New vinylogous mesomeric betaines: synthesis and tautomerism of pyridiniopyrimidine appended 5-iminopenta-1,3-dienolates

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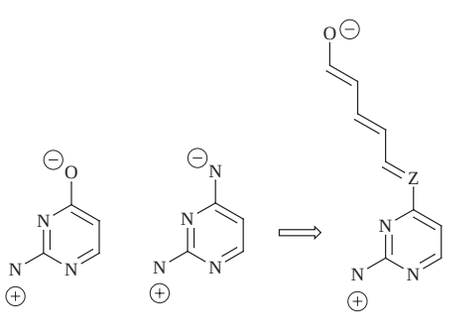
The pyrimidine–pyridinium salts **4**–**15** were regioselectively synthesized by nucleophilic substitution on the 4-amino-2,5,6-trichloropyrimidines **1**–**3**. The structure of **7** was established by X-ray crystallography. The cross-conjugated mesomeric betaines **16** and **17** were formed smoothly on treatment of **6** and **9** in aqueous ethanol with the anion exchange resin Amberlite® IRA-400 in its hydroxy form. Under similar conditions, pericyclic ring-cleavage of the bispyridinium salts **10**–**15** yielded the title compounds **18**–**23** as a mixed population of tautomers in rapid equilibrium.

Introduction

All types of mesomeric betaines,[1] including sydnones,[2] münchnones,[3] ylides,[4] *N*-oxides,[5] and mesoions,[6] as well as betainic alkaloids[7] and nucleobases,[8] can be comprehensively divided into four major classes, conjugated (CMB), cross-conjugated (CCMB), pseudo-cross-conjugated mesomeric betaines (PCCMB), and heterocyclic *N*-ylides. Isoconjugate relationships to hydrocarbon monoanions and dianions, respectively, subdivide these four classes into sixteen categories, some of which are represented by a large number of compounds, whereas other classes are either sparsely populated, or are hypothetical.[1]

In view of *Kröhnke*'s rule[4b] that originally relates the stability of ylides to the extent of the negative charge delocalisation, we were interested in the construction of new types of mesomeric betaines with a negative charge delocalised in modified pyrimidin-4-olate and pyrimidin-4-aminide moieties **I** and **II**, respectively, that are appended to a polyene segment (Scheme 1). Thus, the target fragment **III** is a polymethine derivative



I **II** **III**

Scheme 1

of **I** or **II** and is related to *heterocyclic*[1] as well as *acyclic* mesomeric betaines which are 1,3- and 1,5-dipoles.[9] A synthetic approach to those molecules could be the pericyclic ring-cleavage of 1,1′-(pyrimidinediyl)dipyridinium salts. In continuation of our work on charge-cumulated and charge-separated species,[10] this publication describes the synthesis and spectroscopic features of such new mesomeric betaines and of their precursors.

Results and discussion

Syntheses of the starting materials

The chlorine atom at C-4 of tetrachloropyrimidine is the most reactive one so that monosubstitution with *aliphatic* nucleophiles gives mainly the 4-substituted products by means of an S_N2 mechanism.[11] However, exceptions have been described.[12] Due to the additivity of substituent effects treatment of chloropyrimidines with *heteroaromatic* nucleophiles yields perheteroarenium compounds.[13] In order to avoid deleterious side-reactions induced by the high electron-deficiency brought about by the heteroarenium rings, we chose 4-amino-substituted chloropyrimidines as the starting materials for mesomeric betaines. In so far as we are aware, nucleophilic displacement reactions with heteroaromatic nucleophiles have not been described to date. Therefore, the regiochemistry of the heteroaromatic monosubstitution on 4-amino-2,5,6-trichloropyrimidine derivatives (in principle governed by steric as well as inductive effects[11a]) was established by means of X-ray crystallography and HH-COSY experiments.

In contrast to aliphatic nucleophiles,[11,12] treatment of the 4-amino-substituted trichloropyrimidines **1**–**3** with pyridine in toluene resulted in the ready formation of the pyrimidin-2-ylpyridinium chlorides **4**–**6** which precipitated as water-soluble solids upon cooling (Scheme 2). No isomers were identified in the reaction mixture. Likewise, the reaction of 4,4′-bipyridine with **1**–**3** was effected by heating the reactants in toluene at reflux temperature to yield the pyridinium salts **7**–**9**. To unambiguously elucidate the regiochemistry of the substitution, we performed X-ray crystallographic analysis of compound **7** (Fig. 1). The ORTEP drawing shows the three heteroaromatic rings of **7** to be slightly twisted by −175.74(19)° [dihedral angle N1–C6–N7–C12] and 173.7(2)° [C9–C10–C13–C14] from planarity. In ^{1}H NMR spectroscopy, the α protons of the heteroarenium rings of **4**–**9** uniformly display doublets in the range of 9.64 to 9.81 ppm. We found that these values are characteristic for C-2 bonded pyridiniums, as C-6 substitution give resonance frequencies significantly more upfield. Due to restricted rotation about the C-4-NH_2 bond the amino groups of **4** and **7** split to two broad signals in a one-to-one ratio which appear at 8.4 and 9.0 ppm in ^{1}H NMR spectroscopy, respectively. Independent of the choice of solvent, the ^{13}C NMR spectrum, however, does not show more than seven distinct signals

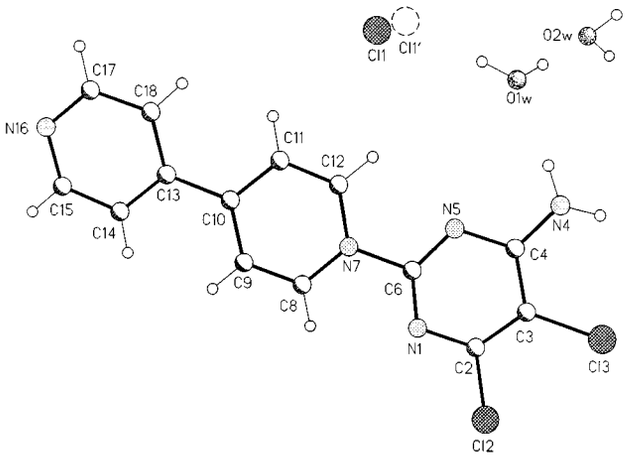
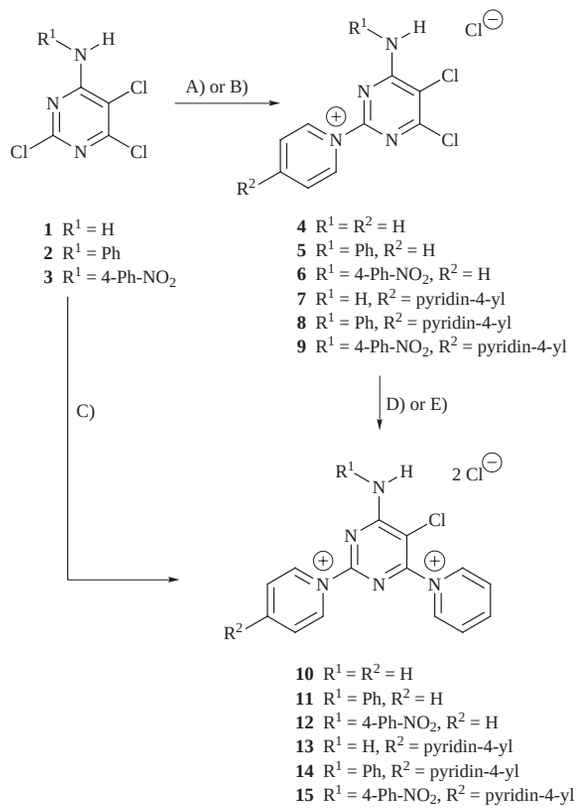


Figure 1 ORTEP drawing of **7**. Selected structural parameters, N1–C2 134.0(3), C2–C3 137.2(3), C3–C4 142.3(3), C4–N5 135.4(3), N5–C6 132.2(3), C6–N1 131.7(3) nm. C6–N1–C2–C3 1.1(3), N1–C2–C3–C4 −4.2(3), C12–C2–C3–C4 175.05(16), C2–C3–C4–N4 −174.1(2), C2–C3–C4–N5 5.0(3), C4–N5–C6–N7 −179.32(17), N5–C6–N7–C12 3.2(3)°.



1 R^1 = H
2 R^1 = Ph
3 R^1 = 4-Ph-NO_2

4 R^1 = R^2 = H
5 R^1 = Ph, R^2 = H
6 R^1 = 4-Ph-NO_2, R^2 = H
7 R^1 = H, R^2 = pyridin-4-yl
8 R^1 = Ph, R^2 = pyridin-4-yl
9 R^1 = 4-Ph-NO_2, R^2 = pyridin-4-yl

10 R^1 = R^2 = H
11 R^1 = Ph, R^2 = H
12 R^1 = 4-Ph-NO_2, R^2 = H
13 R^1 = H, R^2 = pyridin-4-yl
14 R^1 = Ph, R^2 = pyridin-4-yl
15 R^1 = 4-Ph-NO_2, R^2 = pyridin-4-yl

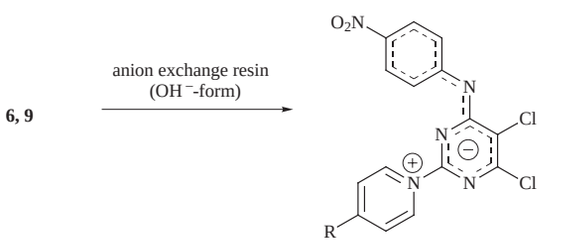
Scheme 2 *Reagents and conditions*: Method A for the synthesis of **4–6**: toluene, pyridine, reflux. Method B for **7–9**: toluene, 4,4′-bipyridine, reflux. Method C for **10**, **11**: **1**, **2**, pyridine, 80 °C. Method D for **12**: **9**, pyridine, reflux, 4 h. Method E for **13–15**: **6–9**, pyridine, 70–80 °C, 1 h.

so that an equilibrium of **4** and **7**, respectively, and tautomers were excluded from consideration. Disubstitution of **1** and **2** occurs in pure pyridine at elevated temperatures, yielding the bis-pyridinium dichlorides **10** and **11**. Within five minutes, this reaction is completely reversible in DMSO at 120 °C. Under analogous reaction conditions, the synthesis of **12** could not be accomplished because **6** precipitated from the reaction mixture. Alternatively, **12** was prepared from **9**, taking advantage of the nucleofugal properties of the C-2 bonded 4,4′-bipyridinium ring. Heating **7–9** in pyridine at 70–80 °C resulted in the ready formation of the dicationic species **13–15**, respectively. Upon disubstitution, the α protons of the C-2 pyridinium rings characteristically shift 0.14–0.29 ppm to lower field, and the α protons of the pyridinium at C-6 can be identified upfield as doublets at 9.63–9.71 ppm. Thus, the cationic and dicationic species can be differentiated readily by their ^{1}H NMR spectra. The peak assignment of **10** was established by a HH-COSY experiment (see Experimental section).

Ring cleavage and betaine formation. Spectroscopic features

Several synthetic methods are available to cleave pyridinium rings,[14] among these the *Fujiwara* reaction,[15] the *König* and *Zincke*,[16] and *Baumgarten* methods.[16] However, we found that the treatment of aqueous solutions of the pyrimidine–pyridinium salts at room temp. with the anion exchange resins Amberlite® IRA-93 and IRA-400 in their hydroxy forms is a very mild and efficient method to induce ring-cleavage reactions and deprotonations in mesomeric betaines, because the chloride counterions of the starting materials are exchanged in exactly stoichiometric amounts of hydroxide anions. Thus, decomposition of the sensitive 5-aminopenta-2,4-dienal derivatives can be avoided. The outcome of the anion exchange is dependent on the substitution pattern of the starting material.

Whereas neither deprotonation[17] nor ring cleavage of the pyridinium salts **4**, **5**, **7**, and **8** was observed, the nitro derivatives **6** and **9** were smoothly converted into the cross-conjugated aminides **16** and **17**, respectively (Scheme 3). The



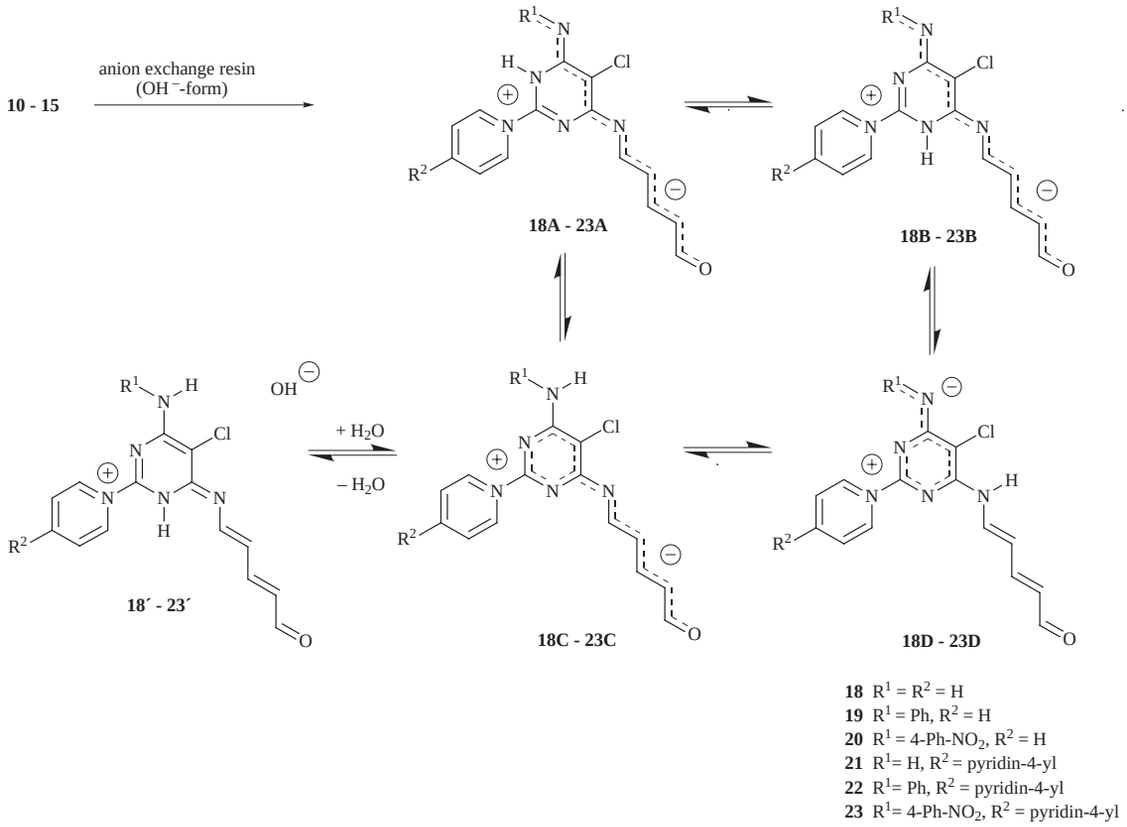
16 R = H
17 R = pyridin-4-yl

Scheme 3

relative stability of **16** and **17** is mainly due to negative charge delocalization involving the strongly electron-withdrawing nitro group. Conjugation *via* the C-4=N imino group, that must be in a *Z* configuration, is proved by the chemical shifts of the *ortho* and *meta* protons of the 4-nitrophenyl groups that were observed shifted approximately 0.70 and 0.27 ppm to higher frequencies upon conversion of **6** and **9** into their mesomeric betaines, **16** and **17**. Accordingly, *Z*-configuration gives rise to two stabilizing interactions between the nitrogen lone pairs of pyrimidine and aromatic C–H bonds of the phenyl rings which are known to be attractive ones.[18] In contrast, *E*-configuration gives a non-planar system with diminished p-overlap due to steric repulsion of the *ortho* protons of the 4-nitrophenyl ring and the chlorine atom at C-5. The mesomeric betaines **16** and **17** unambiguously belong to class 9 of the comprehensive classification proposed by *Ollis*, *Stanforth* and *Ramsden* in 1985, *i.e.* cross-conjugated mesomeric betaines (CCMB) isoconjugate with odd alternant hydrocarbon anions.[1] Known examples of this category are very scarcely described in the literature, and in 1985 only two representatives were known.

The anion exchange resin Amberlite® IRA-93 in its hydroxy form converted the dicationic pyridinium salts **10–15** into the pentadienolates **18–23** (Scheme 4) which are intensely orange to dark purple in colour. However, the amino derivative **18** proved to be unstable so that we were prevented from complete characterization. In accordance with the assigned structure, however, the crude reaction product shows a molecular ion of **18** at *m*/*z* = 303.3 (M^+, 38%) in FAB mass spectrometry and the characteristic NMR spectroscopic features (*vide infra*).

The following spectroscopic methods were applied for structure elucidation. The molecular ions found in FAB mass



18 $R^1 = R^2 = H$
19 $R^1 = Ph$, $R^2 = H$
20 $R^1 = 4\text{-Ph-}NO_2$, $R^2 = H$
21 $R^1 = H$, $R^2 =$ pyridin-4-yl
22 $R^1 = Ph$, $R^2 =$ pyridin-4-yl
23 $R^1 = 4\text{-Ph-}NO_2$, $R^2 =$ pyridin-4-yl

Scheme 4

spectrometry in the positive ion detection mode are consistent with the assigned structures. From the ^{1}H NMR spectra it is apparent that the pyridinium ring at C-6 exclusively undergoes ring-cleavage. Accordingly, the ^{1}H NMR spectra show the characteristic resonance frequencies of push–pull-substituted dienes with two signals of shielded protons at 6.1 and 6.6 ppm. In comparison with (2*E*,4*E*)-5-aminopenta-2,4-dienal and its (2*Z*,4*E*)-isomer,[19] the coupling constants $J_{2,3} = 15$ Hz and $J_{4,5} = 13$ Hz confirm the all-*E*-configuration, which is the thermodynamically most stable configuration of glutacondialdehyde derivatives.[14b] Furthermore, an NMR experiment at elevated temperatures shows no significant differences in the chemical shifts.

Due to the betainic structure of the compounds and similar to the *Fujiwara* compounds,[15] addition of bases does not cause any visible or measurable changes, whereas the color of DMSO solutions of **18–23** turned immediately from orange–red to yellow on acidification with hydrochloric acid. In agreement with the betainic (uncharged) structures, **18–23** display aldehyde signals in ^{1}H NMR spectroscopy, whereas pentadienolate *anions* do not.[20] Correspondingly, the yellow protonated species **18′**–**23′** show sharp, deuterium exchangeable NH signals at 10.2 and 10.7 ppm, whereas the orange–red betaines **18–23** display only one amino group, respectively. As an aldehyde group is observable in ^{1}H NMR spectroscopy, the possible formation of an enol group at C-1 of the side chains was eliminated from consideration. Therefore, four distinct NH tautomeric forms of the betaine can be formulated, involving the prototropic migrations **18A–23A/18B–23B/18C–23C/18D–23D** which obviously form a rapid equilibrium on the NMR timescale. The spectra yield some information about their concentrations in DMSO-d_6. First, the resonance frequencies of 5-H of the pentadienal moieties appear as doublets and should split into doublets of doublets in the presence of an adjacent amino group,[19] so that the concentration of **18D–23D**, containing the 5-aminopenta-2,4-dienal chromophore, seems to be very low in solution. This is also supported by the UV absorption maxima. Thus, the conjugated system of **18–23** must be larger than typical merocyanines that have absorption maxima at 340 to 360 nm. The largest conjugated systems possess conjugated (**18A–23A**) or cross-conjugated chromophores (**18B–23B**), but non-aromatic pyrimidine rings. In comparison with the starting material **11**, **12**, **14** and **15**, the resonance frequencies of the phenyl rings are indeed shifted upfield consistent with the negative charge delocalization depicted in Scheme 4. Accordingly, the β- and γ-protons of the pyridinium ring shift upfield due to the diminished overall charge of the system.

Since in all tautomers the positive fragments and the conjugated anions are cross-conjugated, the compounds **18–23** are new and unusual representatives of the class of cross-conjugated mesomeric betaines (CCMB).

Experimental

General methods

The NMR spectra were recorded on a Bruker ARX 300. For the sake of simplicity, the positions of the hydrogen atoms are referred to as follows: 2-, 3-, and 4-H of i) phenyl rings: *o*-, *m*-, and *p*-H; ii) pyridinium rings at C-2: α-, β-, γ-H; iii) pyridinium rings at C-6; α′-H, β′-H, γ′-H; iv) pyridin-4-yl substituents: α″-, β″-, γ″-H. Peak assignments were established by HH-COSY measurements. *J* values are given in Hz. IR spectra were obtained on a Nicolet 205 in the range from 400 to 4000 cm^{-1} (2.5% pellets in KBr). The 4-aminotrichloropyrimidines **1** and **2** were synthesized as described in the literature.[11a] All chemicals, except for non-deuterated solvents, were purchased from Aldrich Chemical Co. and were used as received. Limited solubilities prevented us from measuring some ^{13}C NMR and UV spectra. In accordance with known heteroarenium compounds[10a,10b,21] and X-ray crystallographic results (*cf*. Fig. 1), all compounds crystallize with varying amounts of water. In UV spectroscopy, the water of hydration causes some changes in solvent polarity as well as in concentration of the solutions.

Therefore, UV spectra were taken qualitatively on a Perkin-Elmer UV/VIS/NIR Spectrometer Lambda 19. All melting points were measured using a Boëtius melting apparatus; the values reported are uncorrected.

Preparation of the 4-(4-nitrophenylamino)-2,5,6-trichloropyrimidine 3

A solution of 6.0 g of 4-nitroaniline (43.4 mmol) in a mixture of 375 mL of acetone and 125 mL of water was treated with 15.0 g (45.9 mmol) of tetrachloropyrimidine. The resulting suspension was heated to 60 °C, and aqueous sodium carbonate was added dropwise over a period of 30 min, until an orange color of the reaction mixture remained for a few minutes. The solution was then heated at reflux temperature for 1 h, during which time the reaction was monitored by TLC (SiO_2/EtOAc). When the color disappeared, additional aqueous sodium carbonate was added dropwise, until a beige precipitate formed which was filtered off. On concentration of the mother liquid *in vacuo*, additional solid precipitated. The combined precipitates were recrystallized from toluene to give a beige solid of **3** (12.0 g, 82%), mp 204 °C (lit.,[11a] 204 °C).

General procedure for the preparation of the 4-amino-substituted 1-(5,6-dichloropyrimidin-2-yl)pyridinium chlorides 4–9

A solution of 5.0 mmol of the 4-amino-substituted 2,5,6-trichloropyrimidines [1.00 g of 4-amino-2,5,6-trichloropyrimidine (**1**), 1.37 g of 2,5,6-trichloro-4-phenylaminopyrimidine (**2**), and 1.60 g of 2,5,6-trichloro-4-(4-nitrophenylamino)-pyrimidine (**3**), respectively] and the pyridines [for **4–6**: 5 mL of pyridine; for **7–9**: 5.0 mmol of 4,4′-bipyridine (0.78 g)] in toluene [**4–6**: 150 mL; **7–9**: 50 mL] was heated at reflux temperature over a period of 3 h. The precipitates of **4–8** were then filtered off, washed with ethyl acetate, and dried *in vacuo*. The synthesis of **9** was accomplished as described below.

1-(4-Amino-5,6-dichloropyrimidin-2-yl)pyridinium chloride 4 (0.85 g, 61%), decomp. > 206 °C (from toluene) (Found: C, 36.3; H, 3.4; N, 19.8. $C_9H_7Cl_3N_4 \cdot H_2O$ requires C, 36.6; H, 3.1; N, 19.0%); $\lambda_{max}(CH_2Cl_2)$/nm 334, 280sh, 244; λ_{max}(MeCN)/nm 316, 271, 237; λ_{max}(MeOH)/nm 323, 270sh, 240; ν_{max}/cm^{-1} 3311, 3126, 1639, 1626, 1600, 1561, 1520, 1467, 1393, 1319, 1202, 1151, 1084, 766, 708, 659; δ_H(300 MHz, DMSO-d_6, Me_4Si) 8.36 (2H, dd, *J* 6.4, 5.6), 8.42 (1H, br s), 8.93 (1H, tt, *J* 6.4, 1.3), 9.04 (1H, br s), 9.74 (2H, dd, *J* 5.6, 1.2); δ_C(75 MHz, DMSO-d_6, Me_4Si) 110.97, 127.99, 140.93, 150.38, 151.70, 155.37, 161.67; *m*/*z* (FAB, mNBA) 242.8 (M^+, 14%).

1-(4-Anilino-5,6-dichloropyrimidin-2-yl)pyridinium chloride 5 (1.3 g, 73%), decomp. > 233 °C (from toluene) (Found: C, 47.42; H, 4.10; N, 14.59. $C_{15}H_{11}Cl_3N_4 \cdot 1.5H_2O$ requires C, 47.32; H, 3.71; N, 14.72%); $\lambda_{max}(CH_2Cl_2)$/nm 296, 254; λ_{max}(MeCN)/nm 295, 251; λ_{max}(MeOH)/nm 279, 251; ν_{max}/cm^{-1} 1607, 1586, 1567, 1516, 1388, 1322, 1059, 759; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.31 (1H, tt, *J* 7.2, 1.2), 7.50 (2H, dd, *J* 7.5, 7.2), 7.64 (2H, dd, *J* 7.5, 1.2), 8.34 (2H, dd, *J* 7.5, 6.9), 8.91 (1H, td, *J* 7.5, 1.2), 9.64 (2H, dd, *J* 6.9, 1.2), 10.41 (1H, s); δ_c(75 MHz, DMSO-d_6; Me_4Si) 112.76, 123.97, 125.89, 128.09, 128.77, 136.73, 140.89, 150.42, 151.31, 155.76, 158.14; *m*/*z* (FAB, mNBA) 318.3 (M^+, 100%).

1-[5,6-Dichloro-4-(4-nitrophenylamino)pyrimidin-2-yl]pyridinium chloride 6 (1.55 g, 78%) mp 267 °C (from toluene) (Found: C, 45.9; H, 3.1; N, 17.2. $C_{15}H_{10}Cl_3N_5O_2$ requires: C, 45.2; H, 2.5; N, 17.5%); $\lambda_{max}(CH_2Cl_2)$/nm 332, 267 nm; λ_{max}(MeCN)/nm 329 nm; λ_{max}(MeOH)/nm 327; ν_{max}/cm^{-1} 1613, 1591, 1556, 1501, 1426, 1345, 1243, 1196, 1112, 1065, 761, 753; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.99 (2H, d, *J* 9.3), 8.36 (4H, m), 8.94 (1H, tt, *J* 7.8, 1.2), 9.73 (2H, d, *J* 9.3), 10.79 (1H, br s); δ_C(75 MHz, DMSO-d_6; Me_4Si) 114.22, 123.53, 124.68, 128.33, 141.26, 143.26, 143.95, 150.74, 151.29, 156.86, 158.06; *m*/*z* (FAB, mNBA) 363.5 (M^+, 100%).

1-(4-Amino-5,6-dichloropyrimidin-2-yl)-4-(pyridin-4-yl)pyridinium chloride 7 (0.96 g, 54%), mp > 300 °C (from toluene) (Found: C, 41.1; H, 3.9; N, 18.4. $C_{14}H_{10}Cl_3H_5 \cdot 3H_2O$ requires C, 41.1; H, 3.9; N, 17.1%); $\lambda_{max}(CH_2Cl_2)$/nm 286 nm; λ_{max}(MeCN) 289; λ_{max}(MeOH) 276 nm; ν_{max}/cm^{-1} 3326, 3168, 1666, 1602, 1562, 1411, 1357, 1271, 1219, 1006, 860, 808, 618; δ_H(300 MHz, DMSO-d_6; Me_4Si) 8.12 (2H, dd, *J* 4.5, 1.5), 8.43 (1H, br s), 8.82 (2H, d, *J* 7.2), 8.93 (2H, dd, *J* 4.5, 1.5), 9.05 (1H, br s), 9.81 (2H, d, *J* 7.2 Hz); *m*/*z* (FAB, mNBA) 319.9 (M^+, 10%).

1-(4-Anilino-5,6-dichloropyrimidin-2-yl)-4-(pyridin-4-yl)pyridinium chloride 8. Additional amounts of product were obtained by treating the mother liquor with 4,4′-bipyridine and heating. The combined solids were washed with ethyl acetate and recrystallized from ethanol to afford **8** (0.39 g, 37%), decomp. > 175 °C (from toluene) (Found: C, 52.5; H, 3.9; N, 14.5. $C_{20}H_{14}N_5Cl_3 \cdot 1.5H_2O$ requires C, 52.5; H, 3.7; N, 15.3%); $\lambda_{max}(CH_2Cl_2)$/nm 300; λ_{max}(MeCN)/nm 295; λ_{max}(MeOH) 292; ν_{max}/cm^{-1} 1633, 1608, 1585, 1566, 1509, 1408, 1325, 1207, 1060, 765; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.34 (1H, t, *J* 7.5), 7.51 (2H, t, *J* 7.5), 7.65 (2H, d, *J* 7.5), 8.10 (2H, dd, *J* 4.5, 1.5), 8.80 (2H, d, *J* 7.2), 8.92 (2H, dd, *J* 4.5, 1.5), 9.69 (2H, d, *J* 7.2), 10.47 (1H, s); *m*/*z* (FAB, mNBA) 395.1 (M^+, 100%).

1-[5,6-Dichloro-4-(4-nitrophenylamino)pyrimidin-2-yl]-4-(pyridin-4-yl)pyridinium chloride 9. The mother liquor was treated with an additional amount of 4,4′-bipyridine in 50 mL of toluene and heated at 80 °C over a period of 1 h. During this time the solution was concentrated by continuously distilling off the solvent by means of a *Zincke* apparatus. The precipitate was filtered off *in vacuo*, the combined solids were subsequently washed with ethyl acetate and ether, and dried in air to give **9** (1.98 g, 90%), slow decomp. on heating; no defined mp < 300 °C (from toluene) (Found: C, 50.6; H, 3.6; N, 16.6. $C_{20}H_{13}Cl_3N_6O_2$ requires: C, 50.5; H, 2.7; N, 17.6%). $\lambda_{max}(CH_2Cl_2)$/nm 317; λ_{max}(MeCN)/nm 286; λ_{max}(MeOH)/nm 283; ν_{max}/cm^{-1} 3117, 1633, 1617, 1587, 1538, 1499, 1341, 1265, 1225, 1114, 1003, 856, 803, 752; δ_H(300 MHz, DMSO-d_6; Me_4Si) 8.02 (2H, d, *J* 9.0), 8.12 (2H, dd, *J* 4.8, 1.5), 8.37 (2H, d, *J* 9.0), 8.80 (2H, d, *J* 6.9), 8.94 (2H, dd, *J* 4.8, 1.5), 9.79 (2H, d, *J* 6.9); *m*/*z* (FAB); mNBA) 440.2 (M^+, 57%).

General procedure for the preparation of the 4-amino-substituted 1,1′-(5-chloropyrimidine-2,6-diyl)dipyridinium dichlorides 10 and 11

5.0 mmol of the aminotrichloropyrimidines **1–3** [1.00 g of 4-amino-2,5,6-trichloropyrimidine (**1**), 1.37 g of 2,5,6-trichloro-4-phenylaminopyrimidine (**2**), respectively] were dissolved in 30 mL of pyridine and heated at 80 °C [**10**: 2 h; **11**: 30 min]. The precipitates were filtered off, subsequently washed with ethyl acetate and ether, and treated as described below.

1,1′-(4-Amino-4-chloropyrimidine-2,6-diyl)dipyridinium dichloride 10 (1.37 g, 77%), mp 220–221 °C (from EtOH) (Found: C, 39.1; H, 5.1; N, 16.1. $C_{14}H_{12}Cl_3N_5 \cdot 4H_2O$ requires C, 39.2; H, 4.7; N, 16.3%); $\lambda_{max}(CH_2Cl_2)$/nm 331; λ_{max}(MeCN)/nm 319, 231; λ_{max}(MeOH)/nm 314, 230; ν_{max}/cm^{-1} 3206, 3119, 3031, 1650, 1606, 1537, 1470, 1427, 1341, 1173, 715, 667; δ_H(300 MHz, DMSO-d_6; Me_4Si) 8.42 (2H, dd, *J* 7.5, 6.6, β-H), 8.55 (2H dd, *J* 7.8, 6.9, β′-H), 8.99 (1H, tt, *J* 6.6, 1.5, γ-H), 9.03 (1H, br s, NH), 9.05 (1H, tt, *J* 7.8, 1.5, γ′-H), 9.61 (2H, ddd, *J* 6.9, 1.5, 1.4, α′-H), 9.64 (1H, br s, NH), 9.89 (2H, dd, *J* 7.5, 1.2, α-H); δ_C(75 MHz, DMSO-d_6; Me_4Si) 108.39, 128.20, 128.50, 141.13, 144.73, 150.36, 150.84, 152.01, 154.11, 163.04; *m*/*z* (FAB, mNBA) 285.2 (M^+, 37%).

1,1′-(4-Anilino-5-chloropyrimidine-2,6-diyl)dipyridinium dichloride 11. The reaction mixture was concentrated *in vacuo* and cooled overnight to 8 °C. The resulting precipitate was filtered off, subsequently washed with ethyl acetate and ether, and recrystallized from aqueous ethanol to furnish **11** (1.73 g, 80%), mp > 300 °C (from EtOH) (Found: C, 52.0; H, 4.6; N, 15.0. $C_{20}H_{16}Cl_3N_5 \cdot 1.5H_2O$ requires: C, 52.3; H, 4.2; N, 15.2%); λ_{max}(MeCN)/nm 262; λ_{max}(MeOH)/nm 257; ν_{max}/cm^{-1} 3120, 1609, 1591, 1568, 1528, 1472, 1342, 1202, 1059, 767, 730; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.39 (1H, tt, *J* 7.2, 0.9), 7.56 (2H, d, *J* 7.5), 7.73 (2H, dd, *J* 7.5, 1.2), 8.40 (2H, dd, *J* 7.8, 6.9), 8.59 (2H, ddd, *J* 8.1, 6.9, 1.2), 8.96 (1H, tt, *J* 7.8, 1.2), 9.09 (1H, tt, *J* 8.1, 1.2), 9.65 (2H, dd, *J* 6.9, 1.5), 9.80 (2H, dd, *J* 6.9, 1.2), 11.02 (1H, s); δ_C(75 MHz, DMSO-d_6; Me_4Si) 110.41, 124.09, 126.63, 128.28, 128.65, 129.05, 136.24, 141.20, 144.76, 150.55, 150.99, 151.73, 154.39; *m*/*z* (FAB, mNBA) 361.6 (M^+, 54%).

Preparation of 1,1′-[5-chloro-4-(4-nitrophenylamino)pyrimidine-2,6-diyl]dipyridinium dichloride 12

A sample of 2.37 g (5.0 mmol) of **9** was dissolved in 60 mL of pyridine. Then, the solution was heated at 70–80 °C over a period of 4 h during which time a dark solid precipitated. The solid was filtered off, subsequently washed with ethyl acetate and ether, and dried *in vacuo* to give **12** (1.05 g, 44%), decomp. 254–256 °C (from EtOH) (Found: C, 49.8; H, 4.1; N, 16.9. $C_{20}H_{15}Cl_3N_6O_2 \cdot 0.5H_2O$ requires C, 49.4; H, 3.3; N, 17.2%); $\lambda_{max}(CH_2Cl_2)$/nm 351; λ_{max}(MeCN)/nm 339, 256; λ_{max}(MeOH)-nm 355; ν_{max}/cm^{-1} 1617, 1587, 1562, 1538, 1509, 1419, 1340, 1231; δ_H(300 MHz, DMSO-d_6; Me_4Si) 8.05 (2H, d, *J* 7.2), 8.41 (4H, m), 8.59 (2H, dd, *J* 8.1, 5.4), 8.98 (1H, t, *J* 7.8), 9.09 (1H, t, *J* 8.1), 9.63 (2H, d, *J* 5.4), 9.87 (2H d, *J* 5.7), 11.37 (1H, br s); δ_C(75 MHz, DMSO-d_6; Me_4Si) 111.62, 123.95, 124.69, 128.35, 128.68, 141.44, 144.30, 144.78, 150.68, 151.14, 151.60, 154.84, 159.35; *m*/*z* (FAB, mNBA) 407.0 (M^+, 19%).

General procedure for the preparation of the 4-amino-substituted 1-(5-chloro-6-(1-pyridinio)pyrimidin-2-yl)-4-(pyridin-4-yl)-pyridinium dichlorides 13–15

1.0 mmol of the 4-amino-substituted (5,6-dichloropyrimidin-2-yl)-4-(pyridin-4-yl)pyridinium chlorides **7–9** [0.35 g of **7**; 0.43 g of **8**; 0.47 g of **9**, respectively] were dissolved in 30 mL of pyridine and heated at 70–80 °C for 1 h. After cooling, the precipitates were filtered off, washed with ethyl acetate and dried *in vacuo.*

1-[4-Amino-5-chloro-6-(1-pyridinio)pyrimidin-2-yl]-4-(pyridin-4-yl)pyridinium dichloride 13 (0.24 g, 56%), mp > 300 °C (from EtOH–H_2O) (Found: C, 44.3; H, 3.7; N, 18.3. $C_{19}H_{15}Cl_3N_6 \cdot 4.5H_2O$ requires C, 44.3; H, 4.7; N, 16.3%); λ_{max}(MeCN)/nm 276, 211; λ_{max}(MeOH)/nm 265, 228; ν_{max}/cm^{-1} 3115, 3051, 1630, 1611, 1426, 1346, 1293, 1212, 1173, 1050, 770; δ_H(300 MHz, DMSO-d_6; Me_4Si), 8.17 (2H, dd, *J* 4.5, 1.5), 8.56 (2H, t, *J* 7.5), 8.90 (2H, d, *J* 7.2), 8.95 (2H, dd, *J* 4.5, 1.5), 9.06 (1H, t, *J* 7.5), 9.64 (overlapped, 3H), 90.96 (2H, d, *J* 7.2); δ_C(75 MHz, DMSO-d_6; Me_4Si) 108.55, 122.24, 125.46, 128.61, 140.31, 141.46, 144.85, 150.48, 151.21, 151.76, 154.29, 157.09, 163.18; *m*/*z* (FAB; mNBA) 362.7 (M^+, 15%).

1-[4-Anilino-5-chloro-6-(1-pyridinio)pyrimidin-2-yl]-4-(pyridin-4-yl)pyridinium dichloride 14 (0.24, 47%), mp 228–230 °C (from EtOH–H_2O) (Found: C, 51.6; H, 4.5; N, 14.5. $C_{25}H_{19}Cl_3N_6 \cdot 4H_2O$ requires C, 51.6; H, 4.7; N, 14.4%); $\lambda_{max}(CH_2Cl_2)$/nm 290sh, 242; λ_{max}(MeCN)/nm 284; λ_{max}(MeOH)/nm 265; ν_{max}/cm^{-1} 3470, 3400, 3115, 3033, 1632, 1613, 1594, 1344, 1212, 1064, 825, 769, 733, 685; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.37 (1H, t, *J* 7.5), 7.57 (2H, t, *J* 7.5), 7.73 (2H, d, *J* 7.5), 8.15 (2H, dd, *J* 4.5, 1.8), 8.60 (2H, dd, *J* 7.8, 7.0), 8.87 (2H, d, *J* 7.2), 8.93 (2H, dd, *J* 4.5, 1.8), 9.10 (1H, t, *J* 7.8), 9.71 (2H, d, *J* 7.2), 9.88 (2H d, *J* 7.0), 11.09 (1H, s); δ_C(75 MHz, DMSO-d_6; Me_4Si) 110.56, 122.21, 124.34, 125.52, 126.74, 128.72, 129.12, 136.44, 140.25, 141.60, 144.96, 150.61, 151.19, 151.52, 154.51, 157.13, 159.60; *m*/*z* (FAB, mNBA) 439.0 (M^+ + 1, 44%).

1-[5-Chloro-4-(4-nitrophenylamino)-6-(1-pyridinio)pyrimidin-2-yl]-4-(pyridin-4-yl)pyridinium dichloride 15 (0.24 g, 43%), mp > 300 °C (from EtOH–H_2O) (Found: C, 48.8; H, 4.3; N, 16.4. $C_{25}H_{18}Cl_3N_7O_2$ requires C, 49.3, H, 4.0, N. 16.1%); λ_{max}(MeCN)/nm 319, 224; λ_{max}(MeOH)/nm 332, 263, 227; ν_{max}/cm^{-1} 1628, 1588, 1501, 1335, 855; δ_H(300 MHz, DMSO-d_6; Me_4Si) 8.12 (2H, d, *J* 9.0), 8.16 (2H, dd, *J* 4.5, 1.8), 8.42 (2H, d, *J* 9.0), 8.61 (2H, dd, *J* 7.8, 6.3), 8.86 (2H, d, *J* 7.2), 8.95 (2H, dd, *J* 4.5, 1.8), 9.08 (2H, t, *J* 7.8), 9.69 (2H, d, *J* 6.3), 9.96 (2H, d, *J* 7.2); *m*/*z* (FAB, mNBA) 484.1 (M^+ + 1; 17%).

General procedure for the preparation of the mesomeric betaines 16 and 17

60 mL of the anion exchange resin Amberlite® IRA-400 was filled into a column (height: 12 cm, diameter: 4 cm) and washed with 2 L of water. After 150 mL of 5% aqueous hydrochloric acid and 2 L of water were consecutively passed through the column, 150 mL of an 8% aqueous sodium hydroxide solution was added and remained in the column for 30 min. The sodium hydroxide was then rinsed out with water until pH 7 was reached. The synthesis was accomplished as described below.

5,6-Dichloro-2-pyridiniopyrimidin-4-yl(4-nitrophenyl)-aminide 16. The resin was prepared as described above and then treated with 150 mL of 70% aqueous ethanol. A sample of 0.5 mmol (0.20 g) of **6**, dissolved in 20 mL of the same solvent mixture, was passed through the column. The eluent was evaporated *in vacuo* to dryness to give **16** a an orange solid (0.14 g, 78%), mp > 300 °C (from EtOH–H_2O) (Found: C, 43.4; H, 3.5; N, 15.4. $C_{15}H_9Cl_2N_5O_2 \cdot 3H_2O$ requires C, 43.3; H, 3.6; N, 16.8%); $\lambda_{max}(CH_2Cl_2)$/nm 342; λ_{max}(MeCN)/nm 348; λ_{max}-(MeOH)/nm 344; ν_{max}/cm^{-1} 1622, 1590, 1560, 1526, 1504, 1478, 1417, 1327, 1250, 1193, 1110, 1036, 1021; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.30 (2H, d, *J* 10.1), 8.09 (2H, d, *J* 10.1), 8.22 (2H, t, *J* 7.4), 8.78 (1H, tt, *J* 7.6, 1.4), 9.64 (2H, dd, *J* 6.8, 1.2); *m*/*z* (FAB, mNBA) 363.6 (M^+ + 1, 68%), 176.6 (100).

{5,6-Dichloro-2-[4-(pyridin-4-yl)pyridinio]pyrimidin-4-yl}(4-nitrophenyl)aminide 17. After treatment of the resin prepared as described above with 150 mL of 70% aqueous ethanol, a solution of 0.42 mmol (0.2 g) of **9** in 70% aqueous ethanol was passed through the column. The eluent was evaporated to dryness at room temp. to give **17** as an orange solid (0.15 g, 82%), mp > 300 °C (from EtOH–H_2O) (Found: C, 47.9; H, 3.5; N, 16.3. $C_{20}H_{12}Cl_2N_6O_2 \cdot 3.5H_2O$ requires C, 47.8; H, 3.8; N, 16.7%); $\lambda_{max}(CH_2Cl_2)$/nm 290, 350sh; λ_{max}(MeCN)/nm 352, 282; λ_{max}(MeOH)/nm 357, 285; ν_{max}/cm^{-1} 1624, 1602, 1567, 1497, 1446; δ_H(300 MHz, DMSO-d_6; Me_4Si) 7.31 (2H, d, *J* 9.3), 8.05 (2H d, *J* 6.3), 8.11 (2H, d, *J* 9.3), 8.68 (2H d, *J* 7.2), 8.89 (2H, d, *J* 6.3) 9.70 (2H, d, *J* 7.2); *m*/*z* (FAB, mNBA) 432.2 (M^+, 7%), 299.3 ($M^+ - O_2NC_6H_4 - NH_2$, 100).

General procedure for the preparation of the 5-imino-pentadienolate betaines 19–23

150 mL of the anion exchange resin Amberlite® IRA-93 was placed in a column without frit (height: 16 cm, diameter: 3 cm) and washed with 2 L of water. Then, 150 mL of an 8% aqueous sodium hydroxide solution was added and remained in the column for 45 min. The sodium hydroxide was then rinsed out with water until pH 7 was reached and then washed with 200 mL of 50% aqueous ethanol. The preparations of **19–23** were accomplished as follows. A sample of 250 mg of **12–15**, respectively, [**12**: 0.52 mmol; **13**: 0.57 mmol; **14**: 0.49 mmol; **15**: 0.45 mmol] was dissolved in 35 mL of 50% aqueous ethanol. Then, the solution was poured into the column and eluted by the same

solvent mixture. A flow rate of one drop per second was used. The coloured eluates were concentrated *in vacuo* at 15 °C, and the resulting precipitates were filtered off, and washed with dichloromethane and dried *in vacuo*.

(1*E*,3*E*)-*N*-(6-Anilino-5-chloro-2-pyridiniopyrimidin-4-yl)-5-iminopenta-1,3-dienolate 19. A sample of 200 mg (0.46 mmol) of **11** dissolved in 30 mL of water was added to the anion exchange resin. Cautious evaporation of the eluate to dryness gives **19** as an orange solid (74 mg, 44%), mp > 300 °C (from EtOH–H_2O) (Found: C, 35.6; H, 4.7; N, 10.0. $C_{20}H_{16}ClN_5O\cdot 16H_2O$ requires C, 36.0; H, 7.3; N, 10.5%); $\lambda_{max}(CH_2Cl_2)$/nm 353; λ_{max}(MeOH)/nm 363, 248; ν_{max}/cm^{-1} 1623, 1597, 1562, 1498, 1448, 1420, 1344, 1142, 1054, 762; δ_H(300 MHz, DMSO-d_6; Me_4Si) 6.11 (2H, dd, *J* 15.0, 8.1, 2-H), 6.58 (1H, dd, *J* 13.2, 11.7, 4-H), 7.23 (1H t, *J* 7.5, *p*-H), 7.34 (1H, m, 3-H), 7.45 (2H t, *J* 7.5, *m*-H), 7.61 (2H, d, *J* 7.5, *o*-H), 8.33 (3H, m, 5-H + β-H), 8.88 1H, tt, *J* 9.0, 1.2, γ-H), 9.48 (1H, d, *J* 8.1, 1-H), 9.90 (2H, dd, *J* 6.9, 1.2, α-H), 10.56 (1H, br s, NH); *m*/*z* (FAB; mNBA) 379.7 (M^+ + 2%, 41), 299.2 ($M^+ - C_5H_5N$), 154.7 (100).

(1*E*,3*E*)-*N*-[6-(4-Nitrophenyl)amino-5-chloro-2-pyridiniopyrimidin-4-yl]-5-iminopenta-1,3-dienolate 20 (0.19 g, 82%) was obtained as a dark red solid, decomp. > 80 °C (from EtOH–H_2O) (Found: C, 50.7; H, 4.5; N, 17.8. $C_{20}H_{17}ClN_6O_3\cdot 2.5H_2O$ requires C, 51.1; H, 4.7; N, 17.9%); λ_{max}(MeOH)/nm 374; ν_{max}/cm^{-1} 1668, 1622, 1614, 1561, 1501, 1422, 1329, 1236, 1144; δ_H(300 MHz, DMSO-d_6; Me_4Si) 6.08 (1H dd, *J* 14.8, 8.2), 6.50 (1H, dd, *J* 13.2, 11.6), 7.56 (1H, dd, *J* 14.8, 11.6), 7.83 (2H, d, *J* 8.9), 8.30 (5H, m), 8.80 (1H, t, *J* 7.8), 9.46 (1H d, *J* 8.2), 9.94 (2H, d, *J* 6.0); *m*/*z* (FAB; mNBA) 423 (M^+; 3), 55.2 (100).

(1*E*,3*E*)-*N*-[6-Amino-5-chloro-2-(4-pyridin-4′-ylpyridinio)-pyrimidin-4-yl]-5-iminopenta-1,3-dienolate 21 (0.16 g, 75%) was isolated as an orange–brown solid, mp > 300 °C (from EtOH–H_2O) (Found: C, 35.1; H, 4.2; N, 12.8. $C_{19}H_{16}ClN_6O\cdot 15H_2O$: C, 35.1; H, 7.1; N, 12.9%); $\lambda_{max}(CH_2Cl_2)$/nm 345, 270; λ_{max}(MeCN)/nm 346, 274; λ_{max}(MeOH)/nm 356, 274; ν_{max}/cm^{-1} 1623, 1598, 1563, 1477, 1410, 1345, 1242, 1160, 1137; δ_H(300 MHz, DMSO-d_6; Me_4Si) 6.10 (1H, dd, *J* 15.0, 8.1), 6.51 (1H dd, *J* 13.2, 11.4), 7.53 (1H, dd, *J* 15.0, 11.4), 8.13 (2H, dd, *J* 4.5, 1.8), 8.31 (1H, m), 8.76 (2H, d, *J* 7.2), 8.94 (2H, dd, *J* 4.5, 1.8), 9.48 (1H, d, *J* 8.1), 10.05 (2H, d, *J* 8.1), 10.35 (1H, br s); δ_C(75 MHz, DMSO-d_6, Me_4Si; DEPT 90) 110.0, 122.1, 124.8, 126.6, 138.2, 141.1, 151.1, 153.9, 192.7; *m*/*z* (FAB, mNBA) 380.8 (M^+ + 1, 28%), 154.7 (100).

(1*E*,3*E*)-*N*-[6-Anilino-5-chloro-2-(4-pyridin-4′-ylpyridinio)-pyrimidin-4-yl]-5-iminopenta-1,3-dienolate 22 (0.15 g, 67%) was isolated as an orange solid, decomp. > 180–185 °C (from EtOH–H_2O) (Found: C, 55.3; H, 5.9; N, 16.0. $C_{25}H_{19}ClN_6O\cdot 5H_2O$ requires C, 55.1; H, 5.4; N, 15.4%); λ_{max}(MeOH)nm 355, 276; ν_{max}/cm^{-1} 1625, 1604, 1562, 1497, 1454, 1421, 1345, 1233, 1162, 1141; δ_H(300 MHz, DMSO-d_6; Me_4Si) 6.14 (1H, dd, *J* 14.7, 8.1), 6.57 (1H, dd, *J* 13.2, 11.7), 7.26 (1H, t, *J* 7.2), 7.47 (2H, dd, *J* 7.5, 7.2), 7.53 (1H, dd, *J* 14.7, 11.7), 7.62 (2H d, *J* 7.5), 8.11 (2H, dd, *J* 4.5, 1.8), 8.31 (1H, d, *J* 13.2), 8.74 (2H, d, *J* 7.2), 8.93 (2H, dd, *J* 4.5, 1.8), 9.50 (1H d, *J* 8.1), 9.94 (2H, d, *J* 7.2), 10.53 (1H, br s); *m*/*z* (FAB, mNBA) 457.2 (M^+ + 2, 4%), 58.3 (100).

(1*E*,3*E*)-*N*-[6-(4-Nitrophenylamino)-5-chloro-2-(pyridin-4′-ylpyridinio)pyrimidin-4-yl]-5-iminopenta-1,3-dienolate 23 (0.13 g, 58%), decomp. 181–185 °C (from EtOH–H_2O (Found: C, 51.8; H, 5.1. $C_{25}H_{19}ClN_7O_3\cdot 6H_2O$ requires C, 52.0; H, 5.4%); $\lambda_{max}(CH_2Cl_2)$/nm 368; λ_{max}(MeCN)/nm 386, 275; λ_{max}(MeOH)/nm 372, 275; ν_{max}/cm^{-1} 1700sh, 1625, 1613, 1562, 1500, 1420, 1338, 1235, 1162, 1143, 1113; δ_H(300 MHz, DMSO-d_6; Me_4Si) 6.13 (1H, dd, *J* 14.7, 8.1), 6.58 (1H, dd, *J* 12.9, 11.4), 7.55 (2H dd, *J* 14.7, 11.4), 7.91 (2H, d, *J* 9.3), 8.13 (2H, dd, *J* 4.5, 1.5), 8.31 (2H, d, *J* 9.3), 8.38 (1H, d, *J* 12.9), 8.75 (2H, d, *J* 6.9), 8.94 (2H, dd, *J* 4.5, 1.4), 9.49 (1H, d, *J* 8.1), 10.03 (2H, d, *J* 7.2), 10.36 (1H, br s); *m*/*z* (FAB, mNBA) 502.5 (M^+ + 2, 1%), 58.3 (100).

X-ray crystal structure for 7

Monoclinic crystals of **7** were obtained by slow evaporation of a concentrated solution in toluene.

Crystal data. $[C_{14}H_{10}N_5Cl_2]^+ Cl^- 2H_2O$, M = 390.65. Monoclinic, a = 7.8039(3), b = 16.9741(4), c = 12.6159(6) Å, β = 99.222(2)°, V = 1649.6(1) Å^3, space group $P2_1/n$ (no. 14), Z = 4, D_c = 1.57 Mg m^{-3}. Red crystals, dimensions 0.20 × 0.30 × 0.45 mm^3, μ(Mo-Kα) = 0.57 mm^{-1}.†

Data collection and processing.[22] Nonius KappaCCD diffractometer, graphite-monochromated Mo-Kα radiation, 22923 reflections measured ($3 \le \theta \le 26°$, $-9 \le h \le 9$, $-20 \le k \le 20$, $-15 \le l \le 15$), 3159 symmetry independent reflections (merging R = 0.025), giving 2801 reflections with $I > 2\sigma(I)$.

Structure analysis and refinement. Structure was solved by direct methods[22] and all non-H-atoms were refined anisotropically (full-matrix least-squares refinement on F^2),[23] H-atoms using a riding model [H(O, N) free], R_1[for $I > 2\sigma(I)$] = 0.040, wR_2 (all data) = 0.109.

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† CCDC reference number 207/316. See http://www.rsc.org/suppdata/pl/1999/1325 for crystallographic files in .cif format.

References

1 W. D. Ollis, S. P. Stanforth and C. A. Ramsden, *Tetrahedron*, 1985, **41**, 2239.
2 (*a*) J. C. Earl and A. W. Mackney, *J. Chem. Soc.*, 1935, 899; (*b*) R. A. Eade and J. C. Earl, *J. Chem. Soc.*, 1946, 591; (*c*) F. H. C. Stewart, *Chem. Rev.*, 1964, **64**, 129.
3 (*a*) R. Huisgen, H. Gotthardt, H. O. Bayer and F. C. Schäfer, *Angew. Chem.*, 1964, **76**, 185; *Angew Chem., Int. Ed. Engl.*, 1964, **3**, 136; (*b*) H. O. Bayer, R. Huisgen, R. Knorr and F. C. Schäfer, *Chem. Ber.*, 1970, **103**, 2581.
4 (*a*) A. W. Johnson, *Ylid Chemistry*, Academic Press, New York, 1966; (*b*) I. Zugravescu and M. Petrovanu, *N-Ylid Chemistry*, McGraw-Hill, New York, 1976.
5 (*a*) A. R. Katritzky and J. M. Lagowski, *The Chemistry of Heterocyclic N-Oxides*, Academic Press, New York, 1971; (*b*) E. Ochiai, *Aromatic Amine Oxides*, Elsevier, Amsterdam, 1967.
6 (*a*) W. D. Ollis and C. A. Ramsden, *Adv. Heterocycl. Chem.*, 1976, **19**, 1; (*b*) C. A. Ramsden, in *Comprehensive Organic Chemistry*, ed. D. H. R. Barton and W. D. Ollis, Pergamon Press, Oxford, 1979, vol. 4; (*c*) C. G. Newton and C. A. Ramsden, *Tetrahedron*, 1982, **38**, 2965.
7 (*a*) J. N. Peng, X.-Z. Feng, Q.-T. Zheng and Z. T. Liang, *Phytochemistry*, 1997, **46**, 1119; (*b*) M. D. Menachery, H. M. Mandell, S. A. DeSaw, N. A. DeAntonio, A. J. Freyer and L. B. Killmer, *J. Nat Prod.*, 1997, **60**, 1328; (*c*) T. Jahn, G. M. König and A. D. Wright, *Tetrahedron Lett.*, 1997, **38**, 3883.
8 (*a*) P. A. Limbach, P. F. Crain and J. A. McCloskey, *Nucleic Acids Res.*, 1994, **22**, 2183; (*b*) R. Liou and T. Blumenthal, *Mol. Cell. Biol.*, 1990, **10**, 1764; (*c*) G. Dirheimer, in *Modified Nucleosides and Cancer*, ed. G. Glass, Springer-Verlag, Berlin, Heidelberg, 1983, p. 15; (*d*) C. C. Hsu-Chen and D. T. Dublin, *Nature*, 1976, **264**, 190; (*e*) A. G. Saponara and M. D. Enger, *Nature*, 1969, **223**, 1365.

9 (*a*) R. Huisgen, *Angew. Chem.*, 1980, **92**, 979; *Angew. Chem.*, *Int. Ed. Engl.*, 1980, **19**, 947; (*b*) R. Huisgen, *Angew. Chem.*, 1963, **75**, 742; *Angew. Chem.*, *Int. Ed. Engl.*, 1963, **2**, 565; (*c*) E. C. Taylor and I. J. Turchi, *Chem. Rev.*, 1979, **79**, 181.
10 (*a*) A. Schmidt, M. K. Kindermann and M. Nieger, *Heterocycles*, 1999, **51**, 237; (*b*) A. Schmidt and M. K. Kindermann, *J. Org. Chem.*, 1998, **63**, 4636; (*c*) A. Schmidt, *Heterocycles*, 1998, **48**, 865; (*d*) A. Schmidt and M. K. Kindermann, *J. Org. Chem.*, 1997, **62**, 3910.
11 (*a*) H. Ackermann and P. Dussy, *Helv. Chim. Acta*, 1962, **45**, 1683; (*b*) S. J. Childress and R. I. McKee, *J. Am. Chem. Soc.*, 1951, **73**, 3862; (*c*) J. Bratt, B. Iddon, A. G. Mack, H. Suschitzky, J. A. Taylor and B. J. Wakefield, *J. Chem. Soc.*, *Perkin Trans. 1*, 1980, 648; (*d*) R. D. Chambers, P. A. Martin, J. S. Waterhouse, D. L. H. Williams and B. Anderson, *J. Fluorine Chem.*, 1982, **20**, 507.
12 (*a*) S. J. Childress and R. I. McKee, *J. Am. Chem. Soc.*, 1950, **72**, 4271; (*b*) D. L. Ladd, *J. Heterocycl. Chem.*, 1982, **19**, 917.
13 A. Schmidt and A. Hetzheim, *Tetrahedron*, 1997, **53**, 1295.
14 (*a*) T. Zincke and W. Würker, *Justus Liebigs Ann. Chem.*, 1904, **338**, 121; (*b*) T. Zincke and W. Würker, *Justus Liebigs Ann. Chem.*, 1904, **338**, 127; (*c*) J. Becher, *Synthesis*, 1980, 589; (*d*) H. van der Plas, *Ring Transformations of Heterocycles*, Academic Press, London, 1973, vol. 2; (*e*) F. M. Hamer, *The Cyanine Dyes and Related Compounds*, in *The Chemistry of Heterocyclic Compounds*, ed. A. Weissberger, 1964; (*f*) K. S. Schofield, *Hetero-Aromatic Nitrogen Compounds*, *Pyrroles and Pyridines*, Butterworths, London, 1967; (*g*) O. Bayer, in *Houben-Weyl*, *Methoden der Organischen Chemie*, 4th edn., ed. E. Müller, vol 7/1, p. 262; (*h*) G. Spielberger, H. Glaser, F. Möller and R. Schröter, in *Houben-Weyl*, *Methoden der Organischen Chemie*, 4th edn., ed. E. Müller, vol. XI/1, p. 263.
15 T. Uno, K. Okumura and Y. Kuroda, *J. Org. Chem.*, 1980, **46**, 3175.
16 J. Becher, *Org. Synth.*, 1980, **59**, 79.
17 E. Alcalde, J. Dinarés, J. Elguero, J.-P. Fayet, M.-C. Vertut, C. Miravitlles and E. Molins, *J Org. Chem.*, 1987, **52**, 5009.
18 (*a*) E. Alcalde, I. Dinarés, J. Frigola, C. Jaime, J.-P. Fayet, M.-C. Vertut, C. Miravitlles and J. Rius, *J. Org. Chem.*, 1991, **56**, 4223; (*b*) M. L. Castellenos, S. Olivella, N. Roca, J. De Mendoza and J. Elguero, *Can. J. Chem.*, 1984, **62**, 687.
19 (*a*) D. Reinehr and T. Winkler, *Angew. Chem.*, 1991, **93**, 911; *Angew. Chem.*, *Int. Ed. Engl.*, 1981, **20**, 881; (*b*) K. E. Wilzbach, D. J. Rausch, *J. Am. Chem. Soc.*, 1970, **92**, 2178.
20 K. Kigasawa, K. Ohkubo, T. Kohagisawa, H. Shimizu, S. Saitoh and T. Kametani, *Heterocycles*, 1976, **4**, 1257.
21 A. S. Koch, K. C. Waterman, K. Banks and A. Streitwieser, *J. Org. Chem.*, 1990, **55**, 166.
22 G. M. Sheldrick, SHELXS-96, *Acta Crystallogr.*, *Sect. A.*, 1990, **46**, 467.
23 G. M. Sheldrick, SHELXL-97, University of Göttingen, 1997.

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