trimethylsilyl ether of GA_{62} (4b) was identical with that of the putative gibberellin, detected [1] in grain of *T. aestivum*. It was also identical with the mass spectrum of the methyl ester trimethylsilyl ether of a gibberellin detected in extracts of immature seed of apple, supplied by Professor F. G. Dennis.

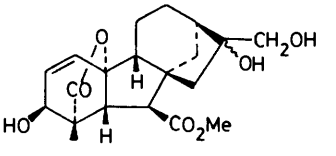
GA_{62} (4b) was not obtained in sufficient quantity for its chemical properties to be compared with those of the allylic isomer GA_7 (5b).



(21) R = Br
(22) R = OH



(23) R^1 = H, R^2 = CH_2
(24) R^1 = H, R^2 = OH,CH_2OH
(25) R^1 = OH, R^2 = CH_2



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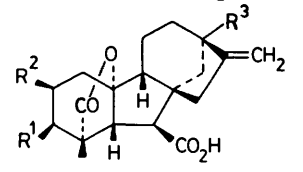


(27) R^1 = R^2 = R^3 = OH
(28) R^1 = R^3 = H, R^2 = OH
(29) R^1 = OH, R^2 = R^3 = H
(30) R^1 = H, R^2 = R^3 = OH
(31) R^1 = R^3 = OH, R^2 = H
(32) R^1 = R^2 = R^3 = H
(33) R^1 = R^2 = H, R^3 = OH

Attempted Synthesis of 1β,2β,3β-*Trihydroxygibberellin* A_9 (3b).—Structure (3b) was a likely candidate for the trihydroxygibberellin A_9, detected as the methyl ester trimethylsilyl ether in extracts of grain of *T. aestivum*, since 1β-hydroxygibberellin A_9 (GA_{61}) (2b) and 1β,3β-dihydroxygibberellin A_9 (GA_{54}) (1b) occur in the plant material and since 2β-hydroxylation is a common feature of gibberellin metabolism in higher plants.[10]

It is known [11] that the 2,3-double bond in gibberellin A_5 methyl ester (17) reacts faster with osmium tetraoxide than the 16,17-double bond. The preparation of the triol (3b) was therefore attempted by direct hydroxyl-

ation of GA_7 (5b) (Scheme 1). Initially the osmylation was tried on GA_7 methyl ester, which gave starting material (75%) and one product (25%) which, as the methyl ester trimethylsilyl derivative, gave a mass spectrum very similar to that of the natural compound. The major differences in the spectrum of the synthetic product were the presence of the ions at *m/z* 547 ($M^+ - 47$) and 519 ($M^+ - 75$), indicative of hydroxy-groups in 1α-, 2α-, or 3α-positions.[1] The synthetic product therefore appeared to be the 1α,2α,3β-triol (23). However, in a larger scale experiment, the major product was 16,17-dihydro-16,17-dihydroxy-GA_7 methyl ester (26) (60%), accompanied by starting material (35%), the presumed 1α,2α,3β-triol (23) (0.6%), and the presumed pentahydroxy-derivative (24) (4%). Osmium tetraoxide oxidation of a mixture (85 : 15) of free GA_7 and GA_4 also gave a complex mixture containing 22% of the presumed 1α,2α,3β-triol. No attempt was made to isolate the presumed 1α,2α,3β-triol from these mixtures.

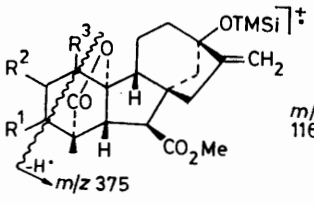
Treatment of the methyl ester of GA_3 (5a) with osmium tetraoxide gave starting material (36%) and the 1α,2α,3β,13-tetrol (25) (64%). The mass spectrum of the methyl ester trimethylsilyl derivative of the tetraol (25) also contained ions at $M^+ - 47$ (*m/z* 635), $M^+ - 75$ (*m/z* 607) and $M^+ - 119$ (*m/z* 563), indicative [1] of 1α,2α,3α-*O*-trimethylsilyl groups.

It thus appears that the 1,2-double bond of gibberellins A_3 (5a) and A_7 (5b) reacts with osmium tetraoxide from the α-face. However GA_8 (27) has been prepared [11] from the reaction of osmium tetraoxide with GA_5 (18), which involves β-attack. The reaction of GA_{62} methyl ester (20) (Scheme 2) with osmium tetraoxide gave a complex mixture, the components of which could not be identified by g.l.c.–mass spectrometry. A similar complex mixture of products was obtained from the enone (6b) (Scheme 1b) and osmium tetraoxide.

Mass Spectra.—The mass spectra of the methyl esters and methyl ester trimethylsilyl ethers (MeTMS derivatives) of the 1β-, 2β-, and 3β-monohydroxygibberellins A_{61} (2b), A_{51} (28), and A_4 (29), and of the 1β,13-, 2β,13-, and 3β,13-dihydroxygibberellins A_{60} (2a), A_{29} (30), and A_1 (31), are similar but sufficiently different for the isomers to be distinguished. This is also true for the allylic isomers GA_{62} (4b) and GA_7 (5b). Some of the characteristic ions of the new GAs are as follows.

The MeTMSi derivative of GA_{60} (2a) shows an intense (75%) ion at *m/z* 375 which is only of moderate intensity in the spectra of the MeTMSi derivatives of GA_1 (31) and GA_{29} (30). This ion has the composition, $C_{20}H_{27}O_5Si$; it could arise by the fragmentation shown in (34) with hydrogen transfer and be facilitated in the case of GA_{60} (2a) by the vicinal oxygen functions.

The spectrum of the MeTMSi derivative of GA_{61} (2b) is characterised by ions at *m/z* 347 (26%, $C_{20}H_{31}O_3Si$), 296 (97%, $M^+ - 122$), and 116 (100%, $C_5H_{12}OSi$); the *m/z* 347 and 116 ions are either weak or absent in the spectra of the MeTMSi derivatives of the isomeric GA_4 (29) and GA_{51} (28). The *m/z* 347 ion could arise by the fragmentation (35; cleavage *b*) with hydrogen transfer. The composition of the ion *m/z* 116 corresponds to $Me_3Si{-}\overset{+}{\underset{\cdot\cdot}{O}}{-}CH{=}CH_2$, which could be formed by the cleavage *a*, shown in (35). This ion is also present in the spectrum of the MeTMSi derivatives of GA_{60} (2a) and of compound (36),[11] suggesting that the fragmentation is a consequence of the vicinal oxygen functions.



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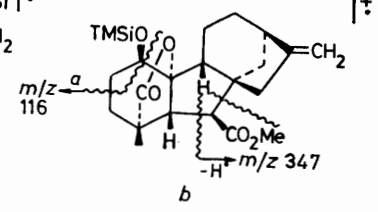

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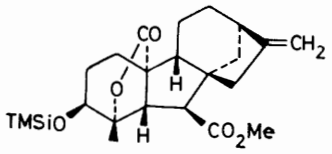
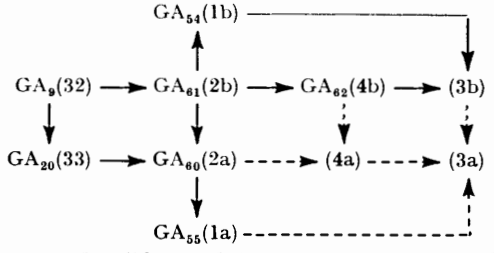


(36)

The main difference in the mass spectra of the methyl esters and TMSi derivatives of the allylic isomers GA_7 (5b) and GA_{62} (4b) lies in the fragmentations associated with loss of the oxygen functions from ring *A*. Thus for the methyl esters, GA_7 (5b) shows an intense ion (95%) at *m/z* 281 ($M^+ - 63$), which is absent in the spectrum of GA_{62} methyl ester (20). In the case of the MeTMSi derivatives, the $M^+ - 44$ ion is more intense for GA_{62} (4b).

Conclusion.—This and the previous paper [1] provide the first reports of the natural occurrence of 1β-hydroxy-GAs in plants. No 1β-hydroxy-C_{20}-GAs have been detected, suggesting that 1β-hydroxylation may take place on the co-occurring GA_{20} (33) [1] or on GA_9 (32), possible precursors of which co-occur.[1] A possible metabolic grid is shown in Scheme 3. The 13-hydroxy (R = OH) and 13-deoxy (R = H) series may represent separate pathways or 13-hydroxylation may occur at any stage.



SCHEME 3 Possible metabolic grid in developing grain of *T. aestivum*

The allylic isomer (4a) of GA_3 (5a) and the tetrahydroxy-derivative (3a) are missing links. The allylic isomer (4a) has been synthesised by a route to be

described in an accompanying paper (see page 707) but it has not been detected either in wheat or in apple seed.

The biological activities of the 1β-hydroxy-GAs found in wheat grain will be reported elsewhere.

EXPERIMENTAL

For general experimental details, see ref. 13. Mass spectral data were obtained in g.l.c.–mass spectrometry unless otherwise stated.

Attempted Deoxygenation of ent-1α,13-*Dihydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (8a).—The ketone (8a) (10 mg), prepared as described by Gaskin *et al.*,[1] and tolylsulphonylhydrazine (8 mg) were refluxed in ethanol (1 ml) for 2 h. The solvent was evaporated off, water was added, and the product was extracted with ethyl acetate at pH 3.0. The presumed hydrazone of the ketone (8a) had δ 1.14 (s, 18-H_3), 2.40 (s, ArMe), 2.58 (br, d, *J* 17 Hz, 2β-H), 2.69 (d, *J* 10 Hz, 6-H), 2.92 (br, d, *J* = 17 Hz, 2α-H), 3.29 (d, *J* 10 Hz, 5-H), 3.69 (s, CO_2Me), 4.12 (br, s, 1α-H), 4.87 and 5.15 (both br, s, 17-H_2), and 7.1—7.9 (4 × Ar-H); *m/z* 560 (M^+, 0%), 328 (12), 319 (11), 124 (43), 91 (100), 79 (11), 77 (11), and 71 (29). This product (12 mg) and toluene-*p*-sulphonic acid (1 mg) were heated to 110 °C under nitrogen in dry dimethylformamide (0.5 ml) and tetramethylene sulphone (0.5 ml). Then sodium cyanoborohydride (12 mg) was added and heating at 110 °C was continued for 3 h. Water was added and the product, extracted with ethyl acetate, was analysed (after trimethylsilylation) by g.l.c.–mass spectrometry. The following compounds were identified as the MeTMSi derivatives: (*a*) starting material (8a) (5%); (*b*) the 2,3-ene (4a) (33%) [*m/z* 504 (M^+, 38%), 489 (8), 465 (16), 445 (6), 387 (32), 208 (34), 193 (20), 183 (64), 75 (34), and 73 (100)]; (*c*) gibberellin A_{55} (1a) (15%); (*d*) traces of gibberellin A_{60} (2a) (see later for mass spectrum); (*e*) traces of the 16,17-dihydro-derivative of the 2-ene (4a) [*m/z* 506 (M^+, 11%), 491 (8), 463 (100), 389 (35), 329 (13), 269 (17), 210 (16), 183 (33), 179 (15), 143 (8), 75 (43), and 73 (100)]; (*f*) traces of the 16,17-dihydro-derivative of gibberellin A_{55} (1a) [*m/z* 596 (M^+, 10%), 553 (100), 506 (10), 480 (8), 463 (74), 419 (19), 377 (15), 375 (10), 217 (20), 210 (16), 209 (17), 147 (13), 103 (11), 75 (70), and 73 (92)]; and (*g*) traces of the 16,17-dihydro-derivative of the ketone (8a) [*m/z* 522 (M^+, 17%), 507 (7), 479 (100), 463 (10), 375 (20), 209 (13), 194 (13), 103 (8), 75 (50), and 73 (80)].

ent-1α,13-*Diacetoxy*-10-*hydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (9a).—The 1β,13-diol (8a) (540 mg) [1] and toluene-*p*-sulphonic acid (5 mg) were dissolved in acetic anhydride (4 ml). After 18 h water was added. The usual work-up procedure by extracting the product with ethyl acetate gave the *diacetate* (9a) (624 mg), m.p. 101—103 °C (from acetone–light petroleum) (Found: C, 62.5; H, 6.6%; M^+ 460.174. $C_{24}H_{28}O_9$ requires C, 63.0; H, 6.6%; M^+ 460.173); $\nu_{max.}$ 1 799, 1 764sh, 1 746, 1 728, 1 715sh, 1 665, 927, and 900 cm^{-1}; δ 1.19 (s, 18-H_3), 2.00 (s, 13-OCOMe), 2.10 (s, 1-OCOMe), 2.60 (dd, *J* 1 and 17 Hz, 2β-H), 2.81 (d, *J* 10 Hz, 6-H), 2.92 (dd, *J* 6 and 17 Hz, 2α-H), 3.45 (d, *J* 10 Hz, 5-H), 3.73 (s, CO_2Me), 4.97 and 5.11 (both br, 17-H_2), and 5.40 (dd, *J* 1 and 6 Hz, 1α-H); *m/z* (probe) 460 (M^+, 2%), 418 (10), 358 (30), 356 (46), 340 (15), 296 (41), 282 (14), 254 (21), 237 (30), and 43 (100).

Sodium Trimethoxyborohydride Reduction of the Diacetate (9a).—Sodium borohydride (100 mg) was added to methanol (40 ml) at −10 °C. After 10 min, a solution of the diacetate (9a) (550 mg) in methanol (6 ml) at −10 °C was added and the mixture was stirred at −10 °C for 1 h. Acetic acid (1.5 ml) was added and the solvent was evaporated off. Addition of water and extraction with ethyl acetate yielded a mixture (2 : 1) of the 3α- and 3β-alcohols (10a) and (11a) as a gum (520 mg) (for characterisation of these alcohols, see later).

ent-1α,13-*Diacetoxy*-10-*hydroxy*-3β-*thiobenzoyloxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (12a).—The preceding mixture (2 : 1; 520 mg) of the 3α- and 3β-alcohols (10a) and (11a), *N*-methylbenzimidoyl chloride methochloride in dichloromethane (0.5M; 8.5 ml), and di-isopropylethylamine (0.85 ml) were left at room temperature for 64 h. Pyridine (0.42 ml) was added and, after 5 min, dry hydrogen sulphide was passed through the solution for 5 min. Water was added and the solution, acidified to pH 3 with 10M-hydrochloric acid, was extracted with ethyl acetate. The products, recovered from the extract, were subjected to p.l.c. using ethyl acetate–light petroleum (7 : 3) to give, from R_F 0.75 to 0.85, the 3α-*thiobenzoate* (12a) as a gum (312 mg) (Found: M^+, 582.191. $C_{31}H_{34}O_9S$ requires *M*, 582.192); $\nu_{max.}$ ($CHCl_3$) 1 785, 1 732, 1 663, and 1 599 cm^{-1}; δ 1.15 (s, 18-H_3), 2.02 (s, 13-OCOMe), 2.17 (s, 1-OCOMe), 2.84 (d, *J* 11 Hz, 6-H), 3.30 (d, *J* 11 Hz, 5-H), 3.75 (s, CO_2Me), 5.02 and 5.16 (both br, 17-H_2), 5.27 (d, *J* 4 Hz, 1α-H), 6.02 (dd, *J* 7 and 10 Hz, 3β-H), 7.2—7.6 (m, 3 × ArH), and 8.17 (br, d, 2 × Ar-H); *m/z* (probe) 582 (M^+, 9%), 539 (4), 524 (7), 522 (6), 444 (22), 385 (22), 343 (59), 281 (74), 280 (57), 239 (34), 221 (100), 121 (62), 105 (92), 77 (30), and 43 (87).

Elution of the band at R_F 0.6—0.7 yielded *N*,*N*-dimethylthiobenzamide. Elution of the band at R_F 0.35—0.45 yielded a mixture (1 : 2) of unchanged 3α- and 3β-alcohols (10a) and (11a) as a gum (215 mg).

ent-1α,13-*Diacetoxy*-3α,10-*dihydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (11a).—A portion (76 mg) of the mixture (1 : 2) of the 3α- and 3β-alcohols (10a) and (11a), recovered from the preceding experiment, was subjected to two successive thiobenzoylation reactions, and the products were separated by p.l.c. as described in the preceding experiment. From R_F 0.35 to 0.45 the 3β-*alcohol* (11a) (31 mg) was obtained as a gum (Found: M^+, 462.189. $C_{24}H_{30}O_9$ requires *M*, 462.189); $\nu_{max.}$ ($CHCl_3$) 3 550, 1 782, 1 733, 1 664, and 903 cm^{-1}; δ 1.17 (s, 18-H_3), 2.02 (s, 13-OCOMe), 2.14 (s, 1-OCOMe), 2.74 (d, *J* 11 Hz, 6-H), 3.57 (d, *J* 11 Hz, 5-H), 3.74 (s, OCOMe), 3.79 (br, 3α-H), 4.99 (br, s, 17-H), and 5.13 (br, s, 1α-H and 17-H); *m/z* (probe) 462 (M^+, 19%), 420 (100), 402 (12), 370 (16), 360 (19), 342 (28), 328 (23), 310 (26), 298 (27), and 43 (53); *m/z* (TMSi ether) 534 (M^+, 4%), 492 (46), 474 (70), 459 (11), 442 (26), 414 (33), 298 (52), 221 (75), 145 (38), 75 (56), 73 (100), and 43 (84).

ent-1α,13-*Diacetoxy*-10-*hydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (13a).—The thiobenzoate (12a) (285 mg), 2,2′-azobis-(2-methylpropiononitrile) (5 mg), polymethylhydrosiloxane (0.05 ml), and bis(tri-n-butylstannyl) oxide (0.15 ml) in toluene (10 ml) were refluxed in nitrogen for 4 h. Evaporation and p.l.c. (× 2) using ethyl acetate–light petroleum (1 : 1) gave, from R_F 0.4 to 0.6, the *diacetate* (13a) as a gum (90 mg) (Found: M^+, 446.195. $C_{24}H_{30}O_8$ requires *M*, 446.194); $\nu_{max.}$ ($CHCl_3$) 1 780, 1 732, 1 663, and 926 cm^{-1}; δ 1.09 (s, 18-H_3), 2.00 (s, 13-OCOMe), 2.10 (s, 1-OCOMe), 2.71 (d, *J* 10 Hz, 6-H), 3.07 (d, *J* 10 Hz, 5-H), 3.74 (s, CO_2Me), 4.98 (br, s, 17-H),

and 5.13 (br, s, 1α-H and 17-H); *m/z* (probe) 446 (M^+, 23%), 404 (100), 386 (10), 354 (15), 344 (26), 326 (22), 312 (38), 239 (17), 223 (23), and 43 (72).

Elution of the band at R_F 0.20—0.35 yielded the 3α-*alcohol* (10a) as a gum (8 mg) (Found: M^+ 462.190. $C_{24}H_{30}O_9$ requires M, 462.190); $\nu_{max.}$ ($CHCl_3$) 3 580, 1 779, 1 732, 1 666, and 930 cm^{-1}; δ 1.17 (s, 18-H_3), 2.00 (s, 13-OCOMe), 2.10 (s, 1-OCOMe), 2.77 (d, *J* 10 Hz, 6-H), 3.06 (d, *J* 10 Hz, 5-H), 3.74 (s, CO_2Me), 3.89 (m, 3-H), 4.97 (br, s, 17-H), and 5.13 (br, s, 1-H and 17-H); *m/z* 462 (M^+, 17%), 420 (100), 370 (14), 342 (27), 328 (23), 310 (33), 298 (24), and 43 (53); *m/z* (TMSi ether) 534 (M^+, 2%), 492 (31), 474 (60), 442 (19), 427 (40), 414 (28), 310 (42), 298 (46), 145 (36), 75 (49), 73 (100), and 43 (50).

ent-1α,10,13-*Trihydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (*Gibberellin* A_{60} *Methyl Ester*) (14a).—The diacetate (13a) (90 mg) and anhydrous potassium carbonate (90 mg) in methanol (4 ml) were stirred at room temperature for 16 h. Acetic acid (0.23 ml) was added and the solution was evaporated. Addition of water, then extraction with ethyl acetate, yielded *gibberellin* A_{60} *methyl ester* (14a), which crystallised from acetone–light petroleum as needles (63 mg), m.p. 201—204 °C (Found: C, 66.55; H, 7.3. $C_{20}H_{26}O_6$ requires C, 66.3; H, 7.2%); $\nu_{max.}$ 3 460, 3 400, 1 788, 1 727, 1 667, 928, and 905 cm^{-1}; δ[$(CD_3)_2CO$] 1.03 (s, 18-H_3), 2.63 (d, *J* 10 Hz, 6-H), 3.12 (d, *J* 10 Hz, 5-H), 3.74 (s, CO_2Me), 3.99 (br, s, 1-H), and 4.91 and 5.22 (both br, s, 17-H_2); *m/z* (probe) 362 (M^+, 48%), 344 (10), 330 (100), 312 (27), 303 (85), 284 (21), 257 (9), 239 (14), 135 (20), 136 (11), and 122 (11); *m/z* (TMSi ether) 506 (M^+, 66%), 491 (12), 447 (14), 375.163 ($C_{20}H_{27}O_5Si$ requires 375.163; 75%), 321 (8), 309 (10), 238 (14), 207 (35), 194 (33), 167 (10), 129 (10), 75 (72), 73 (100), and 44 (70).

In one experiment, g.l.c.–mass spectrometry of the trimethylsilylated product revealed the presence of (*a*) *ca.* 3% of the MeTMSi derivative of the 1α-epimeric alcohol, *m/z* 506 (M^+, 50%), 491 (8), 477 (4), 459 (3), 447 (3), 375 (100), 235 (7), 207 (10), 137 (9), 129 (5), 75 (18), 73 (60), and 44 (34); and (*b*) a trace of the MeTMSi derivative of a 1-methoxy-GA_{20}, *m/z* 448 (M^+, 28%), 375 (39), 309 (13), 281 (14), 208 (22), 207 (13), 194 (39), 193 (8), 157 (5), 129 (15), 103 (18), 93 (9), 75 (100), 73 (70), 59 (21), and 44 (85).

In an exploratory experiment, when an excess of Amberlite IR-120 (H^+) resin was used in the work-up, the rings *C*/*D* rearrangement product of GA_{60} methyl ester (14a) was the major product, identified by g.l.c.–mass spectrometry of the TMSi ether, *m/z* 434 (M^+, 11%), 419 (29), 388 (9), 387 (9), 378 (12), 375 (19), 363 (46), 239 (23), 238 (21), 129 (19), 116 (100), 101 (29), 75 (25), and 73 (57).

ent-1α,10,13-*Trihydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 19,10-*Lactone* (*Gibberellin* A_{60}) (2a).—Gibberellin A_{60} methyl ester (14a) (63 mg) and potassium hydroxide (100 mg) in methanol (10 ml) and water (10 ml) were refluxed for 22 h. After evaporation of the methanol, the aqueous residue was adjusted to pH 3 with 10M-hydrochloric acid and extracted with ethyl acetate. The ethyl acetate was washed with a little water and evaporated *in vacuo*. The residue was heated at 50 °C for 0.5 h, then partitioned between water at pH 9.0 and ethyl acetate; the organic layer was evaporated to give the methyl ester (14a) (13 mg). The aqueous fraction, adjusted to pH 3.0 with 10M-hydrochloric acid, was extracted with ethyl acetate and the extract was worked up as usual to give *gibberellin* A_{60} (2a) (13 mg), m.p. 245—247 °C (from acetone–light petroleum) (Found: M^+, 348.157. $C_{19}H_{24}O_6$ requires M, 348.157); $\nu_{max.}$ 3 600—2 600br, 3 540, 3 280, 1 765, 1 728, 1 660, and 921 cm^{-1}; δ[$(CD_3)_2CO$] 1.04 (s, 18-H_3), 2.62 (d, *J* 10 Hz, 6-H), 3.14 (d, *J* 10 Hz, 5-H), 4.00 (br, s, 1α-H), and 4.89 and 5.22 (both br, s, 17-H_2); *m/z* (probe) 348 (M^+, 16%), 330 (47), 312 (32), 303 (49), 289 (50), 284 (37), 149 (29), 135 (35), and 44 (100); *m/z* (TMSi ester bis-TMSi ether) 564 (M^+, 24%), 549 (14), 444 (47), 433 (23), 309 (6), 207 (18), 194 (15), 75 (54), and 73 (100).

ent-1α,10-*Dihydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (8b).—The enone (6b) [13] (3 g) in tetrahydrofuran (120 ml) and aqueous 2M-hydrochloric acid (72 ml) were left for 5 days at room temperature in the dark. Sodium hydrogen carbonate (*ca.* 17 g) was added and the tetrahydrofuran was removed under vacuum. Extraction of the residual aqueous solution with ethyl acetate gave crude product, which was chromatographed on silica gel (43 × 2.5 cm; 120 g), made up in light petroleum and eluted with portions (3 × 50 ml) of light petroleum containing increasing concentrations (5% steps) of ethyl acetate. Elution with 35—40% ethyl acetate yielded the 1β-*alcohol* (8b) (640 mg), m.p. 169—172 °C (from acetone–light petroleum) (Found: C, 67.2; H, 6.8%; M^+, 360.158. $C_{20}H_{24}O_6$ requires C, 66.7; H, 6.7%; M, 360.157); $\nu_{max.}$ 3 490, 1 786, 1 725, and 1 658 cm^{-1}; δ 1.17 (s, 18-H_3), 2.62 (dd, *J* 1 and 17 Hz, 2β-H), 2.85 (d, *J* 10 Hz, 6-H), 2.94 (dd, *J* 6 and 17 Hz, 2α-H), 3.52 (d, *J* 10 Hz, 5-H), 3.72 (s, CO_2Me), 4.40 (br, d, *J* 4 Hz, 1-H), and 4.87 and 5.00 (both br, s, 17-H_2); *m/z* (probe) 360 (M^+, 23%), 342 (27), 328 (29), 318 (100), 310 (36), 301 (33), 300 (65), 241 (69), 91 (34), and 71 (35); *m/z* (TMSi ether) 432 (M^+, 7%), 417 (4), 373 (10), 301 (34), 300 (24), 241 (100), 75 (38), and 73 (100); *m/z* (enol TMSi) 504 (M^+, 1%), 476 (14), 460 (36), 401 (22), 370 (30), 311 (74), 147 (22), 75 (44), and 73 (100).

G.l.c. analysis of the crude reaction product, after trimethylsilylation, showed the presence of (i) the 1α-alcohol (7b); *m/z* (TMSi ether) 432 (M^+, 3%), 385 (24), 301 (25), 288 (25), 241 (53), 201 (25), 75 (46), and 73 (100); *m/z* (enol TMSi) 504 (M^+, 2%), 476 (40), 460 (28), 311 (44), 147 (22), 75 (32) and 73 (100); (ii) starting material; and (iii) peaks giving ill-defined spectra, tentatively indicating 16,17-dihydro-16-hydroxy-compounds.

Sodium Borohydride Reduction of a Mixture of ent-1α-*Hydroxy- and* ent-1β-*Hydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (7b) *and* (8b).—A mixture (10 mg) containing 75% of the *ent*-1α-alcohol (8b) and 25% of the *ent*-1β-alcohol (7b), in ethanol (1 ml), was reduced with sodium borohydride in the usual way. Trimethylsilylation of the product (10 mg), and g.l.c.–mass spectroscopic analysis showed the products to be (*a*) the 1β,3α-diol (15) (76%); *m/z* 506 (M^+, 1%), 491 (2), 459 (4), 390 (60), 375 (16), 217 (100), 75 (60), and 73 (60); and (*b*) the 1α,3α-diol (16) (24%); *m/z* 506 (M^+, 2%), 491 (3), 459 (8), 390 (100), 375 (28), 241 (29), 217 (60), 75 (70), and 73 (34).

Attempted Deoxygenation of ent-1α-*Hydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (8b).—The ketone (8b) (10 mg) was treated with *p*-tolylsulphonylhydrazine (8 mg) in ethanol (1 ml) as described for the ketone (8a). The product showed δ 1.15 (s, 18-H_3), 2.40 (s, ArMe), 2.72 (br, d, *J* 17 Hz, 2β-H), 2.79 (d, *J* 10 Hz, 6-H), 3.02 (br, d, *J* 17 Hz, 2α-H), 3.39 (d, *J* 10 Hz, 5-H), 3.70 (s, CO_2Me), 4.26 (br, d, *J* 6 Hz, 1α-H), 4.90 and 5.02 (br, s, 17-H_2), and 7.32 and 7.82 (both d, *J* 8 Hz, 4 × ArH). This presumed *p*-tolylsulphonylhydrazone was

reduced as described for the corresponding derivative of the ketone (8a). The products included (g.l.c.–mass spectrometry of the TMSi derivatives) (*a*) the 1β,3α-diol (15) (36%) (see previous experiment for mass spectrum); (*b*) gibberellin A_{62} methyl ester (20) (7%) (see later for characterisation); (*c*) traces of the 16,17-dihydro-derivative of the 1β,3α-diol (15) [*m/z* 508 (M^+, 0.5%), 493 (4), 461 (5), 392 (74), 377 (25), 349 (13), 243 (40), 217 (100), 75 (54), and 73 (50)]; (*d*) traces of the 16,17-dihydro-derivative of gibberellin A_{62} methyl ester (20) [*m/z* 418 (M^+, 0%), 403 (1), 390 (2), 374 (5), 315 (7), 284 (12), 225 (64), 224 (52), 180 (30), 75 (100), 73 (40), and 44 (42)].

ent-1α-*Acetoxy*-10-*hydroxy*-3-*oxo*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (9b).—The 1β-alcohol (8b) (640 mg) and toluene-*p*-sulphonic acid (5 mg) in dry acetic anhydride (5 ml) were left for 16 h. After the addition of water, extraction with ethyl acetate gave the 1β-*acetate* (9b) as a gum (710 mg) (Found: M^+, 402.168. $C_{22}H_{26}O_7$ requires *M*, 402.168); $\nu_{max.}$ ($CHCl_3$) 1 789, 1 733, 1 660, 926, and 893 cm^{-1}; δ 1.20 (s, 18-H_3), 2.11 (s, 1β-OCOMe), 2.60 (dd, *J* 1.5 and 18 Hz, 2β-H), 2.83 (d, *J* 10 Hz, 6-H), 2.94 (dd, *J* 5.5 and 18 Hz, 2α-H), 3.46 (d, *J* 10 Hz, 5-H), 3.73 (CO_2Me), 4.88 and 5.00 (both br, s, 17-H_2), and 5.43 (dd, *J* 1.5 and 5.5 Hz, 1-H); *m/z* (probe) 402 (M^+, absent), 342 (2%), 298 (55), 238 (100), 171 (27), and 147 (13).

Attempts to purify the 1β-acetate by p.l.c. gave the enone (6b), which was also obtained by treatment of the 1β-alcohol with acetic anhydride in pyridine.

Reduction of the 1β-*Acetate* (9b) *with Sodium Trimethoxyborohydride*.—Sodium borohydride (120 mg) was added to methanol (30 ml) at −10 °C with stirring. After 10 min, the 1β-acetate (9b) (700 mg) in methanol (5 ml) was cooled to −10 °C and added. Stirring was continued for 1 h at −10 °C. Acetic acid (1.8 ml) was added, the methanol was evaporated off, and water was added. Extraction with ethyl acetate gave a mixture (3 : 2 by n.m.r.) of the 3α-alcohol (10b) and the 3β-alcohol (11b) as a gum (700 mg): δ(3α-alcohol) 2.15 (s, 1-OCOMe), 2.82 (d, *J* 11 Hz, 6-H), 3.10 (*J* 11 Hz, 5-H); δ(3β-alcohol) 2.17 (s, 1-OCOMe), 2.79 (d, *J* 11 Hz, 6-H), and 3.60 (d, *J* 11 Hz, 5-H); δ(common signals) 1.23 (s, 18-H_3), 3.79 (s, CO_2Me), 3.87 (br, s, 3-H), 4.93 and 5.05 (both br, s, 17-H_2), and 5.24 (br, d, *J* 4 Hz, 1-H); *m/z* (3α-alcohol TMSi ether) 476 (M^+, absent), 445 (1%), 429 (3), 416 (66), 384 (68), 369 (29), 300 (28), 268 (28), 241 (45), 75 (88), 73 (100), and 43 (30); *m/z* (3β-alcohol TMSi ether) 476 (M^+, 1%), 416 (28), 384 (36), 300 (29), 268 (18), 241 (13), 233 (50), 232 (49), 75 (100), 73 (62), and 43 (29).

ent-1α-*Acetoxy*-10-*hydroxy*-3β-*thiobenzoyloxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (12b).—A mixture (480 mg) containing the 3α-alcohol (10b) (60%) and the 3β-alcohol (11b) (40%), di-isopropylethylamine (0.5 ml), and a solution of *N*-methylbenzimidoyl chloride methochloride in dichloromethane (0.5M; 5 ml) was left at room temperature for 44 h. Pyridine (1.6 ml) was added and, after 5 min, hydrogen sulphide gas was bubbled through the solution for 5 min. Water and 10M-hydrochloric acid were added to reach pH 3.0. Extraction with ethyl acetate gave the crude product, which was purified by p.l.c. using ethyl acetate–light petroleum (2 : 1). Elution of the band at R_F 0.8—0.9 yielded the required *thiobenzoate* (12b) as a yellow gum (300 mg) (Found: M^+, 524.188. $C_{29}H_{32}O_7S$ requires *M*, 524.187); $\nu_{max.}$ ($CHCl_3$) 1 788, 1 734, 1 659, and 909 cm^{-1}; δ 1.15 (s, 18-H_3), 2.17 (s, 1-OAc), 2.84 (d, *J* 10 Hz, 6-H), 3.28 (d, *J* 10 Hz, 5-H), 3.73 (s, CO_2Me), 4.88 and 5.00 (both br, s, 17-H_2), 5.27 (br, d, *J* 5 Hz, 1α-H), 6.03 (dd, *J* 6 and 11 Hz, 3β-H), 7.2—7.6 (m, 3 × ArH), and 8.20 (br, d, 2 × ArH); *m/z* (probe) 524 (M^+, 2%), 493 (3), 491 (1), 387 (13), 386 (10), 327 (35), 223 (100), 222 (46), 121 (39), and 105 (42).

Elution of the band at R_F 0.65—0.75 yielded *N*,*N*-dimethylthiobenzamide as a yellow oil.

Elution of the band at R_F 0.35—0.55 yielded a mixture (230 mg; 1 : 3) of the 3α- and 3β-alcohols (10b) and (11b).

ent-1α-*Acetoxy*-10-*hydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (13b).—The thiobenzoate (12b) (300 mg), 2,2′-azobis-(2-methylpropiononitrile) (5 mg), polymethylhydrosiloxane (0.11 ml), and bis(tri-n-butylstannyl) oxide (0.27 ml) in toluene (10 ml) were refluxed under nitrogen for 3 h. The toluene was evaporated off and the residue was fractionated by p.l.c. (×2) with ethyl acetate–light petroleum (2 : 3). From R_F 0.6 to 0.7, the *acetate* (13b) was obtained as a gum (114 mg) (Found: M^+, 388.189. $C_{22}H_{28}O_6$ requires *M*, 388.189); $\nu_{max.}$ ($CHCl_3$) 1 778, 1 732, and 1 658 cm^{-1}; δ 1.10 (s, 18-H_3), 2.12 (s, 1-OCOMe), 2.64 (br, 13-H), 2.72 (d, *J* 11 Hz, 6-H), 3.06 (d, *J* 11 Hz, 5-H), 3.72 (s, CO_2Me), 4.84 and 4.97 (both br, s, 17-H_2), and 5.11 (br, s, 1-H); *m/z* (probe) 388 (M^+, 3%), 356 (5), 328 (14), 296 (100), 284 (15), 268 (13), 241 (11), 225 (17), 223 (17), 91 (10), and 43 (12).

ent-1α,10-*Dihydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 7-*Methyl Ester* 19,10-*Lactone* (GA_{61} *Methyl Ester*) (14b).—The acetate (13b) (114 mg) and anhydrous potassium carbonate (120 mg) in methanol (5 ml) were stirred for 16 h. Acetic acid (0.35 ml) was added and the methanol was evaporated off. Water was added and the product, recovered in ethyl acetate, was fractionated by p.l.c. with ethyl acetate–light petroleum (2 : 1). Elution of the band at R_F 0.6—0.75 yielded *gibberellin* A_{61} *methyl ester* (14b) (63 mg), m.p. 178—180 °C (from acetone–light petroleum) (Found: C, 68.7; H, 7.75%; M^+, 346.179. $C_{20}H_{26}O_5$ requires C, 69.4; H, 7.5%; *M*, 346.178); $\nu_{max.}$ 3 486, 1 782, 1 717, 1 660, 926, and 880 cm^{-1}; δ 1.09 (s, 18-H_3), 2.65 (br, 13-H), 2.73 (d, *J* 11 Hz, 6-H), 3.15 (d, *J* 11 Hz, 5-H), 3.72 (s, CO_2Me), 4.05 (br, s, 1-H), and 4.87 and 5.00 (both br, s, 17-H_2); *m/z* (probe) 346 (M^+, 24%), 315 (27), 314 (83), 296 (23), 287 (40), 286 (100), 284 (14), 259 (13), 258 (14), and 225 (25); *m/z* (TMSi ether) 418 (M^+, 7%), 403 (14), 359 (41), 347 (26), 296 (96), 284 (30), 274 (26), 268 (14), 225 (45), 129 (42), 116 (100), 101 (62), 75 (52), and 73 (80).

Elution of the band at R_F 0.5—0.6 yielded a mixture (1 : 1) (15 mg) of gibberellin A_{61} methyl ester (14b) and the 1α-*epimer*; the TMSi ether of the latter had *m/z* 418 (M^+, 5%), 371 (17), 359 (42), 347 (14), 300 (11), 296 (12), 294 (21), 185 (24), 129 (31), 116 (100), 101 (32), 75 (28), and 73 (42).

ent-1α,10-*Dihydroxy*-20-*norgibberell*-16-*ene*-7,19-*dioic Acid* 19,10-*Lactone* (*Gibberellin* A_{61}) (2b).—Gibberellin A_{61} methyl ester (14b) (63 mg) and potassium hydroxide (150 mg) in methanol (8 ml) and water (8 ml) were refluxed for 19 h. The usual work-up gave unchanged methyl ester (30 mg) and *gibberellin* A_{61} (2b) (23 mg), m.p. 257—259 °C (from acetone–light petroleum) (Found: M^+, 332.163. $C_{19}H_{24}O_5$ requires *M*, 332.162); $\nu_{max.}$ 3 478, 3 400—2 500br, 1 743, 1 716, 1 662, 926, and 892 cm^{-1}; δ[$(CD_3)_2CO$] 1.04 (s, 18-H_3), 2.62 (d, *J* 11 Hz, 6-H), 3.13 (d, *J* 11 Hz, 5-H), 3.99 (br, s, 1-H), and 4.87 and 4.98 (both br, s, 17-H_2); *m/z* (probe) 332 (M^+, 46%), 314 (66), 296 (100), 287 (51), 286 (64), 273 (44), 270 (67), 261 (53), 225 (67), and 91 (38); *m/z* (TMSi ether TMSi ester) 476 (M^+, 1%), 461 (15), 386 (5),

358 (41), 296 (19), 225 (26), 129 (10), 116 (16), 101 (8), 75 (81), and 73 (100).

ent-1α-*Acetoxy*-10-*hydroxy*-20-*norgibberella*-2,16-*diene*-7,19-*dioic Acid* 19,10-*Lactone* 7-*Methyl Ester* (19).—(a) *Small scale*. A mixture (1 : 3; 71 mg) of the alcohols (10b) and (11b) and phosphoryl bromide (90 mg) in pyridine (2 ml) were refluxed in nitrogen for 1 h. Water was added and the pH of the solution was adjusted to 3. The product, recovered in ethyl acetate, and 1,5-diazabicyclo[5.4.0]undec-5-ene (DBU) (0.02 ml) in pyridine (2 ml) were refluxed for 1 h in nitrogen. Work-up as before yielded a gum (57 mg) which was subjected to p.l.c. using ethyl acetate–light petroleum (1 : 1). Elution of the band at R_F 0.65—0.75 gave the 2,3-*olefin* (19) as a gum (36 mg) (Found: M^+, 386.173. $C_{22}H_{26}O_6$ requires M, 386.173); $\nu_{max.}$ ($CHCl_3$) 1 784, 1 739, 1 660, and 966 cm^{-1}; δ 1.22 (s, 18-H_3), 2.11 (s, 1-OCOMe), 2.66 (d, J 10 Hz, 6-H), 2.98 (d, J 10 Hz, 5-H), 3.72 (s, CO_2Me), 4.87 and 4.99 (both br, s, 17-H_2), 5.33 (d, J 3 Hz, 1-H), 5.83 (dd, J 3 and 10 Hz, 2-H), and 5.95 (d, J 10 Hz, 3-H); m/z (at 24 eV) 386 (M^+, 0%), 355 (1), 326 (1), 300 (1), 282 (14), 223 (97), 222 (100), 193 (22), and 155 (52).

(b) *Larger scale*. The mixture (1 : 3; 300 mg) of the alcohols (10b) and (11b) was treated with phosphoryl bromide (360 mg) in pyridine, and the reaction mixture was worked up as in (a). The product [δ 1.22 (s, 18-H_3), 2.11 (s, 1-OCOMe), 2.67 (d, J 10 Hz, 6-H), 2.99 (d, J 10 Hz, 5-H), 3.74 (s, CO_2Me), 5.35 (d, J 3 Hz, 1-H), 5.95 (m, *ca.* 2.5 H, 2-, 3-, and 15-H)] was treated with DBU (0.12 ml) in pyridine (5 ml) as in (a) to give a product with unchanged n.m.r. spectrum.

Field desorption mass spectrometry of the product before and after treatment with DBU gave M^+ 446/444 corresponding to the bromo-compound (21).

ent-1α,10-*Dihydroxy*-20-*norgibberella*-2,16-*diene*-7,19-*dioic Acid* 19,10-*Lactone* 7-*Methyl Ester* (*Gibberellin* A_{62} *Methyl Ester*) (20).—The 2,3-olefin (19) (24 mg) and anhydrous potassium carbonate (37 mg) in methanol (3 ml) were stirred for 16 h. Acetic acid (0.11 ml) was added and the mixture was worked up as for gibberellin A_{61} methyl ester. To remove the 17-bromide (21), shown to be *ca.* 10% of the product by g.l.c.–mass spectrometry, the product and potassium hydroxide (50 mg) were refluxed in methanol–water (1 : 1; 4 ml) for 2 h. Removal of the methanol, acidification of the aqueous residue to pH 3.0, and extraction with ethyl acetate gave a gum which was re-methylated with diazomethane and subjected to p.l.c. using ethyl acetate–light petroleum (2 : 1). Elution of the band at R_F 0.55—0.70 yielded *gibberellin* A_{62} *methyl ester* (20) as a gum (12 mg) (Found: M^+, 344.163. $C_{20}H_{24}O_5$ requires M, 344.162); $\nu_{max.}$ ($CHCl_3$) 3 600, 1 778, 1 729, 1 658, and 936 cm^{-1}; δ 1.20 (s, 18-H_3), 2.67 (d, J 10 Hz, 6-H), 2.88 (d, J 10 Hz, 5-H), 3.73 (s, CO_2Me), 4.16 (br, s, collapsed to d, J 2 Hz on addition of D_2O, 1-H), 4.87 and 4.99 (both br, s, 17-H_2), and 5.89 (s, 2- and 3-H); m/z (probe) 344 (M^+, 0.5%), 313 (2), 300 (4), 282 (12), 223 (100), 222 (84), 195 (16), 194 (11), 193 (16), 181 (22), 180 (10), 179 (15), 155 (32), 143 (14), 131 (12), 108 (17), 105 (13), 93 (12), 91 (13), 81 (13), and 44 (25); m/z (TMSi ether) 416 (M^+, 0%), 401 (4), 282 (23), 223 (100), 222 (93), 195 (16), 194 (12), 193 (18), 181 (27), 180 (36), 179 (15), 165 (19), 155 (25), 143 (12), 131 (11), 75 (52), 73 (78), and 44 (30).

The gibberellin A_{62} methyl ester (20) contained 11% (by g.l.c.–mass spectrometry) of the endocyclic double bond isomer; m/z 344 (M^+, 11%), 300 (6), 282 (47), 238 (25), 223 (66), 214 (53), 195 (65), 193 (69), 181 (21), 179 (42), 155 (100), 108 (82), 105 (28), and 44 (85); m/z (TMSi ether) 416 (M^+, 0.3%), 401 (2), 388 (3), 372 (5), 313 (6), 282 (16), 223 (12), 214 (14), 193 (11), 180 (100), 179 (12), 165 (13), 155 (25), 75 (37), 73 (42), and 44 (29).

Before p.l.c., g.l.c.–mass spectrometry of the crude sample showed the presence of *ca.* 5% of the 1α-epimer of gibberellin A_{62} methyl ester; m/z 416 (M^+, 0%), 388 (14), 372 (23), 369 (8), 313 (13), 282 (15), 223 (88), 180 (46), 75 (84), 73 (100), and 44 (45).

ent-1α,10-*Dihydroxy*-20-*norgibberella*-2,16-*diene*-7,19-*dioic Acid* 19,10-*Lactone* (*Gibberellin* A_{62}) (4b).—Gibberellin A_{62} methyl ester (20) (12 mg) and potassium hydroxide (50 mg) in methanol (1 ml) and water (1 ml) were refluxed for 28 h. Work-up as for gibberellin A_{60} (2b) gave unchanged ester (5 mg) and *gibberellin* A_{62} (4b) as a gum (7 mg) (Found: M^+, 330.147. $C_{19}H_{22}O_5$ requires M, 330.147); $\nu_{max.}$ (tetrahydrofuran) 3 460br, 1 771, 1 718, and 1 643 cm^{-1}; δ[$(CD_3)_2CO$] 1.15 (s, 18-H_3), 2.56 (d, J 10 Hz, 6-H), 2.90 (d, J 10 Hz, 5-H), 4.08 (d, J 2 Hz, 1-H), 4.86 and 4.98 (both br, s, 17-H_2), and 5.87 (s, 2- and 3-H); m/z (probe) 330 (M^+, 5%), 268 (66), 223 (100), 155 (44), 108 (56), 91 (45), and 79 (31); m/z (TMSi ether TMSi ester) 474 (M^+, 0.2%), 459 (22), 340 (12), 223 (64) 222 (82), 181 (11), 180 (15), 75 (37), and 73 (100).

Osmium Tetraoxide Oxidations.—(a) *Gibberellin* A_7 *methyl ester* (*small scale*). The methyl ester (13 mg, 0.038 mmol), osmium tetraoxide (10 mg, 0.039 mmol), pyridine (0.06 ml), and chloroform (0.06 ml) were left for 4 days. Sodium disulphite (200 mg) in water (2 ml) was added to the mixture, which was extracted with ethyl acetate at pH 3.0 to give a gum (4 mg). Analysis of the trimethylsilylated product by g.l.c.–mass spectrometry (2% SP2100 column) showed the presence of the TMSi derivatives of: gibberellin A_7 methyl ester (75%) and the 1α,2α,3β-triol (23) (25%) [m/z 594 (M^+, 30%), 579 (5), 547 (10), 519 (2), 390 (25), 319 (26), 306 (20), 305 (32), 241 (12), 231 (15), 217 (60), 204 (41), 191 (23), 147 (25), 103 (9), 75 (42), and 73 (100)].

(b) *Gibberellin* A_7 *methyl ester* (*large scale*). A mixture of gibberellin A_7 methyl ester (177 mg, 0.53 mmol) and gibberellin A_4 methyl ester (31 mg), in pyridine (0.6 ml) and chloroform (0.6 ml), was treated for 5 days with osmium tetraoxide (177 mg, 0.70 mmol). Work-up, and analysis as in (a) showed the product (118 mg) to contain: the methyl esters of gibberellins A_4 and A_7; a trace of the 1α,2α,-3β-triol (23); a main product, presumed to be an unresolved mixture of the 16,17-dihydro-16,17-dihydroxy-derivatives of gibberellin A_7 methyl ester (26) and of gibberellin A_4 methyl ester [see (c) for mass spectra]; and a minor product, believed to be the pentaol (24) [m/z 772 (M^+, 3%), 757 (3), 357 (3), 669 (100), 217 (16), 147 (18), 75 (28), and 73 (40)].

(c) *Gibberellin* A_7. A mixture of gibberellin A_7 (8.5 mg) and gibberellin A_4 (1.5 mg) was treated with osmium tetraoxide (8.5 mg) as in (a). The following products were identified as the MeTMSi derivatives by g.l.c.–mass spectrometry (2% QF-1 column): gibberellin A_4; gibberellin A_7; the 1α,2α,3β-triol (23); 16,17-dihydro-16,17-dihydroxy-gibberellin A_7 (26) [m/z 594 (M^+, absent), 579 (2%), 504 (1), 491 (71), 401 (7), 357 (25), 179 (24), 147 (25), 129 (15), 75 (100), and 73 (81)]; and 16,17-dihydro-16,17-dihydroxy-gibberellin A_4 [m/z 596 (M^+, 0.5%), 581 (2), 506 (1), 493 (100), 147 (15), 129 (15), 75 (97), and 73 (60)].

(d) *Gibberellin* A_3 *methyl ester*. The methyl ester (15 mg) was treated with osmium tetraoxide (12 mg) as in (a) to give (by g.l.c.–mass spectrometry on a 2% QF-1 column) starting material (36%) and the presumed 1α,2α,3β,13-

tetraol (25) (64%) with *m/z* 682 (M^+, 20%), 667 (3), 635 (3), 607 (0.5), 563 (0.5), 448 (100), 375 (28), 305 (15), 217 (35), 191 (18), 147 (19), 103 (24), 75 (23), and 73 (82).

(e) *Gibberellin* A_{62} *methyl ester and the enone* (6b). The methyl esters (10 mg) were each treated with osmium tetraoxide (9 mg) as in (a). No products could be identified by g.l.c.–mass spectrometry (2% QF-1 column).

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