Ring Enlargement of Diaziridinone with 2-Substituted Pyrrole Leading to Bicyclic Triazine and Its Transformation to Novel Mesomeric Betaine

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A ring enlargement reaction of a diaziridinone was investigated as a possible method for synthesizing heterobicyclic compounds having a bridgehead nitrogen atom. One of the products was transformed to a mesomeric betaine. Thus, the reaction of *N,N'*-di-*tert*-butyldiaziridinone (1) and deprotonated pyrrole-2-carboxaldehyde gave 2,3-di-*tert*-butyl-1-hydroxy-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]-triazin-4-one (4) in good yield. Similarly, 1 was treated with deprotonated imidazole-2-carboxaldehyde to afford the corresponding heterobicycle 5. Under similar conditions, pyrrole-2-carbonitrile gave an acyclic 1:1 adduct, 1-(*N,N'*-di-*tert*-butylcarbazoyl)-2-cyanopyrrole (8), which was successfully cyclized under acid catalysis to 2,3-di-*tert*-butyl-1-imino-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (9) and the de-*tert*-butylated product 10. A novel mesomeric betaine, 2-*tert*-butylpyrrolo-[1,2-*d*][1,2,4]triazinium-4-olate (11), was obtained along with its isomer 12 by acidic de-*tert*-butylation of 4.

Diaziridinone[1,2] is among the highly strained, three-membered heterocycles that have received much attention because of their characteristically high reactivities.[1-5] This reactivity arises from their highly strained structures and polar carbon–heteroatom and/or heteroatom–heteroatom bonds. Their ring-opening propensity leads to ring enlargement reactions, and this has provided several versatile methods for the synthesis of medium-sized heterocycles.[3-5] Although the ring enlargement reactions of three-membered heterocycles containing one heteroatom (oxiranes, aziridines, and thiiranes) are well studied, those of two-heteroatom-containing three-membered rings are not.[2,6] We have focused on the representative diaziridinone as part of our effort to develop new synthetic reagents and routes to heterocyclic compounds important to the study of biologically active substances and materials science.

Previously, we reported the cycloaddition and addition–cyclization reactions of *N,N'*-di-*tert*-butyldiaziridinone (1), which lead to nitrogen-containing monocyclic and spirocyclic compounds.[3,4] This transformation involves carbon–nitrogen bond fission resulting from nucleophilic attack on the carbonyl carbon of 1, followed by recyclization.[3] As an extension of this type of ring enlargement, we investigated the synthesis of bicyclic heterocycles via the reactions of formyl- and cyanopyrroles and formylimidazole, all of which possess an endocyclic, nucleophilic nitrogen atom and an exocyclic, electrophilic group. These heterocycles are usually poor nucleophiles even in their anionic forms, but diaziridinone is unstable enough to be subject to their nucleophilic attack. The reaction proceeded with a catalytic amount of base to afford several bicyclic heterocycles.

Bicyclic compounds bearing a bridgehead nitrogen atom occur frequently in natural alkaloids. Pyrrolo[1,2-*d*][1,2,4]-triazine derivatives, for example, reportedly show biological activity,[7] and furthermore, one of the pyrrolotriazines prepared in this study affords a novel mesomeric betaine upon successive treatment with an acid. Mesomeric betaines[8] are of great interest not only because of their unique structures but also because of their reactivity as 1,3-dipoles that lead to fused heterocyclic compounds.[9]

Results and Discussion

Reaction with Pyrrole Derivative Leading to Pyrrolotriazine. *N,N'*-Di-*tert*-butyldiaziridinone (1) was treated with 1-sodio-2-formylpyrrole, generated from pyrrole-2-carboxaldehyde (2-formylpyrrole, 2) and 0.1 equiv of sodium hydride, at 60 °C in DMF for 20 h to afford the anticipated ring enlargement product, 2,3-di-*tert*-butyl-1-hydroxy-1,2,3,4-tetrahydropyrrolo[1,2-*d*]triazin-4-one (4) in 88% yield along with an unexpected product, 2,3-di-*tert*-butyl-1-(2-formyl-1-pyrrolyl)-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (6, yield 7%).

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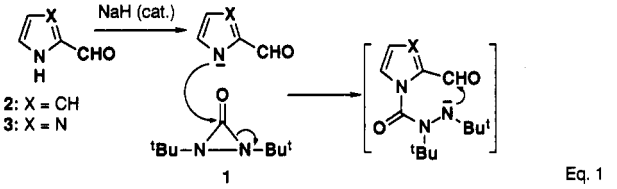
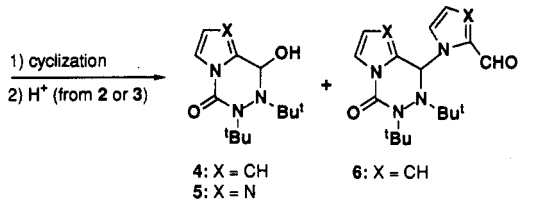
When the amount of sodium hydride was increased to 0.2 equiv, the yield of the pyrrolotriazine 4 was slightly reduced to 84%. With 1.0 equiv, only a small amount (2%) of 4 was obtained and 6 became the major product (yield 66%).

Similarly, the reaction of diaziridinone 1 with the anion generated from imidazole-2-carboxaldehyde (2-formylimidazole, 3) at 60 °C for 20 h gave the corresponding triazine, 6,7-di-*tert*-butyl-8-hydroxy-5,6,7,8-tetrahydroimidazo[1,2-*d*][1,2,4]triazin-5-one (5), but the yield (34%) was lower than that of 4 under the same conditions. The lower nucleophilicity of 1-sodio-2-formylimidazole may account for the decrease, but the yield of 5 increased to 66% when the reaction temperature was raised to 100 °C. When 1 equiv of sodium hydride was used, the yield of 5 decreased to 2% and no 6,7-di-*tert*-butyl-8-(2-formyl-1-imidazolyl)-5,6,7,8-tetrahydroimidazo[1,2-*d*][1,2,4]triazin-5-one, corresponding to 6, was obtained at all.



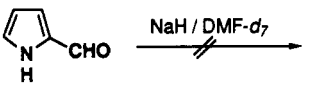
Eq. 1



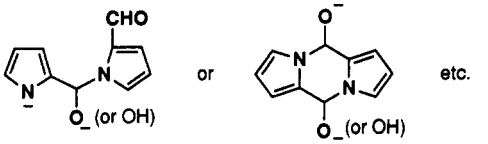
The structures of 4 and 6 were deduced from spectral data and elemental analyses. Formation of the urea-type carbonyl group of 4 was indicated by the ^{13}C NMR spectrum (a singlet at δ 150.8) and the IR spectrum (a strong absorption at 1672 cm^{-1}). In the ^1H NMR spectrum, a doublet at δ 5.61 coupled with a doublet at δ 2.23 (OH) was assigned as the methine proton at the C-1 position, that carbon signal being observed at δ 72.5 in the ^{13}C NMR spectrum. All other data also supported the presence of the pyrrolotriazine ring (see Experimental Section). On the other hand, spectral data indicated that compound 6 formally corresponds to that resulting from substitution of the hydroxy group of 4 with a 2-formylpyrrolyl group. H-1 was observed as a singlet at δ 7.15 in the ^1H NMR spectrum, and C-1 appeared at δ 63.6 in the ^{13}C NMR spectrum, assigned by a C–H correlated two-dimensional method. The NMR spectra indicated the presence of two types of pyrrole rings as well as a formyl group, as indicated by a doublet at δ 9.65 (^1H NMR) and a doublet at δ 178.8 (^{13}C NMR).

The mechanism of the formation of pyrrolotriazine 6 is not clear. When the formation of 1-sodio-2-formylpyrrole from 2-formylpyrrole and NaH in well-dried DMF-d_7 was monitored by ^1H NMR, no decrease in the area of the formyl proton was observed, suggesting that dimeric anions such as those shown in eq 2 were not generated. Furthermore, neither the reaction of 1-sodio-2-formylpyrrole with the 1:1 adduct 4 at 60 °C for 10 h in DMF nor that with the anion of 4 yielded the 2:1 adduct 6.

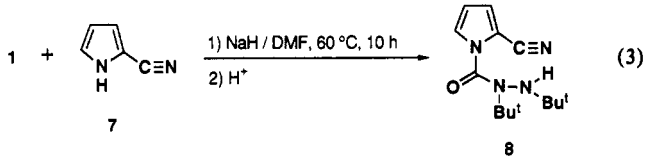
On the other hand, the reaction of diaziridinone 1 with the anion of pyrrole-2-carbonitrile (2-cyanopyrrole, 7) gave no cyclized products, but rather an acyclic 1:1 adduct,



Eq. 2

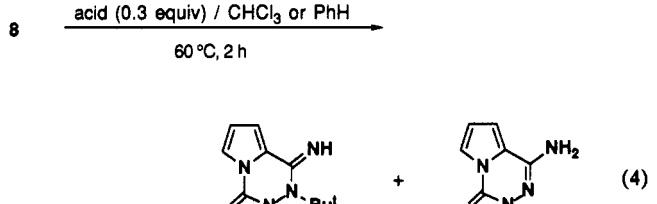


1-(*N*,*N*′-di-*tert*-butylcarbazoyl)-2-cyanopyrrole (8). In this reaction, a catalytic amount of the base again performs better than an equimolar amount (85% yield of 8 with 0.1 equiv of NaH, 80% yield with 0.2 equiv, and 32% yield with 1 equiv). The acyclic compound 8 showed IR absorptions at 2224 (C≡N) and 1712 (C=O) cm^{-1} and singlets at δ 112.9 (C≡N) and 157.7 (C=O) cm^{-1} in the ^{13}C NMR spectrum.



(3)

It is reasonable to assume that addition of the sterically hindered amino group to the cyano group does not occur under basic conditions. Thus, cyclization of the acyclic 1:1 adduct 8 was effected by treating it with an acid, such as *p*-toluenesulfonic acid or borontrifluoride etherate, to give 2,3-di-*tert*-butyl-1-imino-1,2,3,4-tetrahydropyrrolo-[1,2-*d*][1,2,4]triazin-4-one (9) along with the de-*tert*-butylated product, 1-amino-3-*tert*-butyl-3,4-dihydropyrrolo-[1,2-*d*][1,2,4]triazin-4-one (10).



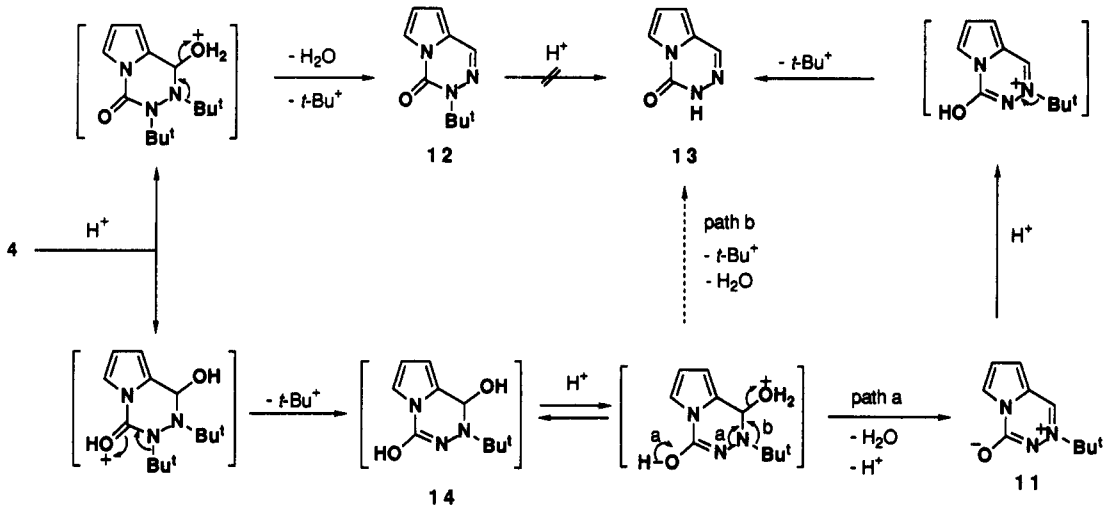
(4)

	9	10
TsOH, $CHCl_3$	17%	77%
$BF_3 \cdot OEt_2$, PhH	55%	43%

The cyclization to 9 could also be carried out in one pot without isolating the 1:1 adduct 8. After the reaction (60 °C, 10 h) of diaziridinone 1 and 2-cyanopyrrole pretreated with 0.1 equiv of sodium hydride, 0.4 equiv of the acid was added to the reaction mixture which was then heated at 60 °C for 3 h to provide a mixture of the cyclized products 9 and 10 in 12% and 79% yields, respectively.

Transformation of Pyrrolotriazine 4 to Mesomeric Betaine. Pyrrolotriazine 4 was easily de-*tert*-butylated by acid-catalyzed thermolysis to give two products, one of which proved to be a mesomeric betaine having a unique structure. Thus, pyrrolotriazine 4 was heated at 60 °C for 0.5 h in the presence of 0.3 equiv of $BF_3 \cdot OEt_2$ in $CHCl_3$ to afford 2-*tert*-butylpyrrolo[1,2-*d*][1,2,4]triazinium-4-olate(11)and3-*tert*-butyl-3,4-dihydropyrrolo[1,2-*d*][1,2,4]-triazin-4-one (12). The structures were deduced by

Scheme I



spectral analysis and that of **11** was confirmed by X-ray crystallographic analysis.

Mass spectra of the products **11** and **12** revealed that both have the same molecular weight (M^+: m/z 191), which corresponds to the loss of C_4H_8 and H_2O from the starting pyrrolotriazine **4**. The de-*tert*-butylation was confirmed by ^1H NMR, which revealed only one *tert*-butyl group for each compound. Product **11** provided an NMR spectrum in which all of the signals were shifted to considerably lower field than those observed for product **12**, indicative of delocalization of the positive charge. While no NOE between the methine proton (δ 7.92) and the *tert*-butyl group was observed for **12**, a significant NOE (13%) was observed between the methine proton (δ 8.37) and the *tert*-butyl protons of **11**, suggesting that de-*tert*-butylation was likely to have occurred at the 3-position of **11** and the 2-position of **12**. The carbonyl absorption of compound **11** occurred at 1626 cm^{-1}, which is atypical of a carbonyl group in a six-membered ring, while the C=O absorption of **12** appeared at 1700 cm^{-1}. These data support the structures assigned to **11** and **12**.

The structure of pyrrolotriazinium-4-olate **11** was unambiguously determined by X-ray crystallographic analysis (see Figure 1). The two fused rings of compound **11** are almost coplanar, and the C(9)–C(1), C(1)–N(2), N(2)–N(3), N(3)–C(4), and C(4)–N(5) bond lengths (1.393, 1.310, 1.383, 1.339, and 1.406 Å, respectively) are indicative of extensive conjugation in the 10π-aromatic system. The C=O bond length of 1.231 Å is slightly longer than the 1.20 Å C=O bond length of a typical mesomeric compound such as *N*-(*p*-bromophenyl)sydnone[10] (1.213 Å is the mean value of the C=O bond lengths of 13 compounds having a partial structure of NCON=N– selected from the Cambridge Crystallographic Data Base). This implies some contribution of single-bond character to the C=O bond, to some extent reflecting the mesomeric structure, and the larger double bond character is consistent with greater electron density on N-3 than on the carbonyl oxygen. All of these data and the direct X-ray analysis data fully support the mesomeric betaine structure of **11**.

The results of the de-*tert*-butylation of pyrrolotriazine **4** under various conditions are listed in Table I. After a reaction time of 20 h, 3,4-dihydropyrrolo[1,2-*d*][1,2,4]-triazin-4-one (**13**) was formed by bis de-*tert*-butylation.

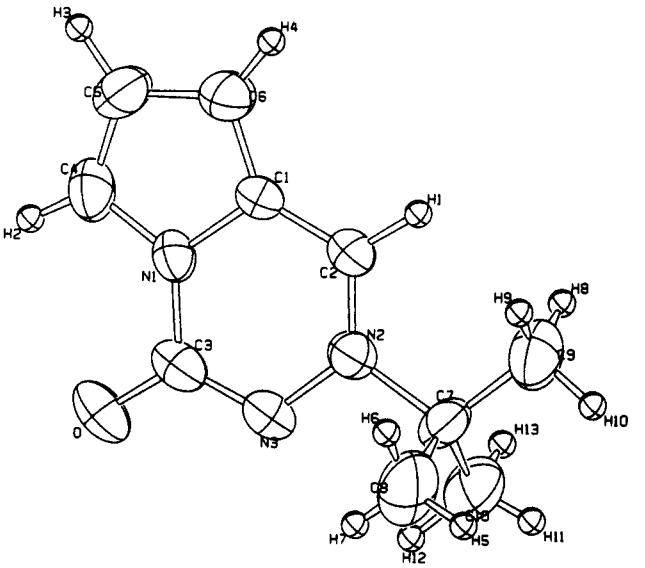


Figure 1. ORTEP drawing of the molecular structure of the mesomeric betaine **11**.

Table I. De-*tert*-butylation of Pyrrolotriazine 4 with Several Acids (at 60 °C for 20 h)

		yield[b] (%)		
acid[a]	solvent	11	12	13
BF_3·OEt_2	$CHCl_3$	50	32	9
BF_3·OEt_2	PhH	31	45	20
CF_3COOH	$CHCl_3$	49	35	0
CF_3COOH	PhH	34	40	0
TsOH[c]	$CHCl_3$	0	33	55
TsOH[c]	PhH	43	41	0

[a] Mole ratio 4:acid = 1:0.3. [b] By ^1H NMR. [c] *p*-Toluenesulfonic acid.

The ratio of **11** to **12** + **13** was generally greater in $CHCl_3$ than in benzene. Interestingly, *p*-toluenesulfonic acid (TsOH) in $CHCl_3$ accelerated the de-*tert*-butylation to give a higher yield of **13** without giving betaine **11**, whereas no triazinone **13** was formed in benzene. Thus, we may presume that **13** was formed via **11** and not via **12**. This was clearly supported by the independent treatment of isolated **11** and isolated **12** with TsOH under the above conditions. Compound **11** afforded **13** in a moderate yield, but **12** remained unchanged. Hence, the reaction path is believed to be that shown in Scheme I. Protonation of the hydroxy group at 1-position by acid causes dehydration and elimination of *tert*-butyl cation to give **12**. By contrast,

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protonation of the carbonyl oxygen at 4-position promotes elimination of the *tert*-butyl group to afford the intermediate 14. The mesomeric betaine 11 is formed from 14 by dehydration and deprotonation via path a. When the acid works effectively, betaine 11 is further protonated and thermally eliminates a *tert*-butyl group to afford 13. However, a contribution by path b, which involves dehydration and de-*tert*-butylation of 14, cannot be excluded at the moment.

Experimental Section

General. All reactions were carried out under a nitrogen atmosphere. *N,N'*-Di-*tert*-butyldiaziridinone (1),[1] pyrrole-2-carboxaldehyde (2),[11] and pyrrole-2-carbonitrile (7)[12] were prepared according to known methods. Imidazole-2-carboxaldehyde (3) was purchased from Aldrich Chemical Co. and used without further purification. Organic solvents such as dimethylformamide (DMF) and tetrahydrofuran (THF) were dried and distilled according to conventional methods. Melting points are uncorrected. ^1H and ^{13}C NMR spectra were recorded at 270 (or 90) and 70 (or 22.5) MHz, respectively, with tetramethylsilane as an internal standard.

A Typical Procedure for the Reaction of Diaziridinone 1 with Pyrrole-2-carboxaldehyde (2). A three-necked flask equipped with a dropping funnel was charged with sodium hydride (~50% in mineral oil, 43.1 mg, 0.99 mmol) and washed with hexane (5 mL × 2) and DMF (30 mL). The suspension was stirred and cooled with an ice bath while a solution of pyrrole-2-carboxaldehyde (2, 962 mg, 10.1 mmol) in DMF (30 mL) was added dropwise. The solution was stirred at room temperature for 1 h, and a solution of diaziridinone 1 (1.76 g, 10.4 mmol) in DMF (30 mL) was added to the mixture which was then heated at 60 °C for 10 h. After addition of H_2O (5 mL), the solvent was removed under reduced pressure. The residue was partitioned between CH_2Cl_2–H_2O (30 mL × 3), and the organic layer was dried (K_2CO_3) and concentrated. Addition of CH_2Cl_2–hexane to the residue gave 2.12 g (77%) of 2,3-di-*tert*-butyl-1-hydroxy-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (4) as crystalline material upon standing. The filtrate was concentrated and chromatographed (neutral Al_2O_3/hexane–AcOEt) to give 0.29 g (11%) of 4 and 0.14 g (7% based on 2) of 2,3-di-*tert*-butyl-1-(2-formyl-1-pyrrolyl)-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (6).

Pyrrolotriazine 4: mp 131–134 °C (colorless plates from hexane/CH_2Cl_2); IR (KBr disk) 3424 (OH), 1672 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.01 (s, 9H, *t*-Bu-2), 1.51 (s, 9H, *t*-Bu-3), 2.23 (d, $J_{OH,H-1}$ = 3.4 Hz, 1H, OH), 5.61 (d, $J_{H-1,OH}$ = 3.4 Hz, 1H, H-1), 6.11 (dd, $J_{6,8}$ = 1.4 Hz, $J_{7,8}$ = 3.2 Hz, 1H, H-8), 6.18 (dd, $J_{6,7}$ = $J_{7,8}$ = 3.2 Hz, 1H, H-7), 7.25 (dd, $J_{6,7}$ = 3.2 Hz, $J_{6,8}$ = 1.4 Hz, 1H, H-6); ^{13}C NMR ($CDCl_3$) δ 27.9 (*Me*$_3$C-2), 28.4 (*Me*$_3$C-3), 58.9 (Me$_3$*C*-2), 61.6 (Me$_3$*C*-3), 72.5 (C-1), 107.5 (C-8), 111.3 (C-7), 117.0 (C-6), 130.7 (C-9), 150.8 (C=O); MS (CI) *m/z* 266 (M^+ + 1). Anal. Calcd for $C_{14}H_{23}N_3O_2$: C, 63.37; H, 8.74; N, 15.84. Found: C, 63.57; H, 8.84; N, 15.84.

Pyrrolotriazine 6: mp 156–158 °C (colorless prisms from hexane/CH_2Cl_2); IR (KBr disk) 1694 (CHO), 1666 (NCON) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.13 (s, 9H, *t*-Bu-2), 1.16 (s, 9H, *t*-Bu-3), 6.14 (m, 2H, H-7 and H-8), 6.28 (dd, $J_{2',3'}$ = 3.2 Hz, $J_{3',4'}$ = 3.4 Hz, 1H, H-3'), 6.42 (ddd, $J_{2',4'}$ = 1.5 Hz, $J_{3',4'}$ = 3.4 Hz, $J_{H-4',CHO}$ = 1.2 Hz, 1H, H-4'), 7.04 (dd, $J_{6,7}$ = 3.9 Hz, $J_{6,8}$ = 1.7 Hz, 1H, H-6), 7.15 (s, 1H, H-1), 7.39 (dd, $J_{2',3'}$ = 3.2 Hz, $J_{2',4'}$ = 1.5 Hz, 1H, H-2'), 9.65 (d, $J_{H-4',CHO}$ = 1.2 Hz, 1H, CHO); ^{13}C NMR ($CDCl_3$) δ 28.2, 28.4, 61.5, 61.7, 63.6, 108.4, 109.4, 111.7, 117.5, 126.2, 126.2, 131.0, 131.9, 150.1, 178.8; MS (CI) *m/z* 343 (M^+ + 1). Anal. Calcd for $C_{19}H_{26}N_4O_2$: C, 66.64; H, 7.56; N, 16.36. Found: C, 66.45; H, 7.60; N, 16.32.

Reaction of Diaziridinone 1 with Imidazole-2-carboxaldehyde (3). The reaction employing 1 (179.6 mg, 1.06 mmol), imidazole 3 (95.5 mg, 0.99 mmol), and sodium hydride (50% in mineral oil, 5.0 mg, 0.10 mmol) was performed as described for the reaction with pyrrole 2 at 100 °C for 20 h. The reaction mixture was quenched with a small portion of H_2O and concentrated under reduced pressure. The residue was extracted with CH_2Cl_2 (20 mL × 3) and H_2O (10 mL), and the organic layer was washed with aqueous sodium hydrogen sulfite (30 wt %, 10 mL × 2) and H_2O (10 mL). Upon concentration of the CH_2Cl_2 extract was obtained 175.3 mg (66%) of 6,7-di-*tert*-butyl-8-hydroxy-5,6,7,8-tetrahydroimidazo[1,2-*d*][1,2,4]triazin-5-one (5) as white solid.

Imidazotriazine 5: mp 118–120 °C (colorless prisms from CH_2Cl_2); IR (KBr disk) 1712 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 0.95 (s, 9H, *t*-Bu-7), 1.52 (s, 9H, *t*-Bu-6), 5.76 (s, 1H, H-8), 6.90 (d, $J_{2,3}$ = 1.5 Hz, 1H, H-2), 7.36 (d, $J_{2,3}$ = 1.5 Hz, 1H, H-3); ^{13}C NMR ($CDCl_3$) δ 27.8, 27.9, 58.7, 62.5, 71.5, 113.9, 128.3, 148.2, 149.0; MS (CI) *m/z* 267 (M^+ + 1). Anal. Calcd for $C_{13}H_{22}O_2N_4$: C, 58.62; H, 8.33; N, 21.04. Found: C, 58.40; H, 8.40; N, 21.18.

Reaction of Diaziridinone 1 with Pyrrole-2-carbonitrile (7). The reaction employing 1 (1.09 g, 6.38 mmol), pyrrole-2-carbonitrile (7, 0.544 g, 5.91 mmol), and sodium hydride (50% in mineral oil, 0.029 g, 0.594 mmol) was performed as described for the typical procedure shown above to yield an oily residue containing 1-(*N,N'*-di-*tert*-butylcarbazoyl)-2-cyanopyrrole (8, 85% by ^1H NMR). The residue was chromatographed (neutral Al_2O_3/hexane–AcOEt) to give 379.6 mg (25%) of pure 8: colorless oil; IR (neat) 2224 (C≡N), 1712 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.02 (s, 9H, *t*-Bu), 1.36 (s, 9H, *t*-Bu), 4.1 (br s, 1H, NH), 6.25 (dd, $J_{2,3}$ = 2.9 Hz, $J_{3,4}$ = 3.7 Hz, 1H, H-3), 6.93 (dd, $J_{2,4}$ = 1.7 Hz, $J_{3,4}$ = 3.7 Hz, 1H, H-4), 7.35 (dd, $J_{2,3}$ = 2.9 Hz, $J_{2,4}$ = 1.7 Hz, 1H, H-2); ^{13}C NMR ($CDCl_3$) δ 27.4, 28.2, 55.0, 62.4, 103.9, 110.4, 112.9, 123.9, 126.8, 157.7; MS (CI) *m/z* 263 (M^+ + 1). Anal. Calcd for $C_{14}H_{22}ON_4$: C, 64.09; H, 8.45; N, 21.36. Found: C, 63.81; H, 8.38; N, 21.15.

Cyclization of Carbazoylpyrrole 8 to Pyrrolotriazines 9 and 10. A solution of carbazoylpyrrole 8 (82.6 mg, 0.316 mmol) and boron trifluoride etherate (11.7 μL, 0.095 mmol) in chloroform (1.5 mL) was heated at 60 °C for 2 h. Saturated aqueous $NaHCO_3$ (0.5 mL) was added to the reaction mixture which was then extracted with CH_2Cl_2 (10 mL × 2), dried (K_2CO_3), and concentrated. The residue contained 2,3-di-*tert*-butyl-1-imino-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (9) and 1-amino-3-*tert*-butyl-3,4-dihydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (10), whose yields were determined to be 53% and 45%, respectively, by ^1H NMR. The yields of 9 and 10 were changed to 25% and 73% with TsOH in benzene.

Analytical samples of 9 and 10 were obtained by column chromatographic treatment (neutral Al_2O_3/hexane–AcOEt) of the reaction mixture.

Pyrrolotriazine 9: mp 89–92 °C (colorless prisms from hexane); IR (KBr disk) 3388 (NH), 1672 (C=O, C=NH) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.45 (s, 9H, *t*-Bu-2), 1.68 (s, 9H, *t*-Bu-3), 3.9 (br s, 1H, NH), 6.37 (dd, $J_{6,8}$ = 1.5 Hz, $J_{7,8}$ = 3.7 Hz, 1H, H-8), 6.57 (dd, $J_{6,7}$ = 3.0 Hz, $J_{7,8}$ = 3.7 Hz, 1H, H-7), 7.67 (dd, $J_{6,7}$ = 3.0 Hz, $J_{6,8}$ = 1.5 Hz, 1H, H-6); ^{13}C NMR ($CDCl_3$) δ 28.9, 29.1, 51.3, 62.8, 103.5, 117.1, 121.3, 138.8, 143.7; MS (CI) *m/z* 263 (M^+ + 1). Anal. Calcd for $C_{14}H_{22}N_4$: C, 64.09; H, 8.45; N, 21.36. Found: C, 64.07; H, 8.46; N, 21.39.

Pyrrolotriazine 10: mp 125–127 °C (colorless prisms from CH_2Cl_2); IR (KBr disk) 3344 (NH_2), 1668 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.65 (s, 9H, *t*-Bu), 4.1 (br s, 2H, H-4), 6.50 (dd, $J_{6,8}$ = 1.5 Hz, $J_{7,8}$ = 3.7 Hz, 1H, H-8), 6.64 (dd, $J_{6,7}$ = 2.9 Hz, $J_{7,8}$ = 3.7 Hz, 1H, H-7), 7.72 (dd, $J_{6,7}$ = 2.9 Hz, $J_{6,8}$ = 1.5 Hz, 1H, H-6); ^{13}C NMR ($CDCl_3$) δ 28.5, 62.7, 105.0, 114.1, 117.6, 120.3, 139.4, 144.0; MS (EI) *m/z* 206 (M^+). Anal. Calcd for $C_{10}H_{14}ON_4$: C, 58.24; H, 6.84; N, 27.16. Found: C, 58.02; H, 6.79; N, 27.08.

De-*tert*-butylation of Tetrahydropyrrolotriazine 4 by Acidic Treatment. To a solution of 2,3-di-*tert*-butyl-1-hydroxy-1,2,3,4-tetrahydropyrrolo[1,2-*d*][1,2,4]triazine (4, 132.6 mg, 0.50 mmol) in chloroform (3 mL) was added 19 μL (0.15 mmol) of boron trifluoride etherate. The mixture was allowed to warm to 60 °C for 0.5 h and was quenched with saturated aqueous $NaHCO_3$. The mixture was extracted with CH_2Cl_2 (20 mL × 3), dried (K_2CO_3), and concentrated. The residue was chromatographed (neutral Al_2O_3/hexane–AcOEt–MeOH) to give 36.0 mg (38%) of 2-*tert*-butylpyrrolo[1,2-*d*][1,2,4]triazinium-4-olate (11)

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Table II. Crystal Data and Experimental Parameters for X-ray Determination of Compound 11

formula	$C_{10}N_3OH_{13}$
M_r	191.23
cryst dimens, mm	0.30 × 0.20 × 0.2
cryst syst	monoclinic
space grp	$P2_1/n$
a, Å	6.839(3)
b, Å	16.692(3)
c, Å	9.000(2)
β, deg	92.82(2)
V, Å^3	1026.0(5)
Z	4
$F(000)$	408
D_{calcd}, g/cm^3	1.238
temp, °C	25
μ, cm^{-1}	0.78
diffractometer	Rigaku four-circle diffractometer AFC6R
radiation	graphite-monochromated Mo Kα (λ = 0.710 69 Å)
scan type	$\omega - 2\theta$
2θ max, deg	55.0
2θ scan width, deg	1.57 + 0.30 tan θ
2θ scan speed, deg cm^{-1}	12.0
reflns measured	2638
reflns obsd[a]	2445
no of variables	179
R[b]	0.057
R_w[c]	0.034

[a] $|F_o| > 3\sigma(F_o)$. [b] $R = \sum||F_o| - |F_c||/\sum|F_o|$. [c] $R_w = [\sum_w||F_o| - |F_c||^2/\sum_w|F_o|^2]^{1/2}$, $w = 4F_o2/\sigma^2(F_o)^2$.

and 53.3 mg (56%) of 3-*tert*-butyl-3,4-dihydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (**12**).

Pyrrolotriazinium-4-olate 11: mp 130–131 °C (colorless prisms from CH_2Cl_2–Et_2O); IR (KBr disk) 1626 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ 1.74 (s, 9H, *t*-Bu), 6.91 (dd, $J_{6,7}$ = 2.4 Hz, $J_{7,8}$ = 3.9 Hz, 1H, H-7), 7.00 (dd, $J_{6,8}$ = 1.5 Hz, $J_{7,8}$ = 3.9 Hz, 1H, H-4), 7.95 (dd, $J_{6,7}$ = 2.4 Hz, $J_{6,8}$ = 1.5 Hz, 1H, H-6), 8.37 (s, 1H, H-1); ^{13}C NMR ($CDCl_3$) δ 28.8, 67.9, 112.6, 116.7, 117.7, 123.3, 124.0, 150.3; MS (EI) *m/z* 191 (M$^+$). Anal. Calcd for $C_{10}H_{13}ON_3$: C, 62.80; H, 6.85; N, 21.98. Found: C, 62.57; H, 6.76; N, 22.04.

Pyrrolotriazine 12: colorless oil; IR (neat) 1700 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ 1.68 (s, 9H, *t*-Bu), 6.60 (dd, $J_{6,8}$ = 1.2 Hz, $J_{7,8}$ = 3.9 Hz, 1H, H-8), 6.71 (dd, $J_{6,7}$ = 2.9 Hz, $J_{7,8}$ = 3.9 Hz, 1H, H-7), 7.73 (dd, $J_{6,7}$ = 2.9 Hz, $J_{6,8}$ = 1.2 Hz, 1H, H-6), 7.92 (s, 1H, H-1); ^{13}C NMR ($CDCl_3$) δ 28.6, 63.6, 107.1, 115.2, 116.4, 125.4, 129.9, 144.4; MS (EI) *m/z* 191 (M$^+$). Anal. Calcd for $C_{10}H_{13}ON_3$: C, 62.80; H, 6.85; N, 21.98. Found: C, 62.52; H, 7.09; N, 22.05.

Isolation of 3,4-dihydropyrrolo[1,2-*d*][1,2,4]triazin-4-one (**13**) was done as follows. To a solution containing 132.4 mg (0.50 mmol) of pyrrolotriazine **4** in chloroform (3 mL) was added 28.5 mg (0.15 mmol) of *p*-toluenesulfonic acid. The mixture was allowed to warm at 60 °C for 20 h and quenched with saturated aqueous $NaHCO_3$. The mixture was extracted with CH_2Cl_2 (10 mL × 3), concentrated, triturated with hexane (5 mL) and centrifugated. The residue was recrystallized from CH_2Cl_2 to give 34.7 mg (51%) of pyrrolotriazine **13**. The supernatant solution was concentrated to afford **12** (33%/^{1}H NMR) and **13** (4%/^{1}H NMR).

Pyrrolotriazine 13: mp 162 °C (lit.[13] mp 169 °C) (colorless needles from CH_2Cl_2); IR (KBr disk) 1718 cm^{-1} (C=O); ^{1}H NMR (CD_3OD) δ 6.86 (d, $J_{6,7}$ = $J_{6,8}$ = 2.0 Hz, 2H, H-7 and H-8), 7.78 (dd, $J_{6,7}$ = $J_{6,8}$ = 2.0 Hz, 1H, H-6), 8.15 (s, 1H, H-1); ^{13}C NMR (CD_3OD) δ 111.4, 117.5, 118.4, 128.2, 134.9, 148.0; MS (EI) *m/z* 135 (M$^+$).

X-ray Crystallographic Analysis of 11.[14] A summary of the fundamental crystal data and experimental parameters for structural determination is given in Table II. A single crystal of **11** obtained by slow crystallization from CH_2Cl_2–Et_2O was mounted in a diffractometer. The cell dimensions were refined by least-squares fitting the values of 25 reflections (with 27.4 < θ < 29.6). The structure was solved by direct methods.[15] The non-hydrogen atoms were refined anisotropically. All calculations were performed using the TEXSAN[16] crystallographic software package of Molecular Structure Corporation.

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(14) The authors have deposited atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

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