New synthetic routes to pyrrolo-[1,2-*a*]- and -[1,2-*c*]-imidazol-5-ones by flash vacuum pyrolysis

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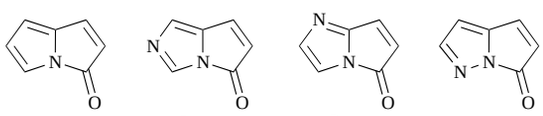
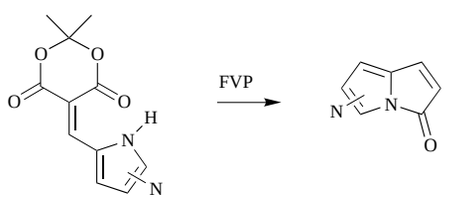
1-Substituted and 1,3-disubstituted pyrrolo[1,2-*c*]imidazol-5-ones 25–27 have been made in fair to excellent yield by flash vacuum pyrolysis (FVP) of the Meldrum's acid precursors 11–13. FVP of the appropriate propenoate precursor 23, 22 and 18–20 gives pyrrolo[1,2-*c*]imidazol-5-one 2, pyrrolo[1,2-*a*]-imidazol-5-one 3 and their 6-methyl derivatives 28–30 respectively in 32–90% yield. The mechanism of the propenoate pyrolyses involves rate determining *E* to *Z* isomerisation of the alkene followed by elimination of an alcohol and electrocyclisation to the fused ring products.

As an extension of our work on the synthesis of the pyrrolizin-3-one ring system **1** by flash vacuum pyrolysis (FVP) of the condensation product of Meldrum's acid and pyrrole-2-carbaldehyde,[1] we have prepared the parent pyrrolo[1,2-*c*]-imidazol-5-one **2**, pyrrolo[1,2-*a*]imidazol-5-one **3** and pyrrolo-[1,2-*b*]pyrazol-6-one **4** by similar strategies (Scheme 1).[2] These



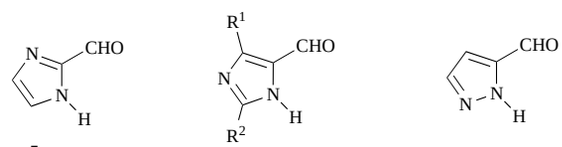
1 **2** **3** **4**



Scheme 1

earlier studies were hampered by the poor solubility of the appropriate azolecarbaldehydes (and consequent low yields of condensation products) and the poor volatility of the Meldrum's acid derivatives. This problem was particularly acute in the pyrrolo[1,2-*a*]imidazol-5-one **3** and pyrrolo[1,2-*b*]-pyrazol-6-one **4** series where no products were obtained under conventional FVP conditions, though recourse to feeding the precursor under gravity through a loosely packed vertical furnace tube *in vacuo* gave **3** (5.8%) and **4** (18%). Since we required substantial quantities of these compounds in order to embark on a study of the basic chemistry of the ring systems, it was essential to develop a more efficient synthetic route. In this paper, we show how the original Meldrum's acid method can be extended to the preparation of substituted pyrrolo[1,2-*c*]-imidazol-5-ones, and how application of the complementary propenoate method[3] has given a straightforward route to a range of pyrrolo[1,2-*a*]imidazol-5-ones and pyrrolo[1,2-*c*]-imidazol-5-ones, including the parent compounds **2** and **3**.[4] Unfortunately, the propenoate methodology could not be applied to the pyrrolo[1,2-*b*]pyrazol-6-one **4** case, and a mechanistic rationale of this observation is presented.

The Meldrum's acid and propenoate precursors are most conveniently obtained by either a Knoevenagel or Wittig type condensation reaction involving an azolecarbaldehyde. 1*H*-Imidazole-2-carbaldehyde **5** was prepared by the *Organic Syntheses* method.[5] 3*H*-Imidazole-4-carbaldehydes **6**–**9** were

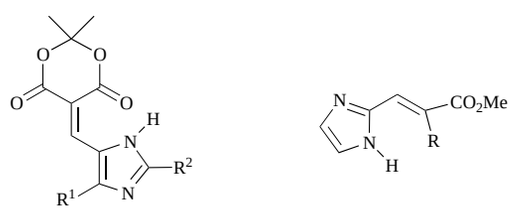


5 **10**

6 $R^1 = R^2 = H$
7 $R^1 = Me$, $R^2 = H$
8 $R^1 = R^2 = Me$
9 $R^1 = Me$, $R^2 = Ph$

obtained by oxidation of the corresponding 4-hydroxymethyl-3*H*-imidazole with manganese(IV) oxide in hot dioxane.[6] These precursors were either commercially available or were prepared by a modification of the method described by Jacquier,[7] involving acid-catalysed rearrangement of the glycol obtained from condensation of butane-2,3-dione with an amidine (see Experimental section). 2*H*-Pyrazole-3-carbaldehyde **10** was also made by a literature method.[8]

The imidazolecarbaldehydes **8** and **9** were condensed with Meldrum's acid under standard conditions using piperidinium acetate catalyst[3] to give yields of the products **12** and **13** in



11 $R^1 = Me$, $R^2 = H$
12 $R^1 = R^2 = Me$
13 $R^1 = Me$, $R^2 = Ph$

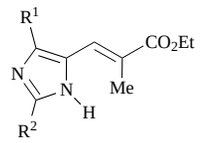
14 $R = CO_2Me$
15 $R = CN$

16 **17**

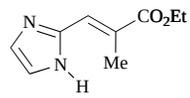
excess of 90%. Due to the poor solubility of the 5-methyl derivative **7** in benzene, the reaction was carried out in pyridine in the absence of further catalyst and the yield of **11** was lower as a result. The methyl 2-substituted 3-azolylpropenoates **14**–**17** were prepared similarly from the appropriate aldehyde and active methylene compound using either toluene or pyridine (for insoluble aldehydes) as solvent. The cyano compounds **15**–

17 were each obtained as single diastereomers and the chemical shifts of the olefinic proton in each example (δ_H > 8) are consistent with the formation of the *E*-isomer (see below). However, the ^{1}H NMR spectrum of the malonate derivative **14** reproducibly contained a number of signals consistent with the presence of further compound(s) in the sample, even after repeated recrystallisation. The presence of a peak in the mass spectrum of **14** at *m*/*z* 420 ($2M^+$), suggests that the compound may actually exist in dimeric form(s) which become partially dissociated in solution.

The propenoate derivatives **18**–**22** were made by Wittig olefination of the appropriate azolecarbaldehyde with methyl (triphenylphosphoranylidene)acetate or ethyl 2-(triphenylphosphoranylidene)propanoate. Reactions were carried out at reflux in benzene or in pyridine depending on the solubility of the azolecarbaldehyde and the products were best isolated by dry flash chromatography; yields were generally in the range 70–80%. However, the two stereoisomers of methyl 3-(imidazol-2-yl)propenoate **22** could be isolated without chromatography owing to the low solubility of the *E*-isomer (38% yield) and the volatility of the *Z*-isomer (22% yield). Usually the Wittig reactions favoured the formation of the *E*-isomer as the main or only product, though in the synthesis of methyl 3-(pyrazol-3-yl)propenoate **21** and methyl 3-(imidazol-2-yl)propenoates **22** significant quantities of both the *E*- and *Z*-isomers were obtained, possibly owing to favourable intramolecular hydrogen bonding interactions contributing to the stability of the latter. As a special case the parent imidazole derivative **23** was most conveniently prepared by esterification of the commercially available urocanic acid **24**.[9]



18 $R^1 = R^2 = H$
19 $R^1 = R^2 = Me$



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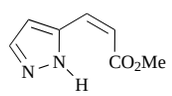
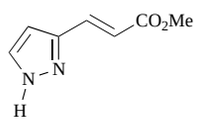
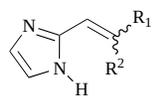


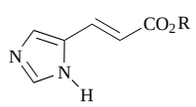
Z-**21 A**



E-**21 B**



E-**22** $R^1 = CO_2Me$, $R^2 = H$
Z-**22** $R^1 = H$, $R^2 = CO_2Me$



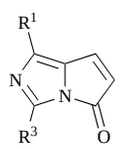
23 R = Me
24 R = H

In the ^{1}H NMR spectra of the propenoate derivatives **18**–**23**, the magnitudes of both the *cis* and *trans* olefinic ^{1}H–^{1}H coupling (^3J *ca.* 12.7 and 16.0 Hz respectively) are similar to those of analogous systems such as (*Z*)- and (*E*)-cinnamic acid (^3J 12.3 and ^3J 15.8 Hz respectively),[10] hence allowing straightforward assignment of the stereochemistry. Where the propenoate chain carries a 2-methyl group, a small allylic coupling (^4J *ca.* 1 Hz) between H-3 and the 2-substituent is observed. The chemical shift of H-3 is consistently more deshielded for the *E*-isomers than *Z*-isomers (δ_H 7.42–7.70 and 6.78–7.02 respectively), and this feature may be used to assign the geometry of 2-substituted examples of the series. In the azole section of the spectrum, no annular couplings were observed for any of the imidazole derivatives. Some variation is observed in the values of the azole $^3J_{4,5}$ of (*E*)- and (*Z*)-methyl 3-(pyrazol-3-yl)propenoates **21** ($^3J_{4,5}$ 2.4 and 1.6 Hz respectively) which is consistent with each of these isomers favouring different tautomeric forms of the pyrazole ring.[11] In the *Z*-form, the potential for intramolecular hydrogen bonding may favour the 2*H* tautomer *Z*-**21A** whereas in the *E*-form, the pyrazole ring reverts to the 1*H* tautomer *E*-**21B**.

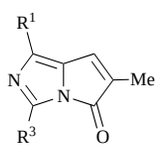
In the ^{13}C NMR spectra, there is considerable broadening of the azole signals in the spectra of imidazol-2-yl derivatives **22** (*E*/*Z*), **20** and **15** which suggests that coalescence of the heteroaromatic methine resonances by exchange of the N–H proton occurs at close to ambient temperature.

The mass spectra of the azolylpropenoates generally contain strong peaks corresponding to the molecular ion (M^+) and subsequently exhibit a relatively simple fragmentation pattern due to initial loss of 'OR' (R = Me, Et) to give a peak at M − 31/32 or M − 45/46, followed by loss of CO (M − OR − 28) and the labile CN group (where present). Subsequent fragmentation involves a further loss of 27 Da (HCN).

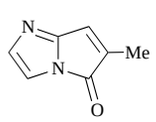
Flash vacuum pyrolysis of the Meldrum's acid condensation products **11**–**13** gave the corresponding pyrrolo[1,2-*c*]imidazol-5-ones **25**–**27** as yellow or orange crystalline solids in analytical purity. The optimum temperature for the pyrolyses was found to be 650 °C, *i.e.* some 50 °C higher than for the parent compound **2**.[2] Although the yield of the 1-methyl derivative **25** was 92%, the corresponding preparations of the 1,3-dimethylpyrroloimidazolone **26** and 1-methyl-3-phenyl compound **27** were less efficient (51 and 43% respectively) due to substantial decomposition of the precursor in the inlet tube.



25 $R^1 = Me$, $R^3 = H$
26 $R^1 = R^3 = Me$
27 $R^1 = Me$, $R^3 = Ph$



28 $R^1 = R^3 = H$
29 $R^1 = R^3 = Me$



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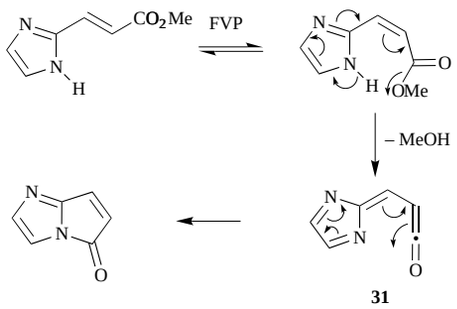
As found for the pyrrolizinone system, pyrolysis of the propenoate esters **18**–**23** has proved to be a highly efficient route to the appropriate condensed ring systems. The precursors do not suffer from the volatility problems of the Meldrum's acid derivatives, and although high furnace temperatures are required (800–850 °C—see below) the products have surprisingly high thermal stability and no significant losses were experienced. Both the parent pyrroloimidazol-5-ones **2** and **3** are now readily accessible by the propenoate route. Thus the yield of the ring closure to form **3** has been improved from 5.8[2] to 90%, and whereas formation of **2** by the Meldrum's acid route required the prior lengthy synthesis of 3*H*-imidazole-4-carbaldehyde **6**, the propenoate precursor **23** can be prepared in a single step from commercially available urocanic acid **24**. The methodology was successfully extended to the synthesis of the 6-methylpyrroloimidazolones **28**–**30**, which are unavailable by the Meldrum's route, but these reactions proved to be lower yielding (40–60%) and some difficulties were found in handling the products.

Two apparent limitations were found in the propenoate route. First, the pyrolyses of **14**–**17** were expected to lead to pyrroloimidazolones (or pyrrolopyrazolones) containing an electron withdrawing group in the 6- (or 5-) position by analogy with the corresponding successful route to pyrrolizin-3-ones.[3] In the event, these reactions gave brightly coloured volatile products which appeared to form insoluble polymeric solids when our standard U-tube trap was warmed to room temperature.

This interpretation was confirmed by a separate pyrolysis of **15** in which a 'cold finger' cooled with dry ice–acetone was used as the trap. A brightly coloured product was deposited on the cold surface which was soluble in acetone at −80 °C, but the colour was discharged and a polymeric product was obtained when this solution was allowed to warm to 0 °C. It therefore appears that such azapyrrolizinones can be formed successfully from the propenoate precursors, but the products are unstable and can only be handled at very low temperatures.

Attempts to prepare the pyrrolo[1,2-*b*]pyrazol-6-one system **4** also proved unsuccessful. Thus pyrolyses of both *E*- and *Z*-isomers of methyl 3-(pyrazol-3-yl)propenoate **21** at appropriate temperatures showed a significant pressure increase in the system (associated with production of dinitrogen) and no significant products could be isolated. The mechanism of the propenoate pyrolyses presumably require *E* to *Z* isomerisation of the alkene (a process known to occur under FVP conditions[12]) followed by concerted elimination of the alcohol to give the key azolylmethylideneketene intermediate **31** which undergoes an electrocyclisation to give the product (shown in Scheme 2 for



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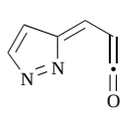
Scheme 2

the formation of **3**). In the pyrazolyl case, this process leads at *ca.* 650 °C to a 3*H*-pyrazole intermediate **32** from which elimin-



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ation of dinitrogen would be expected to be extremely rapid.[13] Extrusion of dinitrogen from 1*H*-pyrazole, *via* 3*H*-pyrazole,[13] occurs only at temperatures above 700 °C in our apparatus, which suggests that our concerted elimination process is faster than a [1,5]-hydrogen shift in the pyrazole system.

The availability of pure samples of the *E*- and *Z*-isomers of methyl 3-(imidazol-2-yl)propenoate **22** allowed the rate determining step of the cyclisation to be identified. Thus, if ring closure of the *Z*-isomer occurred at significantly lower furnace temperatures than for the *E*-isomer then *E*–*Z* isomerisation would be the slow step, but if there was no significant difference in the furnace temperatures then the ketene formation (or a subsequent step) would be identified as the rate limiting process. The percentage conversions of *E*- and *Z*-**22** to **3** are shown in Fig. 1. It is clear that the *Z*-isomer undergoes ring closure at substantially lower temperatures than the *E*-isomer. It follows that isomerisation of the C=C bond is the rate controlling process for the generation of pyrrolizinones and related compounds by FVP of propenoates such as **22**, and hence the *Z*-isomer should be used if low furnace temperatures are required.

Finally, a brief study of the effect of substitution on the spectroscopic properties of the new pyrroloimidazolones was carried out; NMR spectra of the parent systems **1**–**4** have been previously discussed in detail.[14] The incorporation of a methyl group into any position of the pyrrolo[1,2-*c*]imidazol-5-one system induces slight shielding of the remaining signals of the

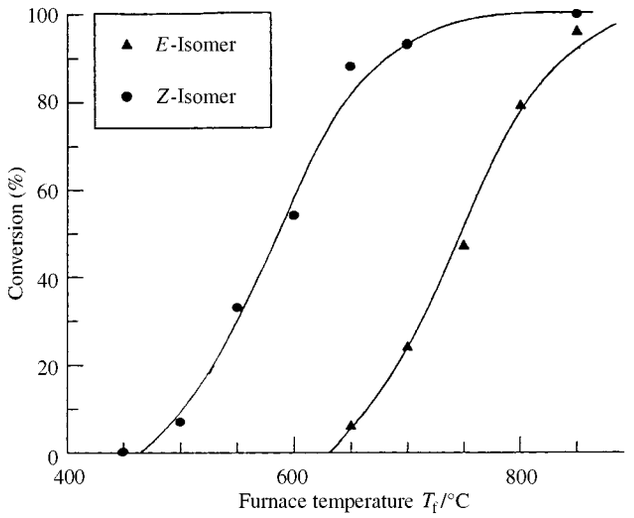

Fig. 1 Conversion of *E*- and *Z*-isomers of **22** to **3** as a function of temperature

ring protons in the ^{1}H NMR spectrum; in the [1,2-*a*] series, this is apparently overridden by solvent effects. With the exception of the signals due to the carbonyl carbon atom and that of the carbon at the site of substitution, which show small (<1 ppm) and large (often >10 ppm) deshielding effects respectively, very similar trends are shown in the ^{13}C NMR spectra. In the [1,2-*c*] series, the magnitude of $^1J_{CH}$ values is also reduced by the presence of a methyl group in the system (Table 1). The 3-phenyl group in **27** apparently acts as a net electron donor, as shown by the rather similar spectra of **27** and the 1,3-dimethyl compound **26**, and by the chemical shift of the *para*-carbon atom of the phenyl ring at δ_C 131.12. This signal was readily identified since it occurred as a triplet of doublets in the ^{1}H-coupled ^{13}C NMR spectrum. Alternatively, the (3-pyrrolo[1,2-*c*]imidazole) system can be regarded as an electron withdrawing group, which, from the deshielding effect on the *para*-carbon atom, is of similar strength to a ketone function.

The mass spectra of the parent pyrroloimidazolones show sequential loss of CO and two molecules of HCN from intense molecular ions.[2] The spectra of the substituted examples have similar features, though the order of cleavage may be reversed. For example, the 1,3-disubstituted compounds **26** and **27** both show significant fragment ions at *m*/*z* 107 due to cleavage of RCN (R = Me or Ph respectively) from the 2- and 3-positions, prior to the loss of CO.

All the pyrroloimidazolones show characteristic carbonyl absorptions at 1735–1770 cm^{-1} in their IR spectra and most have another intense peak at *ca.* 1620 cm^{-1}, not found in the pyrrolizinone series, which may be associated with C=N vibrations. The substituted systems show two characteristic maxima in the UV region, at 276–295 nm together with a less intense peak at 376–425 nm (see Experimental section). Methyl substituents generally cause bathochromic shifts in the long wavelength maxima (which are responsible for the characteristic colours associated with the systems), but the effects are apparently not always additive.

In conclusion, we have shown that the FVP methodologies previously developed for pyrrolizin-3-one formation[3] can also be applied to the syntheses of pyrrolo-[1,2-*a*]- and -[1,2-*c*]-imidazol-5-ones. A range of substituted derivatives of these systems has been synthesised for the first time. In particular, the parent compounds of these series are now readily available by the propenoate route and their chemistry will be reported in later papers.

Experimental

^{1}H and ^{13}C NMR spectra were recorded at 200 and 50 MHz

Table 1 $^1J_{CH}$ values for pyrrolo[1,2-*c*]imidazol-5-ones

Compound	Substituent	$^1J_{CH}$/Hz				
		7	6	3	1	Alkyl
2	—	179.1	183.0	216.9	198.5	—
25	1-Me	177.4	182.7	215.5	—	128.5
26	1,3-Me_2	176.5	181.6	—	—	130.5,[a] 128.4
27	1-Me-3-Ph	175.9	181.1	—	—	128.4
28	6-Me	177.1	—	216.7	195.0	128.9
29	1,3,6-Me_3	174.2	—	—	—	128.9,[a] 130.2, 127.9

[a] Coupling constants associated with methyl substituents of **26** and **29** are given in the order (6), 3, 1.

respectively for solutions in [^{2}H]chloroform unless otherwise stated. Coupling constants (*J*) are quoted in Hz, IR absorption maxima (ν_{max}) in cm^{-1} and UV absorption maxima (λ_{max}) in nm.

Imidazolecarbaldehydes

1*H*-Imidazole-2-carbaldehyde **5** was prepared by the *Organic Syntheses*[5] method and imidazole-4(5)-carbaldehydes were obtained by oxidation of the corresponding 4(5)-hydroxymethylimidazoles. These precursors were commercially available (as their hydrochloride salts) or were prepared as follows by a modification of the method of Jacquier.[7]

4-Hydroxymethyl-2,5-dimethyl-3*H*-imidazole. Butane-2,3-dione was added to a solution of acetamidine hydrochloride (10.07 g, 0.11 mol) dissolved in the minimum amount of water. The mixture was stirred at room temperature for 4 h, neutralised with aqueous sodium hydroxide (2 M) and was set aside overnight. The white precipitate which appeared was collected by filtration and was washed with acetone. The solid was added to aqueous hydrochloric acid (5 M, 80 cm^3) and the solution was heated at reflux for 3 h. The solution was cooled and the water was removed under reduced pressure. The white solid which remained was washed with acetone and dried *in vacuo* to give 4-hydroxymethyl-2,5-dimethyl-3*H*-imidazole hydrochloride (9.86 g, 57%), mp 228–229 °C (from methanol) (lit.,[7] 225 °C); δ_H([$^2H_6$]DMSO) 14.35 (1H, br s), 14.09 (1H, br s), 4.36 (2H, s), 2.48 (3H, s) and 2.16 (3H, s) (in agreement with literature data[7]).

4-Hydroxymethyl-5-methyl-2-phenyl-3*H*-imidazole. Benzamidine hydrochloride hydrate (7.85 g, 50 mmol) was dissolved in the minimum amount of water (37 cm^3), butane-2,3-dione (4.37 g, 51 mmol) was added and the solution was stirred at room temperature for 3.25 h. The white precipitate which formed was filtered and washed thoroughly with acetone. The solid was heated at 90–100 °C in aqueous hydrochloric acid (5 M, 25 cm^3) for 2.5 h, during which time the solid dissolved. After the solution had cooled, it was neutralised with saturated aqueous sodium hydrogen carbonate. The water was removed under vacuum and the solid residue was extracted thoroughly with ethanol (4 × 150 cm^3). Evaporation of the combined extracts gave 4-hydroxymethyl-5-methyl-2-phenyl-3*H*-imidazole (5.98 g, 63%), as a white solid, mp 196–198 °C (from methanol) (lit.,[7] 203–205 °C); δ_H([$^2H_6$]-DMSO) 7.91 (2H, d, ^3J 7.4), 7.44–7.24 (3H, m), 4.41 (2H, s) and 2.20 (3H, s); δ_C([$^2H_6$]DMSO) (two quaternaries missing) 143.19 (q), 130.81 (q), 128.54, 127.41, 124.30, 54.56 and 10.68.

Generation of free base. Where the 4-hydroxymethyl-3*H*-imidazole was obtained as its hydrochloride, the free base was generated from an aqueous solution of the salt by basification with sodium hydrogen carbonate. The water was removed under vacuum and the residue was thoroughly extracted with ethanol. Evaporation of the combined extracts gave the free 4-hydroxymethyl-3*H*-imidazoles. The following free bases were generated by this means and were used immediately in the oxidation: 4-hydroxymethyl-3*H*-imidazole, 4-hydroxymethyl-5-methyl-3*H*-imidazole and 4-hydroxymethyl-2,5-dimethyl-3*H*-imidazole, δ_H([$^2H_6$]DMSO), 4.26 (2H, s), 2.17 (3H, s) and 2.04 (3H, s); δ_C([$^2H_6$]DMSO) (two quaternaries missing) 141.32 (q), 54.27, 13.51 and 10.44.

Oxidation.[6] A solution of the appropriate hydroxymethylimidazole (13 mmol) in 1,4-dioxane (75 cm^3) was heated at reflux with manganese dioxide (0.13 mol) for 1 h (unless otherwise stated). The hot solution was then filtered through Celite and the solids were washed thoroughly with hot 1,4-dioxane. The combined filtrate and washings were evaporated to dryness to give the 3*H*-imidazole-4-carbaldehyde. The material isolated was pure enough for further use.

The following compounds were prepared using this procedure: 3*H*-imidazole-4-carbaldehyde **6** (28%), mp 174–175 °C (lit.,[6] 174–175 °C); 5-methyl-3*H*-imidazole-4-carbaldehyde **7** (45%), mp 159–160 °C (lit.,[15] 167 °C); δ_H([$^2H_6$]DMSO) 9.78 (1H, br s), 7.75 (1H, br s) and 2.44 (3H, d, *J* 0.6); δ_C([$^2H_6$]DMSO) (all resonances very broad) 184.8, 139.5–136.5 and 11.1; 2,5-dimethyl-3*H*-imidazole-4-carbaldehyde **8** (2.5 h, 61%), mp 159–160 °C (from toluene) (lit.,[16] 159–161 °C); δ_H([$^2H_6$]DMSO) 9.66 (1H, s), 2.37 (3H, s) and 2.27 (3H, s); δ_C([$^2H_6$]DMSO) (one quaternary missing) 184.84 (br), 147.35 (q, br), 131.46 (q, br), 13.38 and 11.22; 5-methyl-2-phenyl-3*H*-imidazole-4-carbaldehyde **9** (58%), mp 154–154.5 °C (decomp.) (from water) (lit.,[16] 156–158 °C); δ_H 9.75 (1H, s), 8.01–7.96 (2H, m), 7.37–7.34 (3H, m) and 2.50 (3H, s); δ_C (two peaks missing) 150.00 (q), 130.90 (q), 129.97, 128.76, 128.49, 126.22 and 12.34.

Knoevenagel condensation of azolecarbaldehydes with Meldrum's acid

Method (a). 2,2-Dimethyl-1,3-dioxane-4,6-dione (Meldrum's acid) (5 mmol), piperidine (5 drops) and glacial acetic acid (5 drops) were added to the imidazolecarbaldehyde (5 mmol) previously dissolved by heating in the minimum amount of benzene. The solution was stirred overnight at room temperature, unless otherwise stated. The solvent was removed under vacuum and the orange or yellow solid remaining was conveniently washed and recrystallised from ethanol. Alternatively, any solid which appeared was collected by filtration, washed with the filtrate, and then with a little fresh solvent, before being dried *in vacuo*.

The following 5-azolylmethylidene-2,2-dimethyl-1,3-dioxane-4,6-dione derivatives were prepared by this method. The aldehyde used is indicated.

5-(2,5-*Dimethyl*-3H-*imidazol*-4-*ylmethylidene*)-2,2-*dimethyl*-1,3-*dioxane*-4,6-*dione* **12**.—Compound **12** (from 2,5-dimethyl-3*H*-imidazole-4-carbaldehyde **8**) (98%) had mp 209–211 °C (decomp.) (from toluene) (Found: C, 57.6; H, 5.65; N, 11.15. $C_{12}H_{14}N_2O_4$ requires C, 57.6; H, 5.65; N, 11.15%); ν_{max} 3220 (weak), 1730, 1690 and 1575; δ_H 12.61 (1H, br s), 8.24 (1H, s), 2.52 (3H, s), 2.49 (3H, s) and 1.73 (6H, s); δ_C 164.22 (q), 163.63 (q), 160.48 (q), 153.12 (q), 138.78, 124.81 (q), 104.29 (q), 100.15 (q), 27.09, 14.91 and 13.65, *m*/*z* 250 (M^+, 21%), 192 (17), 148 (39), 120 (11), 107 (56), 79 (100), 52 (26) and 42 (23).

5-(2-*Phenyl*-5-*methyl*-3H-*imidazol*-4-*ylmethylidene*)-2,2-*dimethyl*-1,3-*dioxane*-4,6-*dione* **13**.—Compound **13** (from 2-

phenyl-5-methyl-3*H*-imidazole-4-carbaldehyde **9**) (93%) had mp 190–192 °C (from ethanol) (Found: C, 65.4; H, 5.2; N, 8.95. $C_{17}H_{16}N_2O_4$ requires C, 65.4; H, 5.15; N, 8.95%); ν_{max} 3180 (weak), 1735, 1690 and 1550; δ_H 13.38 (1H, br s), 8.30 (1H, s), 7.98 (2H, m), 7.47 (3H, m), 2.38 (3H, s) and 1.76 (6H, s); δ_C 164.56 (q), 163.59 (q), 161.12 (q), 152.60 (q), 138.43, 131.23, 129.08, 127.45 (q), 126.47, 125.88 (q), 104.42 (q), 100.15 (q), 27.12 and 13.87; *m*/*z* 312 (M^+, 42%), 210 (100), 107 (40), 104 (30), 79 (72), 52 (20) and 43 (15).

Method (b). A solution of 5-methyl-3*H*-imidazole-4-carbaldehyde **7** (1.09 g, 10 mmol) in the minimum amount of pyridine (20 cm^3) was treated with 2,2-dimethyl-1,3-dioxane-4,6-dione (Meldrum's acid) (1.46 g, 10 mmol) at room temperature. The precipitate which appeared after approximately 2 h was collected. A further crop of product was collected after 22 h. The solids were washed with water and dried *in vacuo* to give 5-(5-*methyl*-3*H*-*imidazol*-4-*ylmethylidene*)-2,2-*dimethyl*-1,3-*dioxane*-4,6-*dione* **11** (1.00 g, 43%) as a pale yellow solid, mp 218–220 °C (from ethanol) (Found: C, 55.7; H, 5.1; N, 11.9. $C_{11}H_{12}N_2O_4$ requires C, 55.95; H, 5.1; N, 11.85%); ν_{max} 3300, 1730, 1690 and 1580; δ_H 8.35 (1H, d, *J* 1.0), 7.93 (1H, br s), 2.53 (3H, s) and 1.76 (6H, s); δ_C 163.91 (q), 163.29 (q), 158.81 (q), 141.56, 139.90, 124.11 (q), 104.59 (q), 102.06 (q), 27.18 and 13.75; *m*/*z* 178 [$(M - 58)^+$, 14%], 134 (40), 106 (32), 79 (100), 52 (28) and 43 (28).

Other Knoevenagel condensations of azolecarbaldehydes

Method (a) described above was used to prepare the following 2-substituted 3-azolylpropenoates. Reaction was typically carried out on a 1 mmol scale in 5 cm^3 of toluene. The solid products were generally collected by filtration. The aldehyde and active methylene compound used are quoted, together with the reaction time.

Dimethyl 2-(1*H*-imidazol-2-ylmethylidene)malonate 14. Compound **14** (from 1*H*-imidazole-2-carbaldehyde **5**, dimethyl malonate, 7 days) (0.101 g, 48%) had mp 158.5–159 °C (decomp.) (from ethanol) [Found: C, 51.1; H, 4.8; N, 13.1. $C_9H_{10}N_2O_4$ requires C, 51.4; H, 4.8; N, 13.3%. Found $(2M)^+$, 420.1253. $C_{18}H_{20}N_4O_8$ requires (2*M*), 420.1281]; ν_{max} 3165, 1730 and 1720; δ_H($[^2H_6]$DMSO) 7.49 (1H, s), 7.29 (2H, br s) and 3.77 (6H, s), the additional peaks listed below were reproducibly present in the spectrum and have been attributed to the existence of dimer(s) as suggested by the peak in the mass spectrum at *m*/*z* 420 $(2M)^+$; δ_H 7.01 (d, *J* 1.3), 6.95 (d, *J* 1.2), 6.85 (d, *J* 1.3), 6.13 (s), 6.07 (s), 4.90 (d, *J* 5.8), 4.70 (d, *J* 10.0), 4.44 (d, *J* 10.0), 3.98 (d, *J* 5.8), 3.73 (s), 3.67 (s), 3.62 (s) and 3.32 (s); δ_C($[^2H_6]$DMSO) 169.10 (q), 167.65 (q), 167.47 (q), 167.11 (q), 166.88 (q), 164.06 (q), 149.84, 142.02, 141.57, 140.43, 133.02, 128.50, 128.15, 123.02, 117.31, 114.56, 69.30, 68.62, 57.64, 53.99, 53.52, 53.12, 52.85, 52.62, 52.40 and 50.48; *m*/*z* 420 ($2M^+$, 7%), 361 (56), 210 (M^+, 51), 179 (30), 178 (72), 151 (10), 147 (100) and 59 (24).

Methyl (*E*)-2-cyano-3-(1*H*-imidazol-2-yl)propenoate 15. Compound **15** (from 1*H*-imidazole-2-carbaldehyde **5**, methyl cyanoacetate, 1 h) (0.177 g, 100%) had mp 208–209 °C (decomp.) (from ethanol) (Found: C, 53.9; H, 3.9; N, 23.6. $C_8H_7N_3O_2$ requires C, 54.2; H, 4.0; N, 23.7%); ν_{max} 2230, 1725 and 1620; δ_H($[^2H_6]$DMSO) 8.04 (1H, s), 7.54 (2H, s) and 3.83 (3H, s); δ_C($[^2H_6]$DMSO) 162.98 (q), 140.06 (q), 139.55, 128.50, 114.97 (q), 98.18 (q) and 53.07; *m*/*z* 177 (M^+, 54%), 147 (25), 146 (65), 145 (43), 118 (100), 64 (57), 52 (25), 42 (45) and 40 (78).

Methyl (*E*)-2-cyano-3-(3*H*-imidazol-4-yl)propenoate 16. Compound **16** (from 3*H*-imidazole-4-carbaldehyde **6**, methyl cyanoacetate, overnight) (0.165 g, 93%) had mp 172–174 °C (from ethanol) (Found: M^+, 177.0541. $C_8H_7N_3O_2$ requires *M*, 177.0538); δ_H($[^2H_6]$DMSO) 8.19 (1H, s), 8.09 (1H, s), 7.97 (1H, s) and 3.82 (3H, s); δ_C($[^2H_6]$DMSO) 163.26 (q), 146.70, 138.72, 133.95 (q), 127.82, 115.66 (q), 95.94 (q) and 52.49; *m*/*z* 177 (M^+, 100%), 146 (89), 118 (36), 64 (55) and 40 (11).

Methyl 2-cyano-3-(2*H*-pyrazol-3-yl)propenoate 17

Pyrazole-3-carbaldehyde (0.103 g, 1.1 mmol)[8] was dissolved in hot pyridine (2 cm^3). The solution was allowed to cool, methyl cyanoacetate (0.113 g, 1.1 mmol) was added and the solution was stirred at room temperature for 2 days. The solvent was removed and the residue was recrystallised from ethanol to give *methyl* (E)-2-*cyano*-3-(2*H*-*pyrazol*-3-*yl*)*propenoate* **17** (0.127 g, 67%), mp 156–156.5 °C (from ethanol) (Found: C, 54.35; H, 3.95; N, 23.65. $C_8H_7N_3O_2$ requires C, 54.25; H, 4.0; N, 23.7%); ν_{max} 3240, 2220, 1725 and 1620; δ_H 12.12 (1H, br s), 8.32 (1H, s), 7.74 (1H, d, ^3J 2.4), 7.06 (1H, d, ^3J 2.4) and 3.94 (3H, s); δ_C 162.66 (q), 146.40, 144.18 (q), 131.13, 115.73 (q), 109.11, 102.17 (q) and 53.21; *m*/*z* 117 (M^+, 100%), 146 (53), 119 (12), 118 (19) and 91 (5).

Wittig reaction of azolecarbaldehydes

A solution of the appropriate azole-2(4)-carbaldehyde and ylide in dry benzene was heated at reflux under nitrogen for the time stated. The solvent was removed and, unless otherwise stated, the products were obtained by dry flash chromatography of the residue. The following 3-(azolyl)propenoates were obtained by this means. The aldehyde and ylide, volume of solvent, reaction time and the eluent used in the chromatographic separation are quoted.

Ethyl (*E*)-3-(3*H*-imidazol-4-yl)-2-methylpropenoate 18. Compound **18** [from 3*H*-imidazole-4-carbaldehyde **6** (0.190 g, 2.0 mmol), ethyl 2-(triphenylphosphoranylidene)propanoate (0.910 g, 2.5 mmol), 20 cm^3, 4 h, acetone–methylene chloride] (0.253 g, 72%) had mp 128.5–129.5 °C (from toluene) (Found: C, 59.6; H, 6.75; N, 15.4. $C_9H_{12}N_2O_2$ requires C, 60.0; H, 6.70; N, 15.55%); ν_{max} 1710 and 1640; δ_H 7.72 (1H, s), 7.63 (1H, s), 7.30 (1H, s), 4.22 (2H, q, ^3J 7.1), 2.19 (3H, d, ^4J 0.8) and 1.29 (3H, t, ^3J 7.1); δ_C 168.67 (q), 135.94, 134.14 (q), 128.93, 125.19, 123.12 (q), 60.75, 14.27 and 14.14; *m*/*z* 180 (M^+, 51%), 134 (38), 106 (100), 80 (29) and 53 (44).

Ethyl (*E*)-3-(2,5-dimethyl-3*H*-imidazol-4-yl)-2-methylpropenoate 19. Compound **19** [from 2,5-dimethyl-3*H*-imidazole-4-carbaldehyde **8** (0.152 g, 1.2 mmol), ethyl 2-(triphenylphosphoranylidene)propanoate (0.629 g, 1.8 mmol), 20 cm^3, 4 h, acetone–methylene chloride] (0.187 g, 73%) had mp 141–143 °C (Found: C, 63.4; H, 7.55; N, 13.7. $C_{11}H_{16}N_2O_2$ requires C, 63.45; H, 7.75; N, 13.45%); ν_{max} 3480, 1670 and 1640; δ_H 9.14 (1H, br s), 7.43 (1H, q, ^4J 1.1), 4.19 (2H, q, ^3J 7.1), 2.32 (3H, s), 2.22 (6H, s) and 1.28 (3H, t, ^3J 7.1); δ_C 169.31 (q), 145.02 (q), 134.70 (q), 129.12 (q), 127.16, 121.66 (q), 60.44, 14.15, 13.87, 13.64 and 10.81; *m*/*z* 208 (M^+, 100%), 163 (38), 162 (77), 135 (24), 134 (48), 133 (43), 94 (23), 93 (27), 63 (31) and 42 (31).

In the preparation of certain examples of the title compounds, low solubility of the aldehyde in benzene necessitated the use of dry pyridine as solvent. Each aldehyde was dissolved in pyridine by heating and the solution was allowed to cool before addition of the ylide; the usual work-up procedure was followed.

Ethyl (*E*)-3-(1*H*-imidazol-2-yl)-2-methylpropenoate 20. Compound **20** [from 1*H*-imidazole-2-carbaldehyde **5** (0.243 g, 2.5 mmol), ethyl 2-(triphenylphosphoranylidene)propanoate (1.03 g, 2.8 mmol), 12.5 cm^3, 1 h, ethyl acetate–*n*-hexane] (0.350 g, 77%) had mp 155–156.5 °C (from toluene) (Found: C, 59.6; H, 6.6; N, 15.6. $C_9H_{12}N_2O_2$ requires C, 60.0; H, 6.65; N, 15.6%); ν_{max} 3120, 1700 and 1640; δ_H($[^2H_6]$DMSO) 12.48 (1H, br s), 7.39 (1H, q, ^4J 1.3), 7.30 (1H, br s), 7.17 (1H, br s), 4.19 (2H, q, ^3J 7.1), 2.37 (3H, d, ^4J 1.3) and 1.26 (3H, t, ^3J 7.1); δ_C($[^2H_6]$DMSO) 167.68 (q), 143.27 (q), 130.65, 127.12 (q), 124.76, 118.11, 60.37, 14.10 and 13.95; *m*/*z* 180 (M^+, 68%), 135 (37), 106 (100), 80 (7), 53 (15), 42 (12) and 39 (12).

Methyl 3-(1*H*-pyrazol-3-yl)propenoate 21. Compound **21** [from 1*H*-pyrazole-3-carbaldehyde[8] (0.248 g, 2.4 mmol), methyl (triphenylphosphoranylidene)acetate (0.85 g, 2.5 mmol), minimum amount pyridine, 3 h, ethyl acetate–*n*-hexane] (overall yield 0.233 g, 60%, ratio *E* : *Z* = 79 : 21) consisted of the two

isomers *methyl* (E)-3-(1H-*pyrazol*-3-*yl*)*propenoate*, ***E*-21B**, mp 75–76.5 °C [from toluene–light petroleum (bp 40–60 °C)] (Found: C, 55.25; H, 5.35; N, 18.4. $C_7H_8N_2O_2$ requires C, 55.25; H, 5.25; N, 18.4%); ν_{max} 3160, 1715, 1650 and 1540; δ_H 11.68 (1H, br s), 7.70 (1H, d, ^3J 16.2), 7.59 (1H, d, ^3J 2.4), 6.56 (1H, d, ^3J 2.4), 6.43 (1H, d, ^3J 16.2) and 3.79 (3H, s); δ_C 167.15 (q), 135.11, 132.14, 132.02 (q), 119.06, 104.83 and 51.59; *m*/*z* 152 (M^+, 66%), 121 (100), 93 (27), 66 (8) and 39 (33); and *methyl* (Z)-3-(2H-*pyrazol*-3-*yl*)*propenoate*, ***Z*-21A**, mp 46–50 °C (Found: M^+, 152.0581. $C_7H_8N_2O_2$ requires *M*, 152.0586); δ_H 7.57 (1H, d, ^3J 1.6), 6.80 (1H, d, ^3J 12.7), 6.45 (1H, d, ^3J 1.6), 5.88 (1H, d, ^3J 12.7) and 3.78 (3H, s); δ_C 168.15 (q), 139.53, 137.36 (q), 130.35, 115.48, 111.16 and 51.93; *m*/*z* 152 (M^+, 78%), 121 (100), 93 (33), 67 (27), 57 (35), 43 (42) and 39 (23).

Methyl 3-(1*H*-imidazol-2-yl)propenoate. In the reaction of 1*H*-imidazole-2-carbaldehyde **5** (0.49 g, 5.1 mmol) with methyl (triphenylphosphoranylidene)acetate (1.74 g, 5.2 mmol) in pyridine (10 cm^3) over 1 h a modified work-up was used. After thorough removal of the solvent, the residue was taken up as much as possible in methylene chloride (2 cm^3). Filtration gave a solid which was washed with a little fresh methylene chloride and identified as *methyl* (E)-3-(1H-*imidazol*-2-*yl*)*propenoate* ***E*-22** (0.294 g, 38%), mp 210–212 °C (from water) (Found: C, 54.7; H, 5.35; N, 18.2. $C_7H_8N_2O_2{\cdot}0.1H_2O$ requires C, 54.6; H, 5.35; N, 18.2%); λ_{max}(EtOH) (ε/dm^3 mol^{-1} cm^{-1}) 224 (sh) and 306 (13 500); ν_{max} 1710, 1650 and 1560; δ_H([$^2H_6$]DMSO) 12.69 (1H, br s), 7.42 (1H, d, ^3J 16.0), 7.24 (2H, s), 6.57 (1H, d, ^3J 16.0) and 3.72 (3H, s); δ_C([$^2H_6$]DMSO) 166.44 (q), 142.52 (q), 132.66, 124.76, 117.01 and 51.43; *m*/*z* 152 (M^+, 89%), 121 (72), 120 (100), 93 (80), 92 (22), 42 (30) and 39 (18). After the combined filtrate and washings had been evaporated to dryness, the residue was taken up in diethyl ether (10 cm^3) and the triphenylphosphine oxide remaining was removed by filtration. The diethyl ether was removed from the filtrate and the residue was subjected to vacuum sublimation (approx. 100 °C, 0.2 Torr) to yield *methyl* (Z)-3-(1H-*imidazol*-2-*yl*)*propenoate* ***Z*-22** (0.170 g, 22%), mp 62.5–64.5 °C (from *n*-hexane) (Found: C, 55.4; H, 5.25; N, 18.2. $C_7H_8N_2O_2$ requires C, 55.25; H, 5.25; N, 18.4%); λ_{max}(EtOH) (ε/dm^3 mol^{-1} cm^{-1}) 220–225 (sh) and 313–316 (13 500); ν_{max} 3190, 1690 and 1625; δ_H 7.18 (2H, s), 7.01 (1H, d, ^3J 12.8), 5.90 (1H, d, ^3J 12.8) and 3.77 (3H, s); δ_C 168.64 (q), 143.38 (q), 135.0–118.3 (br), 133.99, 114.30 and 51.86; *m*/*z* 152 (M^+, 100%), 121 (52), 120 (92), 93 (69), 92 (24), 46 (28) and 42 (25).

Methyl 3-(3*H*-imidazol-4-yl)propenoate (methyl urocanate) 23

Methyl 3-(3*H*-imidazol-4-yl)propenoate was obtained by esterification of the commercially available propenoic acid (urocanic acid). Urocanic acid **24** (10.06 g, 0.073 mol) was dissolved in warm methanolic hydrogen chloride solution (23% w/v, 75 cm^3) and the solution was heated at reflux for 3 h. The solution was set aside overnight and the white crystalline solid which appeared was collected by filtration. Concentration of the filtrate gave further methyl 3-(3*H*-imidazol-4-yl)propenoate hydrochloride (13.08 g, 96%), mp 232–233 °C (lit.,[9] 233–234 °C); δ_H([$^2H_6$]DMSO) 9.20 (1H, s), 8.05 (1H, s), 7.57 (1H, d, ^3J 16.2), 6.90 (1H, d, ^3J 16.2) and 3.72 (3H, s).

The hydrochloride salt was dissolved in water (90 cm^3). Treatment of this solution with potassium hydroxide (4.20 g) in water (15 cm^3) caused precipitation of the free base which was collected by filtration and dried. The filtrate was extracted continuously with methylene chloride over 12 h. The extract was dried ($MgSO_4$) and the solvent was evaporated to give a further crop of product. Methyl 3-(3*H*-imidazol-4-yl)propenoate **23** (8.92 g, 76% from acid) had mp 93.5–95.5 °C (from ethyl acetate) (lit.,[9] 94–96 °C); λ_{max}(EtOH) (ε/dm^3 mol^{-1} cm^{-1}) 283 (20 900); ν_{max} 3135, 1710 and 1645; δ_H 7.80 (1H, br s), 7.69 (1H, s), 7.59 (1H, d, ^3J 15.8), 7.28 (1H, s), 6.41 (1H, d, ^3J 15.8) and 3.74 (3H, s) (in agreement with literature data[9]); δ_C (one quaternary missing) 167.85 (q), 136.96, 134.76, 122.47, 115.42 and 51.52.

Flash vacuum pyrolysis reactions

Flash vacuum pyrolysis of 5-(azolylmethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione derivatives. Flash vacuum pyrolysis of 5-(azolylmethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione derivatives was carried out by sublimation of the precursor under reduced pressure through an empty silica tube (35 × 2.5 cm) heated by an electrical furnace. The products were collected in a U-tube cooled by liquid nitrogen situated at the exit point of the furnace. Upon completion of the pyrolysis the trap was allowed to warm to room temperature under an atmosphere of dry nitrogen. The brightly coloured product was dissolved in acetone and the solution was removed from the trap. Evaporation of the solvent under reduced pressure gave the product which was then subjected to bulb to bulb (Kugelrohr) distillation. Where distillation was not possible, samples were generally of sufficient purity to give satisfactory elemental analyses. Pyrolysis conditions are reported in the form: precursor (quantity), furnace temperature (T_f), inlet temperature (T_i), pressure (*P*) and pyrolysis time (*t*).

1-Methylpyrrolo[1,2-*c*]imidazol-5-one 25. Compound **25** [from 5-(5-methyl-3*H*-imidazol-4-ylmethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione **11** (0.348 g, 1.5 mmol)] (T_f 650 °C, T_i 120–130 °C, *P* 0.003 Torr, *t* 2 h) (0.182 g, 92%) had bp 48–50 °C (0.1 Torr) (sublimes), mp 108–109 °C (Found: C, 62.9; H, 4.55; N, 20.8. $C_7H_6N_2O$ requires C, 62.7; H, 4.45; N, 20.9%); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 288 (5030) and 381 (2670); ν_{max} 1735 and 1620; δ_H 7.66 (1H, s), 7.26 (1H, d, ^3J 5.9), 5.80 (1H, d, ^3J 5.9) and 2.17 (3H, s); δ_C 162.65 (q), 137.62, 137.59 (q), 134.30, 131.20 (q), 121.73 and 12.95; *m*/*z* 134 (M^+, 100%), 106 (5), 105 (7), 93 (5) and 79 (26).

1,3-Dimethylpyrrolo[1,2-*c*]imidazol-5-one 26. Compound **26** [from 5-(2,5-dimethyl-3*H*-imidazol-4-ylmethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione **12** (0.137 g, 0.55 mmol)] [T_f 650 °C, T_i 100–120 °C, *P* 1–4 × 10^{-4} Torr (diffusion pump), *t* 2 h, residue 0.075 g] (0.044 g, 51%) decomposed on attempted distillation, mp 60–63 °C (decomp.) (Found: C, 61.3; H, 5.75; N, 17.8. $C_8H_8N_2O{\cdot}0.5H_2O$ requires C, 61.15; H, 5.75; N, 17.85%); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 281 (4140) and 394 (2530); δ_H 7.21 (1H, d, ^3J 5.8), 5.69 (1H, d, ^3J 5.8), 2.45 (3H, s) and 2.13 (3H, s); δ_C 163.57 (q), 147.92 (q), 136.91 (q), 136.50, 131.01 (q), 120.82, 13.62 and 12.77; *m*/*z* 148 (M^+, 100%), 119 (6), 107 (14), 79 (73), 52 (22) and 38 (17).

1-Methyl-3-phenylpyrrolo[1,2-*c*]imidazol-5-one 27. Compound **27** [from 5-(5-methyl-2-phenyl-3*H*-imidazol-4-ylmethylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione **13** (0.333 g, 1.1 mmol)] (T_f 650 °C, T_i 120–160 °C, *P* 0.005 Torr, *t* 2 h 30 min, residue 0.104 g) (0.097 g, 43%) had bp 85–90 °C (0.1 Torr) (sublimes), mp 103–105 °C (Found: C, 74.25; H, 4.75; N, 13.25. $C_{13}H_{10}N_2O$ requires C, 74.3; H, 4.75; N, 13.35%); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 253 (18 400), 295 (5910) and 425 (4660); ν_{max} 1735 and 1615; δ_H 8.34 (2H, m), 7.48–7.43 (3H, m), 7.27 (1H, d, ^3J 5.8), 5.76 (1H, dq, ^3J 5.9 and ^6J < 0.5) and 2.22 (3H, d, ^6J < 0.5); δ_C 163.42 (q), 149.96 (q), 137.98 (q), 136.21, 133.19 (q), 131.12, 128.26 (*o*- and *m*-Ph carbon signals), 127.53 (q), 120.84 and 13.06; *m*/*z* 210 (M^+, 100%), 181 (3), 140 (8), 107 (36), 104 (24), 79 (86), 77 (14) and 38 (14).

Pyrolysis of 3-(azolyl)propenoate derivatives. Pyrolysis of the 3-(azolyl)propenoate derivatives was carried out as described above. Upon completion of the pyrolysis the volatile alcohol generated in the reaction was removed into the pump trap by allowing the product trap to warm up partially while the system remained under vacuum. After the removal of the volatiles, the product trap was allowed to warm to room temperature under an atmosphere of nitrogen and the product was worked up in the usual way. The following azapyrrolizinones were prepared by this means. The substrate and pyrolysis parameters are quoted.

Pyrrolo[1,2-*c*]imidazol-5-one 2. Compound **2** [from methyl (*E*)-3-(3*H*-imidazol-4-yl)propenoate ***E*-23** (0.89 g, 5.8 mmol)] (T_f 850 °C, T_i 150–160 °C, *P* 0.001–0.003 Torr, *t* 2 h 30 min)

(0.46 g, 65%) does not melt below 300 °C (decomp.); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 276 (4060) and 366 (2960); δ_H 7.74 (1H, s), 7.30 (1H, d, ^3J 5.9), 6.79 (1H, s) and 5.84 (1H, d, ^3J 5.9) (in agreement with published data[2]).

Pyrrolo[1,2-*a*]imidazol-5-one 3. Compound **3** [from methyl (*Z*)-3-(1*H*-imidazol-2-yl)propenoate ***Z*-22** (0.126 g, 0.83 mmol)] (T_f 800 °C, T_i 40–70 °C, *P* 0.02 Torr, *t* 25 min) (0.090 g, 90%) had bp 65–67 °C (0.1 Torr) [lit.,[2] 90 °C (0.1 Torr)], mp 91–93 °C (lit.,[2] 93–95 °C); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 254 (5360) and 406–409 (710); δ_H 7.21 (1H, d, ^3J 6.2), 7.02 (1H, d, ^3J 1.7), 6.94 (1H, d, ^3J 1.7) and 6.01 (1H, d, ^3J 6.2) (in agreement with published data[2]).

Pyrrolo[1,2-*a*]imidazol-5-one 3. Compound **3** [from methyl (*E*)-3-(1*H*-imidazol-2-yl)propenoate ***E*-22** (0.157 g, 1.0 mmol)] (T_f 850 °C, T_i 150–170 °C, *P* 0.001–0.005 Torr, *t* 1 h) (0.085 g, 69%) had sublimation temperature and ^{1}H NMR spectrum (60 MHz) identical with those of an authentic sample.

6-Methylpyrrolo[1,2-*c*]imidazol-5-one 28. Compound **28** [from ethyl 3-(3*H*-imidazol-4-yl)-2-methylpropenoate **18** (0.032 g, 0.18 mmol)] (T_f 850 °C, T_i 120 °C, *P* 0.005 Torr, *t* 20 min) (0.014 g, 59%) had mp 76–78 °C (Found: C, 61.7; H, 4.75; N, 20.6. $C_7H_6N_2O{\cdot}0.1H_2O$ requires C, 61.85; H, 4.5; N, 20.6%. Found: M$^+$, 134.0485. $C_7H_6N_2O$ requires *M*, 134.0480); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 276 (3920) and 376 (1730); δ_H 7.68 (1H, s), 6.90 (1H, q, ^4J 1.6), 6.62 (1H, s) and 1.89 (3H, d, ^4J 1.6); δ_C (one quaternary missing) 163.65 (q), 134.24, 133.80 (q), 131.44, 124.54 and 10.72; *m*/*z* 134 (M$^+$, 100%), 106 (22), 85 (40), 79 (63), 71 (59), 57 (83), 52 (47) and 43 (57).

1,3,6-Trimethylpyrrolo[1,2-*c*]imidazol-5-one 29. Compound **29** [from ethyl 3-(2,5-dimethyl-3*H*-imidazol-4-yl)-2-methylpropenoate **19** (0.083 g, 0.40 mmol)] (T_f 800 °C, T_i 100–120 °C, *P* 0.001 Torr, *t* 15 min) (0.037 g, 57%) had mp 71–73 °C (decomp.) (Found: C, 65.8; H, 6.65; N, 17.2. $C_9H_{10}N_2O{\cdot}0.15H_2O$ requires C, 65.6; H, 6.30; N, 17.0. Found: M$^+$, 162.0793. $C_9H_{10}N_2O$ requires *M*, 162.0793); λ_{max}(1,4-dioxane) (ε/dm^3 mol^{-1} cm^{-1}) 284 (4320) and 390 (2670); ν_{max} 1735 and 1625; δ_H 6.84 (1H, q, ^4J 1.6), 2.40 (3H, s), 2.06 (3H, s) and 1.89 (3H, d, ^4J 1.6); δ_C 164.51 (q), 147.23 (q), 134.59 (q), 131.03 (q), 130.31, 129.96 (q), 13.72, 12.76 and 10.67; *m*/*z* 162 (M$^+$, 100%), 133 (70), 93 (49), 92 (18), 79 (34), 66 (30), 52 (27), 42 (19) and 39 (16).

6-Methylpyrrolo[1,2-*a*]imidazol-5-one 30. Compound **30** [from ethyl 3-(1*H*-imidazol-2-yl)-2-methylpropenoate **20** (0.098 g, 0.54 mmol)] (T_f 800 °C, T_i 110–120 °C, *P* 0.001 Torr, *t*, 1 h) (0.023 g, 32%) partial decomp. at 180–190 °C, further decomp. at 240–250 °C, bp 57–60 °C (0.2 Torr) (sublimes) (Found: M$^+$, 134.0490. $C_7H_6N_2O$ requires *M*, 134.0480); ν_{max} 1770, 1600 and 1555; δ_H([$^2H_6$] acetone) 7.19 (1H, d, ^3J 1.6), 7.03 (1H, q, ^4J 1.8), 6.95 (1H, d, ^3J 1.6) and 1.95 (3H, d, ^4J 1.8); δ_C (two quaternaries missing) 138.12 (q), 133.46, 129.17, 113.26 and 9.40; *m*/*z* 152 (M + 18, 62%), 134 (M$^+$, 17), 108 (100), 93 (24), 79 (19), 53 (20) and 42 (22) (the NMR spectra showed that the product was essentially pure although the mass spectrum reproducibly gave an M + 18 peak).

Pyrolysis of compounds 14–17 and *E*-21B and *Z*-21A. Pyrolysis of the following compounds at 800 °C gave brightly coloured, insoluble, apparently polymeric solids, which were not characterised: dimethyl (1*H*-imidazol-2-ylmethylidene)-malonate **14**; methyl 2-cyano-3-(1*H*-imidazol-2-yl)propenoate **15** and methyl 2-cyano-3-(3*H*-imidazol-4-yl)propenoate **16**. When the pyrolysis of **15** was repeated with a 'cold finger' trap, the condensed product could be dissolved in acetone at −80 °C, but had decomposed when warmed to −10 °C.

The ^{1}H NMR spectra of the products resulting from the pyrolysis, at the temperatures indicated, of the following pyrazole derivatives, contained no identifiable resonances. The intense colour typical of azapyrrolizinones was generally absent: methyl 2-cyano-3-(3*H*-pyrazol-3-yl)propenoate **17** (T_f 800 °C); methyl (*E*)-3-(1*H*-pyrazol-3-yl)propenoate ***E*21B** (T_f 750–850 °C and methyl (*Z*)-3-(2*H*-pyrazol-3-yl)propenoate ***Z*-21A** (T_f 650–700 °C).

Variable temperature pyrolyses of methyl (*E*)- and (*Z*)-3-(1*H*-imidazol-2-yl)propenoates 22

To investigate the rate controlling process in the pyrolysis of 3-(azolyl)propenoic acid esters, pyrolyses of approximately 0.1 mmol of each of the two stereoisomers of methyl 3-(1*H*-imidazol-2-yl)propenoate **22** was carried out at a number of furnace temperatures. Upon completion of each pyrolysis of the (*Z*)-isomer, the percentage conversion to pyrrolo[1,2-*a*]-imidazol-5-one **3** was determined by washing the trap out with [^{2}H]chloroform and examining the sample by ^{1}H NMR spectroscopy.

The (*E*)-isomer was however insoluble in [^{2}H]chloroform and [$^2H_6$]acetone; the trap was therefore washed out with [$^2H_4$]-methanol and the solution was set aside until all the pyrrolo-[1,2-*a*]imidazol-5-one **3** present had been completely ring opened to [$^2H_3$]methyl (*Z*)-3-(1*H*-imidazol-2-yl)propenoate *i.e.* there was no colour remaining. The percentage of (*Z*)-propenoate present in the sample was then determined by ^{1}H NMR and taken to be the percentage conversion of the (*E*)-isomer **22** to pyrolo[1,2-*a*]imidazol-5-one **3**. Pyrolyses of the (*Z*)-isomer were carried out on a 12–16 mg scale, T_f 450–850 °C, T_i 40–50 °C, *P* 0.001–0.01 Torr, *t* 10–20 min, and those of the (*E*)-isomer on an 8–10 mg scale, T_f 600–850 °C, T_i 150 °C, *P* 0.003–0.04 Torr, *t* 10 min. Results are shown in Fig. 1.

Two additional control experiments were carried out. First, samples from the pyrolysis of methyl (*E*)-3-(1*H*-imidazol-2-yl)propenoate **22** under the following conditions (8 mg, 650 °C, 150 °C, 0.01 Torr: 16 mg, 750 °C, 150 °C, 0.005 Torr) were washed out of the trap with [^{2}H]chloroform and examined by ^{1}H NMR spectroscopy. The (*Z*)-isomer was absent in these samples, showing that, when formed, the (*Z*)-isomer is immediately transformed into the pyrroloimidazolone under these conditions. Second, spectra were recorded for solutions of both (*E*)- and (*Z*)-propenoates in [$^2H_4$]methanol after several days at ambient temperature, and these results showed that no isomerisation occurred in solution.

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