The aza-ene reaction of heterocyclic ketene aminals with enones: an efficient and simple synthetic route to fused di- and tri-heterocycles[1]

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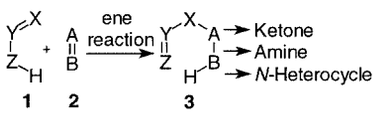
Heterocyclic ketene aminals bearing a secondary amino moiety acted as hetero-ene components to react with a number of enones under very mild conditions. The reaction of five- and six-membered heterocyclic ketene aminals **5** and **8** with methyl vinyl ketone proceeded effectively through the aza-ene addition, imine–enamine tautomerization and intramolecular cyclization to give good yields of 8-aroyl-5-hydroxy-5-methyl-1,2,3,5,6,7-hexahydroimidazo[1,2-*a*]-pyridines **6** and 9-aroyl-6-hydroxy-6-methyl-1,2,3,4,7,8-hexahydroxy-6*H*-pyrido[1,2-*a*]pyrimidines **9**, respectively. When methyl vinyl ketone was present in excess, preliminarily formed product **6** underwent a second aza-ene reaction followed by intramolecular cyclization and water-participating debenzoylation, to yield the *cisoid*-4,9-dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10α-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*][1,8]naphthyridin-10α-ylium benzoate **7** as the sole product. In refluxing acetonitrile, heterocyclic ketene aminals **5** underwent aza-ene addition and cyclocondensation reaction with a number of substituted α,β-unsaturated ketones to afford 1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine derivatives **23** while tricyclic imidazo[1,2-*a*]quinoline derivatives were easily obtained when 2-benzylidene-cyclohexanone and -cyclohexane-1,3-dione were used as enophiles. The effect of the structures of heterocyclic ketene aminals, particularly of the intramolecular hydrogen bond, on the aza-ene reactivity is also discussed.

Introduction

The ene synthesis describes a σ-bond formation from the reaction between an ene component **1** and an enophile **2** with a concomitant 1,5-hydrogen shift and migration of the double bond (Scheme 1). According to the nature of the reactants, the



Scheme 1

ene reaction has been divided into two catagories. An 'all-carbon' ene reaction takes place between an olefin bearing an allylic hydrogen atom (the carba-ene) and an activated alkene or alkyne (the carba-enophile), and a hetero-ene reaction describes that taking place between an ene and enophile, either of which contains at least one heteroatom. Thus, the hetero-ene reactions can be further sub-divided into three types; Type I reactions describe the interaction of all-carba ene components with hetero-enophiles, Type II reactions involve a hetero-ene component and an all-carba enophile, and Type III reactions include those occurring between hetero-ene components and hetero-enophiles.

Due to its synthetic potential and its intriguing reaction mechanism in organic chemistry, the ene reaction has received much attention and great development has been achieved particularly in the past three decades. Both 'all-carbon' ene reactions[2] and the Type I hetero-ene reactions employing hetero-enophiles such as carbonyl and thiocarbonyl compounds,[3] imines,[4] nitroso[5] and azo[6] compounds are well documented. They have been reported to proceed in a stereoselective manner and have very often been utilized in the synthesis of natural products.[7] It has also be shown that most 'all-carbon' ene reactions proceed by a concerted mechanism through a six-membered cyclic transition state under thermal and catalytic conditions.[2,8] Type I hetero-ene and some Lewis-acid-catalyzed ene reactions can be stepwise by way of a zwitterionic intermediate.[2,8] In contrast to these extensively studied 'all-carbon' ene and Type I hetero-ene reactions, however, little is known of the ene reactions involving hetero-ene components, *i.e.* Type II and III hetero-ene reactions. For example, applications of hydrazone[9] (C=N–N–H) and imine[10] (C=N–C–H) functions as the aza-ene components have only been studied briefly while phospha-ene reactions of phosphaalkenes[11] (P=C–C–H) have not been reported until recently. Hetero-ene systems containing a heteroatom at the 2-position such as secondary enamines **1**[12] (X = Y = C, Z = N) and vinyl thiols **1**[13] (X = Y = C, Z = S) (Scheme 1) have been sparingly investigated, with the exception of enols tautomerized from the corresponding ketones, which have been reported to undergo thermal intramolecular ene reactions (the Conia reaction).[14] This is not surprising, however, since hetero-ene components such as secondary enamines and vinyl thiols exist predominantly in the more stable tautomeric forms, as imines[15] and thiocarbonyl compounds,[16] respectively. Therefore they usually act as the hetero-enophiles[3,4] rather than the hetero-ene components. Nevertheless, we envisaged that secondary enamines **1** (X = Y = C, Z = N) or their imine tautomers could be the hetero-ene component provided that the enamine–imine tautomerism shifts to the enamine side. Moreover, the hetero-ene reactions of secondary enamines would provide novel and valuable synthetic approaches to imine intermediates **3** (X = Y = C, Z = N) and to ketones, amines and *N*-heterocycles, respectively, upon hydrolysis, reduction and cyclization of imines (Scheme 1).

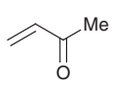
Heterocyclic ketene aminals **5**, **8**, **11** and **13**, also known as cyclic 1,1-enediamines, are powerful and versatile building blocks for the synthesis of various types of compounds that are only accessible with difficulty by other synthetic methods.[17] One of the notable features of heterocyclic ketene aminals is the

enhanced electron density on the α-carbon leading to higher nucleophilicity than that of nitrogen, owing to the conjugation effect of the electron-donating amino groups and the electron-withdrawing substituents.[18] Considerable effort has been made therefore during the past decade to study enaminic reactions such as nucleophilic additions[19] and substitutions[20] with a variety of electrophiles and even 1,3-dipoles.[21] Most noticeably, however, heterocyclic ketene aminals bearing a secondary amino moiety have been shown recently to be a unique aza-ene component and they underwent both Type II and III aza-ene reactions readily when α,β-unsaturated carboxylic acid esters,[22] activated azo[23] and carbonyl[24] compounds were used as carba- and hetero-enophiles, respectively. To examine the scope and limitations of this novel aza-ene component in organic synthesis, we have explored the aza-ene reactions of heterocyclic ketene aminals utilizing a wide range of enophiles. Herein we report a Type II aza-ene reaction of benzoyl-substituted heterocyclic ketene aminals with α,β-unsaturated ketones, a simple and efficient synthetic method for fused di- and tri-*N*-heterocycles.[1]

Results and discussion

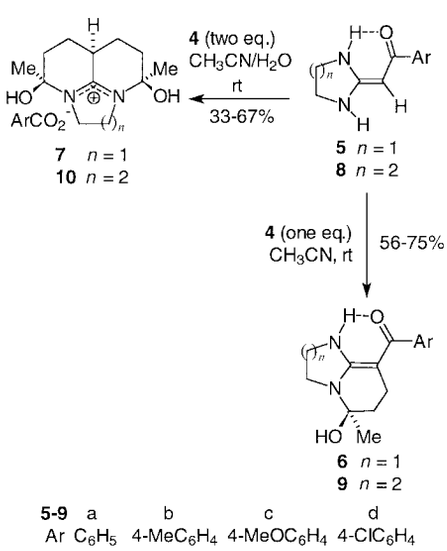
Reaction with methyl vinyl ketone

The *N*-unsubstituted heterocyclic ketene aminals **5** with an imidazolidine ring reacted smoothly with one equivalent of methyl vinyl ketone (MVK) **4** in acetonitrile or ethanol at ambient



4

temperature to give the fused heterocycle **6** as the sole product. Surprisingly, when heated in acetonitrile with or without hydrochloric acid, this *N*,*O*-hemiketal compound **6** did not yield the expected dehydration product. Instead, only a small amount of the hydrochloric acid salt of the heterocyclic ketene aminals was obtained, indicating that a ready fragmentation reaction rather than dehydration of fused heterocycle **6** occurred at the elevated temperature. More amazingly, a fused tricyclic heterocyclic compound **7** was produced from the same reaction when a large excess of MVK **4** (2–5 mol equiv.) was present in the mixture (Scheme 2). The formation of **7** from reactants **4** and **5**

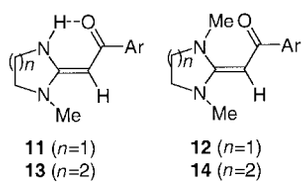


Scheme 2

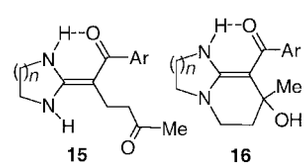
has been found to proceed by way of **6** as it, by treatment with **4**, was converted efficiently into **7**. Most noticeably, this reaction was facilitated by adding several drops of water. It should also be noted that the reaction between **6** and **4** took place in a stereospecific fashion leading to product **7** with the two hydroxy groups orientated *cisoid* to each other (*vide infra*).

Under identical conditions, however, *N*-methylated heterocyclic ketene aminals **11** did not react with **4**. Only an inseparable mixture with an appreciable amount of starting material was formed after the reaction was performed for several hours in refluxing acetonitrile. No reaction at all was observed when *N*,*N*′-dimethylated heterocyclic ketene aminals **12**, the tertiary enamine analogues of **5**, were employed, and only starting material **12** was recovered after seven days' interaction with a large excess of **4**.

Similar results were obtained when six-membered heterocyclic ketene aminals were used. Thus, *N*-unsubstituted compounds **8** underwent addition and cyclization with **4** giving rise to pyrido[1,2-*a*]pyrimidine derivatives **9** while *N*-methylated and *N*,*N*′-dimethylated heterocyclic ketene aminal analogs **13** and **14** were found to be not reactive and they were recovered from the mixture after a long reaction period. In contrast to their five-membered analogs **6**, however, resulting compounds **9** did not undergo further reaction with a second MVK molecule **4**, and no fused triheterocyclic compounds **10** were obtained. Attempts to synthesize **10** either by using more **4** or by heating the mixture have proved unsuccessful.



11 (*n*=1) **12** (*n*=1)
13 (*n*=2) **14** (*n*=2)

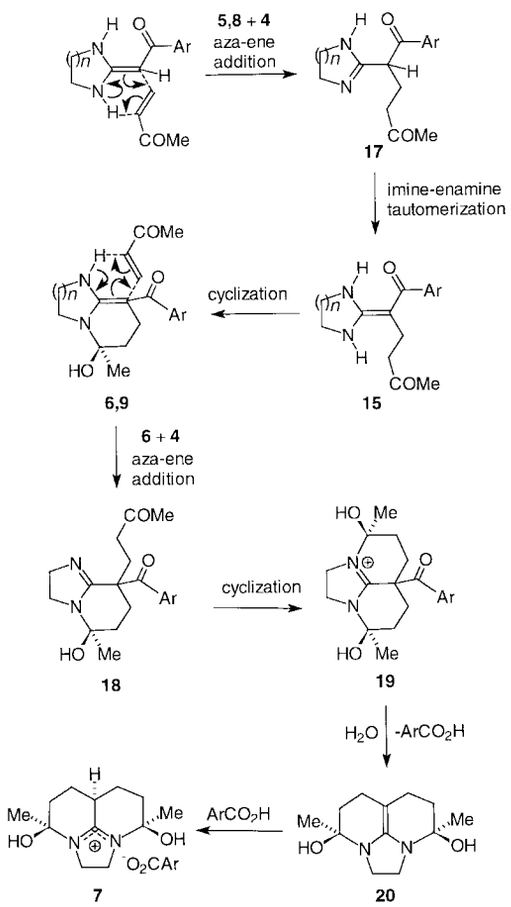


15 **16**

The structures of fused heterocycles **6** and **9** and of tricyclic compounds **7** were established on the basis of spectroscopic evidence and microanalytical data. The observation of only one carbonyl absorption band at around 1570 cm^{-1} in the IR spectra and of only one ketonic carbon signal at 180–187 ppm in the ^{13}C-NMR spectra excluded structure **15** which was the precursor of or the chain tautomer of ring compound **6** or **9**. It is worth noting that the marked bathochromic shift of the carbonyl absorption band to below 1600 cm^{-1}, which is one of the characteristic spectral features of ketene aminals, is due to the effects of the extensive conjugation system involving the 1,1-enediamine segment and the aroyl group and of the formation of an intramolecular hydrogen bond between the aroyl and secondary amino groups.[18] In the ^{1}H-NMR spectrum, signals of ethylene protons of the tetrahydropyridine moiety appeared at higher field (in the range 1.50–2.65 ppm), indicating the ethylene group is not attached to nitrogen. Therefore structure **16** was also ruled out. Hemiketal structures **6** and **9** were further supported by the ^{13}C-NMR spectra in which the quaternary carbon resonated at around 80 ppm. Tricyclic structure **7** was determined unambiguously by X-ray crystallography.[25] Importantly, the single-crystal structure and molecular structure of **7a** revealed that the five-membered ring was almost planar and that both six-membered rings adopted a half-chair conformation with the two hydroxy groups being pseudoaxially bonded at the 4 and 9 positions, respectively. In addition, the *cisoid* hydroxy groups were found to form two strong hydrogen bonds with two oxygen atoms of a benzoate anion from one face of the triheterocycle. It was also concluded from the molecular structure of **7** that the hydroxy group in cyclic hemi-*N*,O-ketal **6** or **9** was attached in an axial position. The preference for the

axial orientation of the hydroxy group is most probably due to the anomeric effect,[26] from which an extra amount of stabilization energy could be gained.

These results suggest that an unusual substituent effect operates during the reaction. Thus with differently *N*-substituted heterocyclic ketene aminals, the reaction differed considerably. It appears essential that the secondary enamine group in the heterocyclic ketene aminals should add to the double bond, since *N*,*N*′-dimethylated cyclic enediamines **12** and **14** did not react with MVK **4**. However, the secondary amino group does not attack the double bond initially, only the *C*-adduct being produced as evidenced by the structure analysis. These facts indicated that the effective reaction unit is the secondary enamine moiety (H–N–C=C) rather than the tertiary enamine. In other words, if the reaction proceeded through the well known Michael addition pathway, *N*,*N*′-dimethylated heterocyclic ketene aminals **12** and **14**, being typical tertiary enamines, would react with **4** to give the desired adducts. It is concluded therefore that the addition of heterocyclic ketene aminals **6** or **8** to MVK **4** most probably proceeds *via* an aza-ene reaction mechanism involving secondary enamine and double bond segments (Scheme 3).



Scheme 3

The mechanism proposed in Scheme 3 best interprets the experimental facts. The aza-ene reaction between heterocyclic ketene aminals **5** or **8** and MVK **4** forms an intermediate **17** which undergoes a rapid imine–enamine tautomerization to give **15**. Intramolecular cyclization of **15** leads to the formation of fused heterocyclic products **6** or **9** with a hydroxy group substituted in an axial position. Starting with *N*,*N*′-dimethylated heterocyclic ketene aminals **12** and **14**, the tertiary enediamine analogues of **5** and **8**, no reaction occurs, simply because of the lack of a secondary enamine moiety (H–N–C=C). The reluctance of mono-*N*-methylated heterocyclic ketene aminals **11** or **13** to interact with the double bond, however,

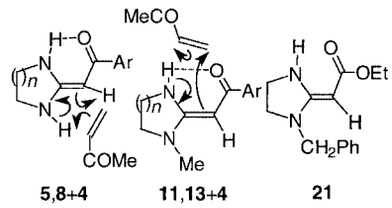


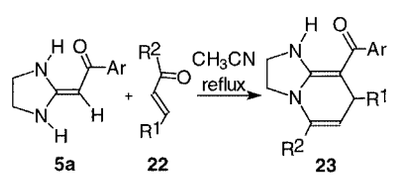
Fig. 1

is entirely different. The only secondary enamine moiety within **11** and **13** forms a very strong intramolecular hydrogen bond with the adjacent carbonyl group. This stabilization effect results in low aza-ene reactivity of the secondary enamine, as the transfer of hydrogen from the amino group to the double bond of enone **4** is highly retarded (Fig. 1). A similar hydrogen-bond effect on the aza-ene reactivity of **11** and **13** has been noted previously during a study of the reaction of heterocyclic ketene aminals with ethyl propiolate,[22] but appeared less salient because ethyl propiolate is a stronger enophile than methyl vinyl ketone. Another important factor determining reactivity of enediamines is the nature of the electron-withdrawing substituents at the α-position. Aroyl-substituted heterocyclic ketene aminals are only moderate nucleophiles, and the same aza-ene addition should occur if more reactive *N*-alkylated heterocyclic ketene aminals were employed. In fact, Jones and Hirst[27] reported in a note that 1-benzyl-2-(ethoxycarbonylmethylene)imidazolidine **21** reacted with **4** readily in warm acetonitrile to give an almost quantitative yield of adduct. Comparison[28] has revealed that the nucleophilicity of ester-substituted enediamines is higher than that of aroyl-substituted analogues including **5**, **8**, **11** and **13**.

Compound **6** undergoes further aza-ene reaction with a second MVK molecule **4** to give dione **18** followed by cyclization to afford amidinium ion **19**. In the presence of water, intermediate **19** undergoes a formal debenzoylation reaction resulting in enediamine **20** and benzoic acid. Being a very electron-rich species,[28] enediamine **20** is readily protonated by benzoic acid to furnish final product **7**. The second aza-ene reaction and/or the following reactions depicted in Scheme 3 appeared to be influenced significantly by the size of the diaza-heterocycle; the reaction is effective and efficient for the fused compounds derived from five-membered heterocyclic ketene aminals **5** but not for those from six-membered analogs **8**. The ring size may play a subtle role in this case in determining the reactivity of **6** and **9** and the stability of tricyclic structures **7** and **10**.

Reaction with other enones

Following MVK **4**, a range of β-phenyl-α,β-unsaturated ketones **22** was examined as enophiles against heterocyclic ketene aminals (Table 1). Not surprisingly, because of the different reasons discussed above, both *N*-methylated and *N*,*N*′-dimethylated heterocyclic ketene aminals **11** and **12** did not react with **22**. Only under harsher conditions, such as in refluxing acetonitrile, did an aza-ene reaction take place between *N*-non-substituted heterocyclic ketene aminal **5a** and **22**. Furthermore, the reaction gave the 1,2,3,7-tetrahydroimidazo-[1,2-*a*]pyridines **23** rather than cyclic *N*,*O*-hemiketals as the sole product, indicating a spontaneous cyclization and dehydration under the heating conditions used (Scheme 4). An interesting



Scheme 4

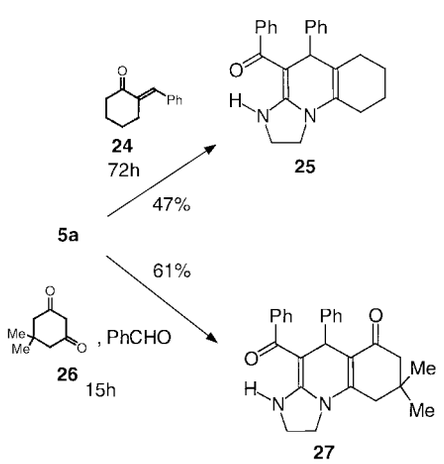
Table 1 Reaction of heterocyclic ketene aminal **5a** with enones **22**

Entry	R^1	R^2	Reaction time (*t*/h)[a]	Yield of **23** (%)[b]
a	Ph	Me	48	57
b	Ph	H	48	33
c	Ph	Ph	48	42
d	Ph	4-$MeOC_6H_4$	48	52
e	Ph	4-MeC_6H_4	48	41
f	Ph	4-ClC_6H_4	48	54
g	Ph	4-BrC_6H_4	48	41
h	4-$NO_2C_6H_4$	Ph	24	45
i	4-FC_6H_4	Ph	48	58
j	4-ClC_6H_4	Ph	48	57
k	4-$MeOC_6H_4$	Ph	48	51
l	4-$Me_2NC_6H_4$	Ph	72	28

[a] Reaction was carried out in refluxing acetonitrile. [b] Isolated yield.

substituent effect on the reaction outcome was observed. As tabulated in Table 1 (entries c–g), the nature of substituent R^2 showed little influence on the reaction, comparable yields being obtained within the same period of time for products **23** in spite of the of use of enones bearing either an electron-rich or -deficient phenyl group. The reaction was equally efficient for both 4-phenylbut-3-en-2-one **22a** (entry a) and cinnamaldehyde **22b** (entry b), though a lower yield was obtained in the latter case due to oligomerization of **22b** under the reaction conditions. In contrast, however, the nature of the β-substituent (R^1) played an important role in determining the reactivity of enones **22** because of the conjugation effect. For example, a *para*-nitrophenyl group rendered enophile **22h** more electron deficient and therefore sped up the aza-ene reaction with **5a** (entry h). With the use of analogue **22l**, which has an electron-donating dimethylamino group, the reaction was retarded and final product **23l**, was afforded only in low yield (entry l). An extreme electronic effect, with no reaction at all, was observed when electron-rich α,β-enones such as 4-methoxybut-3-en-2-one MeOCH=CHCOMe and 3,3-bis(methylthio)-1-phenylprop-2-en-1-one $(MeS)_2C$=CHCOPh were used.

α,β-Unsaturated enones prepared from cyclic ketones and benzaldehyde were found to be good enophiles towards heterocyclic ketene aminals. Thus, the reaction between **5a** and α-benzylidenecyclohexanone **24** proceeded smoothly in hot acetonitrile to yield a condensed triheterocyclic compound **25**. Similarly, imidazo[1,2-*a*]quinoline compound **27** was synthesized accordingly from the enone derived from 5,5-dimethylcyclohexane-1,3-dione **26** and benzaldehyde. Alternatively, preparation[29] of **27** was conveniently accomplished by refluxing a mixture **5a**, **26** and benzaldehyde in acetonitrile (Scheme 5).



Scheme 5

In conclusion, heterocyclic ketene aminals **5** and **8** acted as hetero-ene components to react with a number of enones under mild conditions. The aza-ene addition of **5** or **8** to MVK **4**, followed by imine–enamine tautomerization and intramolecular cyclization, proceeded at room temperature to produce hydroxylated diheterocyclic compounds **6** or **9** in good yield. When **4** was present in excess, a second aza-ene reaction between **6** and **4** took place readily to furnish, after cyclization and water-participating debenzoylation, the corresponding *cisoid*-4,9-dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*][1,8]naphthyridin-10a-ylium benzoate **7**. Triheterocyclic compounds **7** were also prepared efficiently and conveniently by treatment of **5** with an excess of **4** in acetonitrile containing several drops of water. In refluxing acetonitrile, heterocyclic ketene aminal **5a** underwent aza-ene reaction and cyclocondensation with β-phenyl-α,β-unsaturated ketones **22** to give 1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine derivatives **23**. Imidazo[1,2-*a*]quinoline derivatives **25** and **27** were readily synthesized from **5a** when α-benzylidenecyclohexanone and cyclohexane-1,3-dione compounds were used, respectively, as enophiles.

Experimental

Mps, which are uncorrected, were determined using a Reichert Kolfer hot-stage apparatus. IR spectra were obtained on a Perkin-Elmer 782 instrument. NMR spectra were recorded in $CDCl_3$ or [$^2H_6$]DMSO solution with $SiMe_4$ as internal standard on a Varian Unity 200 spectrometer. Chemical shifts are reported in ppm while the coupling-constant *J*-values are in Hz. Mass spectra were measured on AEI MS-50 and KYKY-ZHT-5 mass spectrometers, and microanalyses were carried out at the Analytical Laboratory of this Institute.

General procedure for the reaction of heterocyclic ketene aminals 5 or 8 with methyl vinyl ketone 4

A mixture of heterocyclic ketene aminals **5** or **8** (2 mmol) and MVK **4** (2 mmol) in acetonitrile or ethanol (15 ml) was stirred at room temperature for 15 h. After removal of solvent under vacuum, the residue was recrystallized from a suitable solvent to give pure **6a**–**d** or **9a**–**d**, respectively.

8-Benzoyl-5-hydroxy-5-methyl-1,2,3,5,6,7-hexahydroimidazo[1,2-*a*]pyridine 6a. *White needles* from acetonitrile, yield, 75%, mp 94–96 °C (Found: C, 69.72; H, 7.00; N, 11.01. $C_{15}H_{18}N_2O_2$ requires C, 69.74; H, 7.02; N, 10.85%); ν_{max}(KBr)/cm^{-1} 3350 (OH), 3180 (NH) and 1565 (C=O); δ_H($CDCl_3$) 9.60 (1H, s, NH), 7.30–7.50 (5H, m, ArH), 3.55–3.70 (4H, m, 2 × CH_2), 2.85 (1H, s, OH), 2.30–2.60 (2H, m, CH_2), 1.75–1.96 (2H, m, CH_2) and 1.50 (3H, s, CH_3); δ_C($CDCl_3$) 187.4 (*C*=O), 160.9 (NN*C*=C), 142.5, 128.2, 127.7, 126.9 (aromatic carbons), 83.9 (NNC=*C*), 80.5 (O*C*N), 42.1, 41.9, 36.8, 25.9 and 20.7; *m*/*z* (EI) 258 (M^+, 2%), 239 (100), 225 (37) and 135 (86).

5-Hydroxy-5-methyl-8-(*p*-methylbenzoyl)-1,2,3,5,6,7-hexahydroimidazo[1,2-*a*]pyridine 6b. *White needles* from acetonitrile–ethanol, yield, 68%, mp 156–158 °C (from acetonitrile–ethanol) (Found: C, 70.54; H, 7.36; N, 10.38. $C_{16}H_{20}N_2O_2$ requires C, 70.56; H, 7.40; N, 10.29%); ν_{max}(KBr)/cm^{-1} 3350 (OH), 3100 (NH) and 1560 (C=O); δ_H([$^2H_6$]DMSO) 9.45 (1H, s, NH), 7.24 (2H, d, *J* 6.1, ArH), 7.15 (2H, d, *J* 6.1, ArH), 5.64 (1H, s, OH), 3.54 (4H, s, 2 × CH_2), 2.32 (3H, s, CH_3), 2.10–2.50 (2H, m, CH_2), 1.50–1.76 (2H, m, CH_2) and 1.38 (3H, s, CH_3); δ_C([$^2H_6$]DMSO) 185.7 (*C*=O), 160.3 (NN*C*=C), 140.5, 137.1, 128.1, 126.8 (aromatic carbons), 82.8 (NNC=*C*), 79.3 (O*C*N), 41.8, 41.6, 36.7, 26.4, 20.9 and 20.8; *m*/*z* (EI) 272 (M^+, 1%), 253 (76), 239 (100) and 135 (67).

5-Hydroxy-8-(*p*-methoxylbenzoyl)-5-methyl-1,2,3,5,6,7-hexahydroimidazo[1,2-*a*]pyridine 6c. *White needles* from acetonitrile–ethanol, yield, 63%, mp 147–149 °C (Found: C, 66.54; H, 6.98; N, 9.76. $C_{16}H_{20}N_2O_3$ requires C, 66.64; H, 6.99; N, 9.72%); ν_{max}(KBr)/cm^{-1} 3360 (OH), 3180 (NH) and 1570 cm^{-1} (C=O); δ_H([$^2H_6$]DMSO) 9.45 (1H, s, NH), 7.35 (2H, d, *J* 8.9, ArH), 6.90 (2H, d, *J* 8.9, ArH), 5.64 (1H, s, OH), 3.76 (3H, s, OCH_3), 3.52 (4H, s, 2 × CH_2), 2.40–2.60 (1H, m, CH*H*), 2.15–2.30 (1H, m, C*H*H), 1.50–1.76 (2H, m, CH_2) and 1.38 (3H, s, CH_3); δ_C([$^2H_6$]DMSO) 185.1 (*C*=O), 160.3 (NN*C*=C), 159.0, 135.6, 128.5, 112.8 (aromatic carbons), 82.8 (NNC=*C*), 79.3 (O*C*N), 55.1, 41.8, 41.6, 36.7, 26.4 and 21.0; *m*/*z* (EI) 288 (M^+, 1%), 269 (52), 255 (61), 239 (30) and 135 (100).

8-(*p*-Chlorobenzoyl)-5-hydroxy-5-methyl-1,2,3,5,6,7-hexahydroimidazo[1,2-*a*]pyridine 6d. *White needles* from acetonitrile–ethanol, yield, 56%, mp 152–154 °C (Found: C, 61.28; H, 5.89; N, 9.63. $C_{15}H_{17}ClN_2O_2$ requires C, 61.53; H, 5.85; N, 9.57%); ν_{max}(KBr)/cm^{-1} 3350 (OH), 3180 (NH) and 1570 (C=O); δ_H([$^2H_6$]DMSO) 9.40 (1H, s, NH), 7.40 (2H, d, *J* 7.6, ArH), 7.34 (2H, d, *J* 7.6, ArH), 5.66 (1H, s, OH), 3.54 (4H, s, 2 × CH_2), 2.05–2.55 (2H, m, CH_2), 1.50–1.80 (2H, m, CH_2) and 1.38 (3H, s, CH_3); δ_C([$^2H_6$]DMSO) 184.0 (*C*=O), 160.4 (NN*C*=C), 142.1, 132.5, 128.8, 127.8 (aromatic carbons), 82.9 (NNC=*C*), 79.5 (O*C*N), 41.9, 41.7, 36.7, 26.4 and 20.8; *m*/*z* (EI) 292 (M^+, 1%), 273 (77), 261 (33), 259 (100) and 135 (76).

9-Benzoyl-6-hydroxy-6-methyl-1,2,3,4,7,8-hexahydro-6*H*-pyrido[1,2-*a*]pyrimidine 9a. *White needles* from acetonitrile–ethanol, yield, 72%, mp 165–167 °C (Found: C, 70.53; H, 7.36; N, 10.26. $C_{16}H_{20}N_2O_2$ requires C, 70.56; H, 7.40; N, 10.29%); ν_{max}(KBr)/cm^{-1} 3360 (OH), 3010 (NH) and 1570 (C=O); δ_H([$^2H_6$]DMSO) 12.66 (1H, s, NH), 7.20–7.40 (5H, m, ArH), 5.70 (1H, s, OH), 3.20–3.60 (4H, m, 2 × CH_2), 2.18 (2H, t, *J* 8.4, CH_2), 1.84 (2H, quintet, *J* 8.4, CH_2), 1.66 (2H, t, *J* 8.4, CH_2) and 1.32 (3H, s, CH_3); δ_C($CDCl_3$) 182.4 (*C*=O), 157.1 (NN*C*=C), 144.1, 127.7, 127.2, 126.7 (aromatic carbons), 84.7 (NNC=*C*), 82.6 (O*C*N), 38.1, 37.6, 37.4, 25.5, 21.8 and 20.7; *m*/*z* (EI) 272 (M^+, 4%), 252 (11), 239 (19), 215 (24), 202 (79), 187 (49) and 125 (100).

6-Hydroxy-6-methyl-9-(*p*-methylbenzoyl)-1,2,3,4,7,8-hexahydro-6*H*-pyrido[1,2-*a*]pyrimidine 9b. *White needles* from acetonitrile–ethanol, yield, 61%, mp 169–171 °C (Found: C, 71.38; H, 7.75; N, 9.79. $C_{17}H_{22}N_2O_2$ requires C, 71.30; H, 7.75; N, 9.78%); ν_{max}(KBr)/cm^{-1} 3380 (OH), 3060 (NH) and 1575 (C=O); δ_H([$^2H_6$]DMSO) 12.72 (1H, s, NH), 7.15 (4H, s, ArH), 5.72 (1H, s, OH), 3.20–3.60 (4H, m, 2 × CH_2), 2.30 (3H, s, CH_3), 2.10 (2H, t, *J* 6.9, CH_2), 1.84 (2H, quintet, *J* 6.9, CH_2), 1.66 (2H, t, *J* 6.9, CH_2) and 1.32 (3H, s, CH_3); δ_C($CDCl_3$) 182.5 (*C*=O), 157.1 (NN*C*=C), 141.3, 136.4, 128.2, 126.8 (aromatic carbons), 84.7 (NNC=*C*), 82.6 (O*C*N), 38.1, 37.6, 37.5, 25.6, 21.9, 21.0 and 20.8; *m*/*z* (EI) 286 (M^+, 2%), 268 (11), 253 (20), 215 (100), 201 (55), 187 (70) and 125 (97).

6-Hydroxy-9-(*p*-methoxybenzoyl)-6-methyl-1,2,3,4,7,8-hexahydro-6*H*-pyrido[1,2-*a*]pyrimidine 9c. *White needles* from acetonitrile–ethanol, yield, 63%, mp 149–151 °C (Found: C, 67.47; H, 7.35; N, 9.42. $C_{17}H_{22}N_2O_3$ requires C, 67.52; H, 7.32; N, 9.27%); ν_{max}(KBr)/cm^{-1} 3330 (OH), 3140 (NH) and 1570 (C=O); δ_H([$^2H_6$]DMSO) 12.78 (1H, s, NH), 7.22 (2H, d, *J* 7.5, ArH), 6.86 (2H, d, *J* 7.5, ArH), 5.72 (1H, s, OH), 3.76 (3H, s, OCH_3), 3.20–3.60 (4H, m, 2 × CH_2), 2.24 (2H, t, *J* 6.8, CH_2), 1.84 (2H, quintet, *J* 6.8, CH_2), 1.68 (2H, t, *J* 6.8, CH_2) and 1.32 (3H, s, CH_3); δ_C($CDCl_3$) 182.0 (*C*=O), 157.0 (NN*C*=C), 158.4, 136.4, 128.3, 112.8 (aromatic carbons), 84.7 (NNC=*C*), 82.4 (O*C*N), 55.0, 38.0, 37.5, 37.4, 25.4, 21.9 and 20.7; *m*/*z* (EI) 302 (M^+, 1%), 284 (6), 269 (16), 231 (100) and 204 (45).

9-(*p*-Chlorobenzoyl)-6-hydroxy-6-methyl-1,2,3,4,7,8-hexahydro-6*H*-pyrido[1,2-*a*]pyrimidine 9d. *White needles* from acetonitrile–ethanol, yield, 78%, mp 168–170 °C (Found: C, 62.43; H, 6.13; N, 9.48. $C_{16}H_{19}ClN_2O_2$ requires C, 62.63; H, 6.24; N, 9.13%); ν_{max}(KBr)/cm^{-1} 3360 (OH), 3080 (NH) and 1560 (C=O); δ_H([$^2H_6$]DMSO) 12.62 (1H, s, NH), 7.36 (2H, d, *J* 8.8, ArH), 7.26 (2H, d, *J* 8.8, ArH), 5.78 (1H, s, OH), 3.20–3.60 (4H, m, 2 × CH_2), 2.18 (2H, t, *J* 6.9, CH_2), 1.86 (2H, quintet, *J* 6.9, CH_2), 1.70 (2H, t, *J* 6.9, CH_2) and 1.32 (3H, s, CH_3); δ_C($CDCl_3$) 180.6 (*C*=O), 157.1 (NN*C*=C), 142.8, 131.8, 128.7, 127.7 (aromatic carbons), 84.9 (NNC=*C*), 82.6 (O*C*N), 38.1, 37.6, 37.3, 25.5, 21.7 and 20.6; *m*/*z* (EI) 306 (M^+, 1%), 288 (7), 273 (15), 236 (65) and 125 (100).

General procedure for the synthesis of 4,9-dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*]-[1,8]naphthyridin-10a-ylium salts 7

To a mixture of a heterocyclic ketene aminal **5a**–**d** (2 mmol) and MVK **4** (5 mmol) in acetonitrile (15 ml) were added several drops of water. The mixture was then stirred at room temperature and the reaction course was monitored by TLC. After both reactant **5** and product **6** had been converted into final product **7**, the solvent was removed under reduced pressure. The oily residue solidified when mixed with a small amount of ethyl acetate and cooled in a refrigerator. Further purification by recrystallization in a solvent mixture of ethyl acetate and ethanol gave the corresponding tricycle **7a**–**d** as white crystals.

4,9-Dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*]naphthyridin-10a-ylium benzoate 7a. Yield, 59%, mp 109–111 °C (Found: C, 65.91; H, 7.14; N, 8.01. $C_{19}H_{26}N_2O_4$ requires C, 65.87; H, 7.57; N, 8.09%); ν_{max}(KBr)/cm^{-1} 3360, 3070 (OH), 1580 and 1360 (COO^-); δ_H($CDCl_3$) 8.32 (2H, br s, 2 × OH), 7.95–8.05 (2H, m, ArH), 7.30–7.40 (3H, m, ArH), 4.22 (2H, t, *J* 9.3, CH_2), 3.70 (2H, t, *J* 9.3, CH_2), 2.10–2.30 (5H, m, 2 × CH_2, CH), 1.68–1.95 (4H, m, 2 × CH_2) and 1.52 (6H, s, 2 × CH_3); δ_C($CDCl_3$) 171.8 (*C*OO^-), 167.4 (N*C*N), 137.4, 129.7, 129.1, 127.4 (aromatic carbons), 83.0 (O*C*N), 42.0, 36.7, 34.6, 27.1 and 20.9; *m*/*z* (FAB) 225 (M^+) and 121 ($C_6H_5COO^-$); *m*/*z* (EI) 206 (10%), 191 (2), 163 (6), 135 (100) and 122 (39).

4,9-Dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*]naphthyridin-10*a*-ylium 4-methylbenzoate 7b. Yield, 58%, mp 112–114 °C (Found: C, 66.57; H, 7.87; N, 7.77. $C_{20}H_{28}N_2O_4$ requires C, 66.64; H, 7.83; N, 7.77%); ν_{max}(KBr)/cm^{-1} 3120 (OH), 1580 and 1360 (COO^-); δ_H($CDCl_3$) 7.88 (2H, d, *J* 7.9, ArH), 7.12 (2H, d, *J* 7.9, ArH), 4.26 (2H, t, *J* 8.9, CH_2), 3.72 (2H, t, *J* 8.9, CH_2), 2.36 (3H, s, CH_3), 2.10–2.30 (5H, m, 2 × CH_2, CH), 1.68–1.95 (4H, m, 2 × CH_2) and 1.52 (6H, s, 2 × CH_3); δ_C($CDCl_3$) 172.2 (*C*OO^-), 167.5 (N*C*N), 139.7, 134.8, 129.3, 128.2 (aromatic carbons), 83.1 (O*C*N), 42.1, 37.0, 35.0, 27.3, 21.3 and 21.1; *m*/*z* (EI) 206 (15%), 191 (3), 163 (10), 136 (65) and 135 (100).

4,9-Dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*]naphthyridin-10*a*-ylium 4-methoxybenzoate 7c. Yield, 66.5%, mp 110–112 °C (Found: C, 63.70; H, 7.03; N, 7.36. $C_{20}H_{28}N_2O_5$ requires C, 63.81; H, 7.50; N, 7.44%); ν_{max}(KBr)/cm^{-1} 3460, 3060 (OH), 1570 and 1355 (COO^-); δ_H($CDCl_3$) 7.96 (2H, d, *J* 9.0, ArH), 6.84 (2H, d, *J* 9.0, ArH), 4.26 (2H, t, *J* 9.0, CH_2), 3.80 (3H, s, OCH_3), 3.74 (2H, t, *J* 9.0, CH_2), 2.15–2.35 (5H, m, 2 × CH_2, CH), 1.68–1.95 (4H, m, 2 × CH_2) and 1.52 (6H, s, 2 × CH_3); δ_C($CDCl_3$) 172.0 (*C*OO^-), 167.6 (N*C*N), 160.9, 130.9, 130.2, 112.6 (aromatic carbons), 83.2 (O*C*N), 55.1, 42.1, 37.0, 35.0, 27.3 and 21.1; *m*/*z* (EI) 206 (13%), 191 (3), 163 (9), 152 (99) and 135 (100).

4,9-Dihydroxy-4,9-dimethyl-1,2,5,6,6a,7,8,10a-octahydro-4*H*,9*H*-imidazo[1,2,3-*ij*]naphthyridin-10*a*-ylium 4-chlorobenzoate 7d. Yield 33%, mp 98–100 °C (Found: C, 60.03; H, 6.64; N, 7.23. $C_{19}H_{25}ClN_2O_4$ requires C, 59.91; H, 6.62; N, 7.36%); ν_{max}(KBr)/cm^{-1} 3340, 3150 (OH), 1580 and 1360 (COO$^-$); δ_H($CDCl_3$) 7.92 (2H, d, *J* 8.4, ArH), 7.30 (2H, d, *J* 8.4, ArH), 4.26 (2H, t, *J* 9.2, CH_2), 3.74 (2H, t, *J* 9.2, CH_2), 2.15–2.35 (5H, m, 2 × CH_2, CH), 1.70–1.95 (4H, m, 2 × CH_2) and 1.54 (6H, s, 2 × CH_3); δ_C($CDCl_3$) 170.8 (*C*OO$^-$), 167.4 (N*C*N), 136.2, 135.6, 130.6, 127.5 (aromatic carbons), 83.1 (O*C*N), 42.1, 36.8, 34.8, 27.1 and 20.9; *m*/*z* (EI) 206 (14%), 191 (3), 163 (10), 156 (39), 139 (47) and 135 (100)

General procedure for the reaction of heterocyclic ketene aminal 5a with other enones 22

A mixture of heterocyclic ketene aminal **5a** (2 mmol) and a β-phenyl-α,β-unsaturated ketone **22** (2 mmol) in CH_3CN (20 ml) was refluxed for 15–72 h. After removal of solvent under vacuum the residue was chromatographed on a silica gel column with eluent of chloroform–methanol (50 : 1) as eluent to give products **23**.

8-Benzoyl-5-methyl-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23a. *White crystals*, yield, 57%, mp 160–162 °C (Found: C, 79.85; H, 6.56; N, 8.97. $C_{21}H_{20}N_2O$ requires C, 79.71; H, 6.37; N, 8.86%); ν_{max}(KBr)/cm^{-1} 3260 (NH), 1675, 1605 (C=O), 1525 and 1490; δ_H($CDCl_3$) 9.42 (1H, s, NH), 6.95–7.25 (8H, m, ArH), 6.70–6.80 (2H, m, ArH), 4.76 (1H, d, *J* 5.6, CH), 4.30 (1H, d, *J* 5.6, CH), 3.70–3.90 (4H, m, 2 × CH_2) and 1.88 (3H, s, CH_3); δ_C($CDCl_3$) 192.8 (*C*=O), 158.4 (NN*C*=C), 148.9 (N*C*=C), 142.6, 129.5, 128.0, 127.8, 127.6, 127.0, 126.1, 125.5 (aromatic carbons), 106.6 (NC=*C*), 87.4 (NNC=*C*), 44.7, 42.6, 41.0 and 17.9; *m*/*z* (EI) 316 (M$^+$, 35%), 301 (5), 239 (100) and 211 (60).

8-Benzoyl-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23b. *White crystals*, yield, 33%, mp 163–165 °C (Found: C, 79.24; H, 6.08; N, 9.28. $C_{20}H_{18}N_2O$ requires C, 79.44; H, 6.00; N, 9.27%); ν_{max}(KBr)/cm^{-1} 3370 (NH), 1665, 1600 (C=O), 1515 and 1485; δ_H($CDCl_3$) 9.24 (1H, s, NH), 7.00–7.30 (8H, m, ArH), 6.75–6.85 (2H, m, ArH), 5.98 (1H, d, *J* 5.9, CH), 5.08 (1H, dd, *J* 5.9, 5.3, CH), 4.36 (1H, d, *J* 5.3, CH) and 3.60–3.90 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.9 (*C*=O), 158.2 (NN*C*=C), 148.2 (N*C*=C), 142.4, 128.1, 128.0, 127.7, 127.0, 126.2, 125.8, 122.9 (aromatic carbons), 110.6 (NC=*C*), 87.5 (NNC=*C*), 46.9, 42.6 and 40.5; *m*/*z* (EI) 302 (M$^+$, 26%), 225 (100) and 197 (25).

8-Benzoyl-5,7-diphenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23c. *White crystals*, yield, 42%, mp 138–140 °C (Found: C, 82.49; H, 6.02; N, 7.46. $C_{26}H_{22}N_2O$ requires C, 82.51; H, 5.86; N, 7.40%); ν_{max}(KBr)/cm^{-1} 3310 (NH), 1665, 1610 (C=O), 1520 and 1490; δ_H($CDCl_3$) 9.60 (1H, s, NH), 7.34 (5H, s, ArH), 7.05–7.30 (8H, m, ArH), 6.80–6.90 (2H, m, ArH), 5.00 (1H, d, *J* 5.0, CH), 4.48 (1H, d, *J* 5.0, CH) and 3.40–3.85 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 193.3 (*C*=O), 159.1 (NN*C*=C), 148.8 (N*C*=C), 142.9, 136.0, 135.8, 128.7, 128.6, 128.5, 128.4, 128.0, 127.8, 127.5, 126.5, 126.0 (aromatic carbons), 110.9 (NC=*C*), 87.9 (NNC=*C*), 46.8, 42.9 and 41.8; *m*/*z* (EI) 378 (M$^+$, 21%), 301 (100) and 273 (43).

8-Benzoyl-5-(4-methoxyphenyl)-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23d. *Pale yellow crystals*, yield, 52%, mp 143–145 °C (Found: C, 79.28; H, 5.98; N, 6.86. $C_{27}H_{24}N_2O_2$ requires C, 79.38; H, 5.92; N, 6.86%); ν_{max}(KBr)/cm^{-1} 3280 (NH), 1665, 1605 (C=O), 1515 and 1485; δ_H($CDCl_3$) 9.58 (1H, s, NH), 7.05–7.25 (10H, m, ArH), 6.80–6.90 (4H, m, ArH), 4.96 (1H, d, *J* 5.9, CH), 4.44 (1H, d, *J* 5.9, CH), 3.78 (3H, s, OCH_3), 3.40–3.80 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.8 (*C*=O), 158.7 (NN*C*=C), 148.5 (N*C*=C), 159.5, 142.5, 135.1, 129.4, 128.0, 127.9, 127.8, 127.6, 127.1, 126.1, 125.5, 113.5 (aromatic carbons), 109.9 (NC=*C*), 87.5 (NNC=*C*), 55.2, 46.3, 42.4 and 41.4; *m*/*z* (EI) 408 (M$^+$, 23%), 331 (100) and 303 (43).

8-Benzoyl-5-(4-methylphenyl)-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23e. *Pale yellow crystals*, yield, 41%, mp 115–117 °C (Found: C, 82.39; H, 6.19; N, 7.11. $C_{27}H_{24}N_2O$ requires C, 82.62; H, 6.16; N, 7.14%); ν_{max}(KBr)/cm^{-1} 3330 (NH), 1665, 1605 (C=O), 1520 and 1490; δ_H($CDCl_3$) 9.60 (1H, s, NH), 7.05–7.25 (12H, m, ArH), 6.78–6.88 (2H, m, ArH), 4.98 (1H, d, *J* 5.4, CH), 4.48 (1H, d, *J* 5.4, CH), 3.40–3.80 (4H, m, 2 × CH_2) and 2.36 (3H, s, CH_3); δ_C($CDCl_3$) 192.9 (*C*=O), 158.8 (NN*C*=C), 148.5 (N*C*=C), 142.6, 138.2, 135.5, 132.5, 128.9, 128.5, 128.4, 128.0, 127.7, 127.2, 126.2, 125.6 (aromatic carbons), 110.2 (NC=*C*), 87.6 (NNC=*C*), 46.4, 42.5, 41.4 and 21.1; *m*/*z* (EI) 392 (M$^+$, 21%), 361 (6), 315 (100) and 287 (46).

8-Benzoyl-5-(4-chlorophenyl)-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23f. *Pale yellow crystals*, yield, 54%, mp 155–157 °C (Found: C, 75.51; H, 5.21; N, 6.77. $C_{26}H_{21}ClN_2O$ requires C, 75.63; H, 5.13; N, 6.79%); ν_{max}(KBr)/cm^{-1} 3280 (NH), 1660, 1605 (C=O), 1515 and 1490; δ_C($CDCl_3$) 9.60 (1H, s, NH), 7.05–7.35 (12H, m, ArH), 6.78–6.88 (2H, m, ArH), 5.00 (1H, d, *J* 5.1, CH), 4.46 (1H, d, *J* 5.1, CH) and 3.40–3.80 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 193.1 (*C*=O), 158.6 (NN*C*=C), 148.2 (N*C*=C), 142.4, 134.6, 134.3, 133.8, 129.5, 128.5, 128.1, 128.0, 127.7, 127.2, 126.1, 125.7 (aromatic carbons), 111.0 (NC=*C*), 87.5 (NNC=*C*), 46.4, 42.5 and 41.4; *m*/*z* (EI) 414/412 (M$^+$, 8/23%), 335 (100) and 307 (52).

8-Benzoyl-5-(4-bromophenyl)-7-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23g. *Pale yellow crystals*, yield, 41%, mp 111–113 °C (Found: C, 68.18; H, 4.86; N, 6.06. $C_{26}H_{21}BrN_2O$ requires C, 68.27; H, 4.63; N, 6.13%); ν_{max}(KBr)/cm^{-1} 3280 (NH), 1665, 1605 (C=O), 1515 and 1490; δ_H($CDCl_3$) 9.60 (1H, s, NH), 7.48 (2H, d, *J* 9.0, ArH), 7.05–7.30 (10H, m, ArH), 6.78–6.88 (2H, m, ArH), 5.00 (1H, d, *J* 6.2, CH), 4.46 (1H, d, *J* 6.2, CH) and 3.40–3.85 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 193.1 (*C*=O), 158.6 (NN*C*=C), 148.2 (N*C*=C), 142.4, 134.7, 134.3, 131.5, 129.7, 128.1, 128.0, 127.7, 127.2, 126.1, 125.7, 122.4 (aromatic carbons), 111.0 (NC=*C*), 87.4 (NNC=*C*), 46.4, 42.5 and 41.4; *m*/*z* (EI) 458/456 (M$^+$, 23/24%), 379 (100), 351 (55) and 301 (14).

8-Benzoyl-7-(4-nitrophenyl)-5-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23h. *Orange crystals*, yield, 45%, mp 154–156 °C (Found: C, 73.72; H, 5.40; N, 9.97. $C_{26}H_{21}N_3O_3$ requires C, 73.74; H, 5.60; N, 9.92%); ν_{max}(KBr)/cm^{-1} 3300 (NH), 1660, 1605 (C=O), 1515 and 1345 (NO_2); δ_H($CDCl_3$) 9.62 (1H, s, NH), 7.96 (2H, d, *J* 7.2, ArH), 7.00–7.35 (10H, m, ArH), 6.96 (2H, d, *J* 7.2, ArH), 4.90 (1H, d, *J* 6.1, CH), 4.68 (1H, d, *J* 6.1, CH) and 3.40–3.90 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.7 (*C*=O), 158.5 (NN*C*=C), 145.9 (N*C*=C), 155.7, 142.2, 136.8, 134.9, 128.7, 128.4, 128.3, 128.1, 128.0, 127.9, 125.9, 123.4 (aromatic carbons), 108.5 (NC=*C*), 86.5 (NNC=*C*), 46.4, 42.5 and 41.7; *m*/*z* (EI) 423 (M$^+$, 89%), 392 (31), 360 (30), 318 (34) and 301 (100).

8-Benzoyl-7-(4-fluorophenyl)-5-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23i. *Pale yellow crystals*, yield, 58%, mp 198–200 °C (Found: C, 78.85; H, 5.36; N, 7.02. $C_{26}H_{21}FN_2O$ requires C, 78.76; H, 5.34; N, 7.07%); ν_{max}(KBr)/cm^{-1} 3300 (NH), 1655, 1610 (C=O), 1525 and 1485; δ_H($CDCl_3$) 9.58 (1H, s, NH), 7.34 (5H, s, ArH), 7.05–7.30 (5H, m, ArH), 6.76 (4H, d, *J* 9.3, ArH), 4.96 (1H, d, *J* 5.6, CH), 4.48 (1H, d, *J* 5.6, CH) and 3.40–3.80 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.9 (*C*=O), 158.6 (NN*C*=C), 144.3 (N*C*=C), 163.4, 142.5, 135.7, 135.3, 128.6, 128.4, 128.3, 128.0, 127.7, 126.0, 114.8, 114.4 (aromatic carbons), 110.2 (NC=*C*), 87.5 (NNC=*C*), 46.4, 42.5 and 40.7; *m*/*z* (EI) 396 (M$^+$, 38%), 319 (4), 301 (100) and 291 (57).

8-Benzoyl-7-(4-chlorophenyl)-5-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23j. *Pale yellow crystals*, yield, 57%, mp 130–132 °C (Found: C, 75.58; H, 5.29; N, 6.82. $C_{26}H_{21}ClN_2O$ requires C, 75.63; H, 5.13; N, 6.79%); ν_{max}(KBr)/cm^{-1} 3320 (NH), 1655, 1610 (C=O), 1525 and 1485; δ_H($CDCl_3$) 9.58 (1H, s, NH), 7.34 (5H, s, ArH), 7.05–7.30 (7H, m, ArH), 6.74 (2H, d, *J* 5.9, ArH), 4.94 (1H, d, *J* 5.0, CH), 4.48 (1H, d, *J* 5.0, CH) and 3.40–3.85 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.8 (*C*=O), 158.6 (NN*C*=C), 147.0 (N*C*=C), 142.4, 135.9, 135.2, 131.2, 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.7, 126.0 (aromatic carbons), 109.8 (NC=*C*), 87.2 (NNC=*C*), 46.4, 42.5 and 40.9; *m*/*z* (EI) 414/412 (M^+, 8/24%), 335 (4), 307 (40) and 301 (100).

8-Benzoyl-7-(4-methoxyphenyl)-5-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23k. *Pale yellow crystals*, yield, 51%, mp 96–98 °C (Found: C, 78.91; H, 5.88; N, 6.96. $C_{27}H_{24}N_2O_2$ requires C, 79.38; H, 5.92; N, 6.86%); ν_{max}(KBr)/cm^{-1} 3330 (NH), 1660, 1610 (C=O), 1505 and 1485; δ_H($CDCl_3$) 9.58 (1H, s, NH), 7.34 (5H, s, ArH), 7.05–7.30 (5H, m, ArH), 6.74 (2H, d, *J* 7.6, ArH), 6.66 (2H, d, *J* 7.6, ArH), 4.98 (1H, d, *J* 5.1, CH), 4.42 (1H, d, *J* 5.1, CH), 3.40–3.80 (4H, m, 2 × CH_2) and 3.72 (3H, s, OCH_3); δ_C($CDCl_3$) 192.9 (*C*=O), 158.6 (NN*C*=C), 140.9 (N*C*=C), 157.5, 142.6, 135.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 127.6, 126.1, 113.3 (aromatic carbons), 110.8 (NC=*C*), 87.8 (NNC=*C*), 55.0, 46.4, 42.4 and 40.4; *m*/*z* (EI) 408 (M^+, 34%), 377 (12), 331 (7) and 301 (100).

8-Benzoyl-7-[4-(dimethylamino)phenyl]-5-phenyl-1,2,3,7-tetrahydroimidazo[1,2-*a*]pyridine 23l. *Yellow crystals*, yield, 28%, mp 102–104 °C (Found: C, 79.63; H, 6.51; N, 9.84. $C_{28}H_{27}N_3O$ requires C, 79.78; H, 6.46; N, 9.97%); ν_{max}(KBr)/cm^{-1} 3320 (NH), 1650, 1605 (C=O), 1510 and 1480; δ_H($CDCl_3$) 9.58 (1H, s, NH), 7.34 (5H, s, ArH), 7.10–7.30 (5H, m, ArH), 6.72 (2H, d, *J* 6.7, ArH), 6.56 (2H, d, *J* 6.7, ArH), 5.02 (1H, d, *J* 5.9, CH), 4.34 (1H, d, *J* 5.9, CH), 3.40–3.80 (4H, m, 2 × CH_2) and 2.86 (6H, s, 2 × CH_3); δ_C($CDCl_3$) 192.9 (*C*=O), 158.7 (NN*C*=C), 142.6 (N*C*=C), 148.8, 137.1, 135.6, 135.2, 128.6, 128.2, 128.1, 127.9, 127.7, 127.5, 126.3, 112.7 (aromatic carbons), 111.1 (NC=*C*), 88.0 (NNC=*C*), 46.5, 42.8, 40.8 and 40.1; *m*/*z* (EI) 421 (M^+, 62%), 344 (9), 316 (75) and 301 (100).

4-Benzoyl-5-phenyl-1,2,3,5,6,7,8,9-octahydroimidazo[1,2-*a*]-quinoline 25

Following the same procedure as for the synthesis of **23**, reaction **5a** with α-benzylidenecyclohexanone **24** afforded **25** (47%) as *white crystals*, mp 208–210 °C (Found: C, 80.98; H, 6.94; N, 7.86. $C_{24}H_{24}N_2O$ requires C, 80.86; H, 6.79; N, 7.86%); ν_{max}(KBr)/cm^{-1} 3320 (NH), 1685, 1615 (C=O), 1520 and 1490; δ_H($CDCl_3$) 9.24 (1H, s, NH), 7.00–7.30 (8H, m, ArH), 6.65–6.75 (2H, m, ArH), 4.02 (1H, s, CH), 3.70–3.95 (4H, m, 2 × CH_2), 2.19–2.29 (2H, m, CH_2), 1.72–1.82 (2H, m, CH_2) and 1.47–1.59 (4H, m, 2 × CH_2); δ_C($CDCl_3$) 192.3 (*C*=O), 157.9 (NN*C*=C), 147.8 (N*C*=C), 142.8, 127.7, 127.6, 127.5, 127.4, 126.3, 126.1, 125.4 (aromatic carbons), 114.4 (NC=*C*), 88.4 (NNC=*C*), 46.5, 44.4, 42.7, 27.2, 24.6 and 22.3; *m*/*z* (EI) 356 (M^+, 18%), 279 (100) and 251 (36).

4-Benzoyl-8,8-dimethyl-6-oxo-5-phenyl-1,2,3,5,6,7,8,9-octahydroimidazo[1,2-*a*]quinoline 27

A mixture of **5a** (2 mmol), 5,5-dimethylcyclohexane-1,3-dione **26** (2 mmol) and benzaldehyde (2 mmol) was refluxed in acetonitrile (20 ml) for 15 h to give **27** (61%) as *pale yellow crystals*, mp 244–246 °C (Found: C, 78.30; H, 6.45; N, 7.06. $C_{26}H_{26}N_2O_2$ requires C, 78.36; H, 6.58; N, 7.03%); ν_{max}(KBr)/cm^{-1} 3320 (NH), 1645, 1630, 1600 (C=O), 1535 and 1485; δ_H($CDCl_3$) 9.50 (1H, s, NH), 6.85–7.35 (10H, m, ArH), 5.04 (1H, s, CH), 3.85–4.00 (4H, m, 2 × CH_2), 2.10–2.50 (4H, m, 2 × CH_2), 1.10 (3H, s, CH_3) and 0.86 (3H, s, CH_3); δ_C($CDCl_3$) 194.3 (*C*=O), 193.8 (*C*=O), 156.3 (NN*C*=C), 147.8 (N*C*=C), 147.2, 141.5, 128.7, 127.8, 127.7, 127.2, 126.4, 125.5 (aromatic carbons), 116.0 (NC=*C*), 89.1 (NNC=*C*), 50.1, 44.2, 42.8, 39.6, 36.2, 32.1, 30.0 and 26.5; *m*/*z* (EI) 398 (M^+, 6%), 321 (100) and 293 (47).

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