Research Article

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Reactions of 1,2,5-thiadiazole 1,1-dioxide derivatives with nitrogen nucleophiles. Part IV. Addition of α-diamines

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α-diamines, such as ethylendiamine and *o*-phenylendiamine, add to 3,4-aryl-disubstituted 1,2,5-thiadiazole 1,1-dioxides to give dihydropyrazines or quinoxalines, respectively and sulfamide. The new compound acenaphtho [5,6-b]-2,3-dihydropyrazine was synthesized and characterized. The addition of ethylendiamine to 3,4-diphenyl-1,2,5-thiadiazoline 1,1-dioxide gives 3,4-disubstituted thiadiazolidine 1,1-dioxide, dihydropyrazines, or pyrazines, depending on the reaction condition used. The reactions were followed by cyclic voltammetry and NMR spectroscopy which, in some cases, allowed the detection of the thiadiazolidine intermediate. Copyright © 2008 John Wiley & Sons, Ltd.

Supporting information may be found in the online version of this article.

Keywords: thiadiazoles; nucleophilic addition; α-diamines; dihydropyrazines; pyrazines; quinoxalines

INTRODUCTION

We have reported that several organic nucleophiles (alcohols, thiols, aromatic monoamines, and *N*-unsubstituted monocarboxamides), in aprotic solvent (MeCN, DMF, DMSO) solution,[1–6] add to only one of the two C=N double bonds of **1** (Scheme 1) in an equilibrium reaction. This decreased reactivity of the remaining double bond has also been observed with Grignard reagents.[7] Our work on the molecular structure of these compounds (single-crystal X-ray diffraction and theoretical calculations) allowed us to rationalize this behavior.[8]

However, di-addition products are obtained in the reactions of **1** with bifunctional, nitrogen nucleophiles of similar strength, such as unsubstituted, mono- and symmetrically disubstituted ureas, and thioureas, which add to both C=N double bonds yielding bicyclic thiadiazolidine compounds (Fig. 1). The stability acquired by cycle formation and the intramolecular character of the second addition might justify the increased reactivity.[6,9]

With stronger organic nucleophiles (aliphatic primary monoamines and phenylhydrazine), double addition and sulfamide displacement takes place to give α-bis-imines and α-bis-hydrazone, respectively (Fig. 2).[10]

We report in this work the results of our studies on the reactions of several derivatives of 1,2,5-thiadiazole 1,1-dioxide (Scheme 1): 3,4-diphenyl- (**1a**), phenanthro [9,10-c]- (**1b**) and acenaphtho [1,2-c]- (**1c**) 1,2,5-thiadiazole 1,1-dioxide and 3,4-diphenyl- 1,2,5-thiadiazoline 1,1-dioxide (**2a**), with *o*-phenylenediamine (*o*-**PDA**) and ethylenediamine (**EDA**) to give the corresponding quinoxalines, dihydropyrazines, and pyrazines.

The main reactants and products discussed in this work are summarized in Scheme 1.

The course of the reactions was followed by cyclic voltammetry (CV)[11] and NMR spectroscopy.

EXPERIMENTAL

Compounds **1a, b, c,** and **2a** were synthesized, purified, and characterized according to the literature.[5,13] Standard methods were used for the purification of commercial (p.a. grade) solvents and amines.[14–16] Purified solvents were further dried with freshly activated 4A molecular sieves and stored under a dry nitrogen atmosphere in a glove box. Their water content was 50 ppm or lower, as measured by Karl-Fischer coulometric titration.

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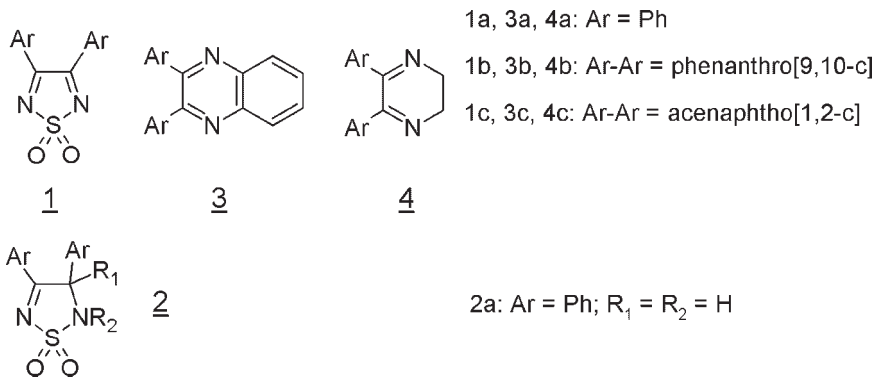

Scheme 1. Structures of the main reactants and products discussed in this work

^{1}H and ^{13}C NMR spectra were measured with a Brucker 200 MHz instrument and IR spectra with a Shimadzu IR-435 spectrophotometer (KBr disk).

The CV experiments were performed in a conventional undivided gas-tight glass cell with dry nitrogen gas inlet and outlet. The working electrode was a 3 mm diameter vitreous carbon disk encapsulated in Teflon, the counter-electrode was a 2 cm^2 Pt foil. A Ag^+ (0.1 M, MeCN)/Ag reference electrode (to which all potentials reported are referred) was used. The supporting electrolyte was $NaClO_4$. A LYP-M2 potentiostat, a 3-module LYP sweep generator, and a Houston Omnigraphic 2000 pen recorder were used. Since sulfamide is one of the products in most of the reactions studied in this work, it was always added to the control CVs scanned for product identification purposes. The CVs scans with added sulfamide are shown only in the cases in which its addition caused changes in the CV of the control substance.

Solution preparation, synthesis reactions, and CV experiments were made in a glove box under a dry nitrogen atmosphere at room temperature (*ca* 20 °C).

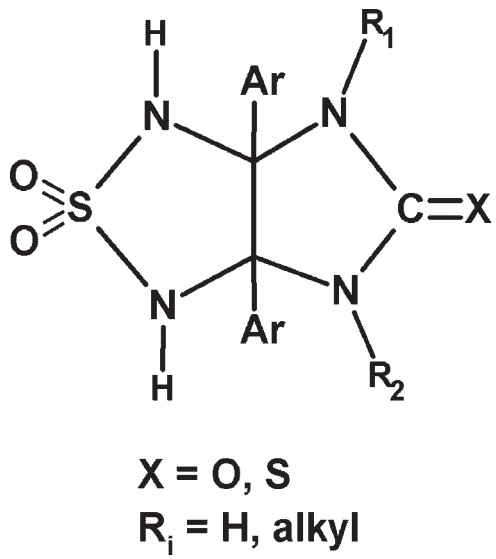

Figure 1. Stable products of the addition of mono- and symmetrically disubstituted ureas and thioureas to both C=N double bonds of **1** (Ar=Ph)

Synthesis of compounds

Quinoxalines

Quinoxalines were obtained in high yield by a general procedure, exemplified here for 2,3-diphenylquinoxaline (**3a**): **1a** (134 mg, 0.496 mmol) and *o*-**PDA** (227 mg, 2.10 mmol) were added to the DMF solvent (1 ml). The solution was left to stand overnight at room temperature. A precipitate was obtained upon addition of water (5 ml). The precipitated was filtered, washed thoroughly with water, dried at reduced pressure at 25 °C and recrystallized (ethanol-water) at r.t. to give 107 mg (0.379 mmol; 76% yield) of the chromatographically (TLC) pure solid **3a**; mp 122.0–123.0 °C (Lit[17]: 124 °C*)*. Its IR spectrum was identical to that reported.[18] Sulfamide was found in the mother liquors.

Dibenzo(a,c)phenazine (**3b**) was obtained by the same procedure through the mixture of similar molar proportions of **1b** and *o*-**PDA**. **3b** (mp 213.0–215.0 °C; Lit[17]: 217 °C) was obtained in 97% yield, and was identified by comparison (TLC, mixture mp, IR) with an authentic sample obtained according to a standard synthesis procedure.[17]

Dihydropyrazines and pyrazines

5,6-diphenyl-2,3-dihydropyrazine (**4a**) *from* **1a**: **1a** (145 mg, 0.537 mmol) and **EDA** (33.0 mg, 0.549 mmol) were added to the DMF solvent (2 ml). The precipitate obtained after a few minutes at r.t. was filtered. Water (5 ml) was added to the liquid filtrate and a new portion of the same solid (TLC) was obtained. Both solid combined were washed thoroughly with water and dried at reduced pressure at 25 °C. The pure (TLC) solid obtained was identified as **4a** (110 mg; 0.469 mmol; 87% yield) by IR

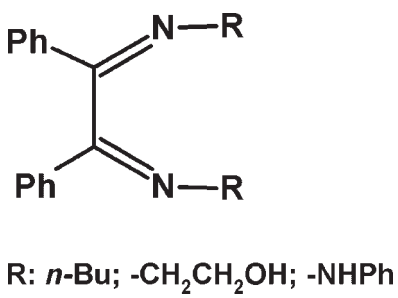

Figure 2. α-bis-imines and α-bis-hydrazone products of the diaddition reaction of aliphatic primary monoamines and pheylhydrazine

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spectrum[19] and melting point (160.4–165.0 °C; Lit:163–165 °C[20]; 162.5–163.5 °C[21,22]).

5,6-diphenyl-2,3-dihydropyrazine (**4a**) *from* **2a**: **2a** (239 mg 0.88 mmol) and **EDA** (112 mg, 1.86 mmol) were added to the DMF solvent (0.53 ml) and left at r.t. for 22 days. The solvent was vacuum rota-evaporated and the orange colored solid obtained was extracted with cyclohexane (20 ml). The remaining solid was dissolved in MeCN/benzene (1:1, 5 ml). The solution was cooled to −5 °C and an oily, orange colored liquid separated. The solution was evaporated to near dryness, and a yellow precipitate was obtained. A similar solid was obtained by rota-evaporation of the extracting cyclohexane solution to a *ca*. 1 ml final volume. Both solids reunited were recrystalized from ethanol-cyclohexane (1:3). The crystals (115 mg, 0.490 mmol, 56% yield) were identified as **4a** as above.

2,3-diphenylpyrazine: **4a** (87 mg; 0.37 mmol) and **EDA** (24 mg; 0.40 mmol) were dissolved in DMF (1 ml) and left to stand at r.t. for a month. The solvent was vacuum rota-evaporated at 40 °C. The remaining crystalline solid (56 mg, 0.33 mmol) was filtered and dried. It was identified as 2,3-diphenylpyrazine (yield: 89%) from its IR spectrum.[23]

Phenanthro [9,10-b]-2,3-dihydropyrazine (**4b**): This compound was identified by NMR spectroscopy in a solution of **1b** (37.0 mg, 0.138 mmol) and **EDA** (10.0 mg, 0.166 mmol) in $CDCl_3$ (0.7 ml) freshly prepared. **4b** dehydrogenates upon work-up yielding the corresponding pyrazine, which was identified by its reported IR spectrum.[24]

^1H NMR (δ, TMS) in $CDCl_3$: 8.26–7.34 (multiplet, C_{Arom}—H, 8H), 3.74 (singlet, $>CH_2$, 4H).

^{13}C NMR (δ, TMS) same solution: 153.8 (—C═N), 133.4–123.5 (six signals, C_{Ar}), 44.9 (heterocyclic sp^3 C-atoms).

Acenaphtho [5,6-b]-2,3-dihydropyrazine (**4c**): **1c** (420 mg; 1.73 mmol) and **EDA** (134 mg; 2.23 mmol) were dissolved in MeCN (15 ml). The dark brown precipitate obtained after a few minutes at r.t. was filtered and washed with ethanol and dried at reduced pressure at 25 °C (78 mg, solid A). The solvent was evaporated from the remaining solution at reduced pressure at r.t., and $CHCl_3$ (20 ml) was added to the resulting residue. An off-white solid remained undissolved and was identified by its IR spectrum as sulfamide (125 mg, 1.30 mmol). The chloroformic solution was decolorized with activated charcoal. Evaporation of the $CHCl_3$ solvent produced a dark orange solid (223 mg), which was found to be identical (TLC, IR) to solid A. Both solids, combined and recrystallized from ethanol/water (1:3) yielded acenaphtho [5,6-b]-2,3-dihydropyrazine (180 mg; 0.873 mmol; 44%), mp 143.0–144.0 °C. The single crystal X-ray analysis showed that the compound crystallyzed from ethanol/water with one hydration water molecule (Fig. 3. The corresponding CIF file is included as a supplementary material).

^1H NMR (δ, TMS) in DMSO-d6: 8.09–7.69 (multiplet, C_{Arom}—H, 6H), 3.79 (singlet, $>CH_2$, 4H).

^{13}C NMR (δ, TMS) same solution: 158.0 (C═N), 141.1–119.0 (six signals, C_{Ar}), 45.0 (heterocyclic sp^3 C-atoms).

IR (BrK, cm^{-1}): 3450 and 3350 (H_2O), 3030 (C_{Arom}—H), 2920 and 2850 (C_{Aliph}—H), 1630 (—C═N), 1580 (C_{Arom}—H), 1440–1405 (C_{Arom}—H).

RESULTS AND DISCUSSION

A summary of the reactions studied in this work is given in Table 1.

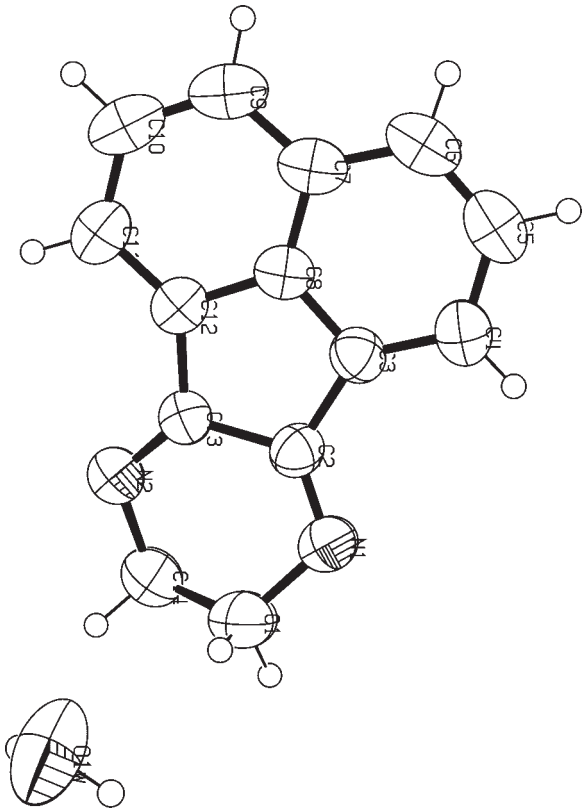


Figure 3. Ortep Diagram [25] of 4c showing the labeling of the non-H atoms and their displacement ellipsoids at the 50% probability level. The plot includes a crystallization water solvent molecule

Reactions of 1,2,5-thiadiazole 1,1-dioxides (1)

Reactions with o-PDA

The reactions of **1a**,**b** with *o*-**PDA** yielded the corresponding 2,3-diaryl substituted quinoxalines **3** (experimental Section) and sulfamide. A typical series of CV scans is shown in Fig. 4 for the reaction of **1a** with *o*-**PDA** at a molar ratio [*o*-**PDA**]/[**1a**] = 3. The initially observed **1a**/**1a**$^{\bullet-}$ and **1a**$^{\bullet-}$/**1a**$^{2-}$ reversible couples ($E_{1/2}$ *ca* −0.86 and −1.40 V, Fig. 4, solid line) were replaced at the end of the reaction by a peak at *ca* −2.0 V (Fig. 4, dotted line), which corresponds to the cathodic reduction of **3a**, as it is identical to that obtained in the CV of a solution of a synthesized sample of **3a** measured in the same experimental conditions (i.e., including the addition of sulfamide). The CV of pure **3a** is changed by the

Table 1. Summary of studied reactions

Substrate	Nucleophile	Products
1a, b	*o*-**PDA**	Quinoxalines
1a, b, c	**EDA**	Dihydropyrazines (**1a, b, c**) or pyrazines (**1a, b**), according to the reaction condition used.
2a	**EDA**	3,4-disubstituted thiadiazolidine 1,1-dioxide, dihydropyrazine or pyrazine depending on the reaction condition used.

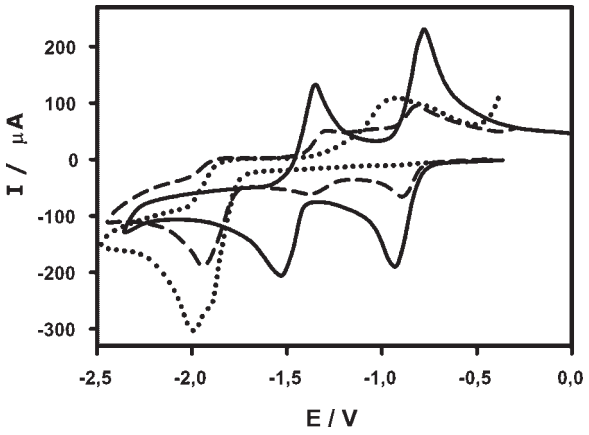


Figure 4. (-) CV of 1a 7.44 mM; (- - -): 7 h after the addition of *o*-PDA (24 mM), (●●●) idem, after 24 h. Solvent: DMF, Supporting electrolyte: 0.1 M $NaClO_4$; sweep rate: 0.2 Vs^{-1}

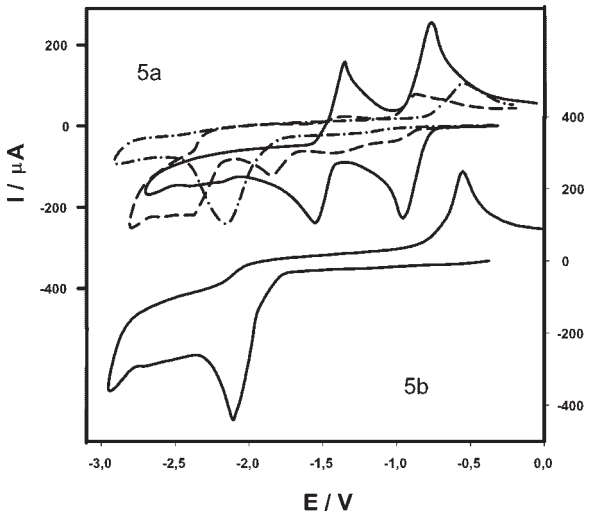


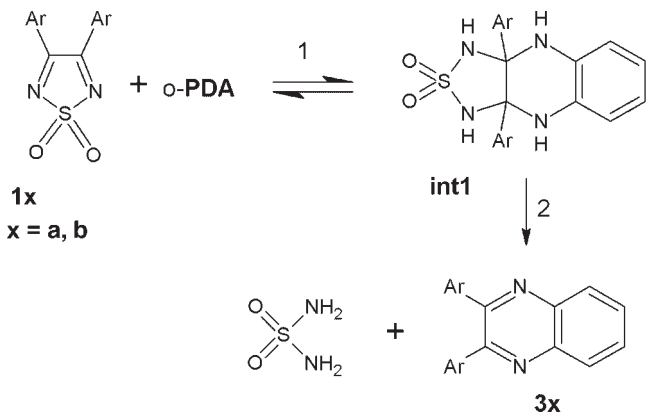
Figure 5. (a) (-) CV of 1a (7.81 mM); (- - -) 10 min after addition of EDA (7.80 mM); (-●-) idem after 92 min. (b) (–) CV of 4a (7.41 mM). Solvent: DMF, Supporting electrolyte: 0.1 M $NaClO_4$; sweep rate: 0.2 Vs^{-1}

presence of sulfamide. A CV of **3a** with and without added sulfamide is shown as a supplementary material in figure SM4c. At intermediate times (Fig. 4, dashed line) the current intensity decrease of the **1a** signals was accompained by a proportional increase of the **3a** peak.

However, essays at larger [*o*-**PDA**]/[**1a**] molar ratios (*ca* 70) showed that the decrease and almost total disappearance of the peaks of **1a** (at t *ca* 5 min) was followed by a time interval in which only a practically featureless CV was observed. The CV peaks of **3a** appeared and developed only afterwards.

We have reported that completely saturated thiadiazolidine cycles do not present voltammetric signals in the experimental cathodic range.[9,10] Thus, it seems reasonable to relate this almost featureless CV to a state of the reaction in which the concentration of an intermediate thiadiazolidine, **int1** (Scheme 2, **Ar**: phenyl-) predominates. Accordingly, reaction 1 should be the RDS at low *o*-**PDA** concentration. The increase in its rate, caused by an [*o*-**PDA**] increase, would produce the accumulation of **int1**, as reaction 2 becomes the RDS at high [*o*-**PDA**]/[**1a**] molar ratio.

Similar CV changes were found for the reactions of **1b** with *o*-**PDA**. These are provided as supplementary material (figures SM1a and 1b).



Scheme 2. Addition reaction of *o*-**PDA** to **1a,b** to give the corresponding quinoxalines **3a,b** and sulfamide

Reactions with EDA

The reactions of **1a**, **b,** and **c** with **EDA** yielded the corresponding 2,3-diaryl disubstituted dihydropyrazines **4** and sulfamide (experimental Section). Under adequate reaction conditions, as mentioned below, further reactions of the product with **EDA** were observed.

The course of the reaction of **1a** with **EDA** was followed by the successive CV scans shown in Fig. 5a,b.

The CV cathodic peaks of **1a** at *ca* −0.8 and −1.5 V (Fig. 5a, solid line) decreased in current intensity, while two cathodic peaks at −1.85 and −2.43 V increased after the addition of **EDA** (Fig. 5a, broken line). The potential of these peaks suggested their assignment to a thiadiazoline intermediate (**int2**, Scheme 3), according to the known CV reduction characteristics of the thiadiazolines of **1a**.[6,9,10,26] The thiadiazoline peaks decreased and disappeared subsequently, while a peak at −2.1 V (Fig. 5a, dash-dot line) increased and remained thereafter. The CV cathodic peak at −2.1 V corresponds to **4a** (Scheme 3), as shown by comparison with an authentic sample (Fig. 5b).

It was always observed, for all experimental molar [**EDA**]/[**1a**] ratios (range: 1–15), that the CV current intensity of the peak(s) of one compound decreased while those of its product(s) simultaneously increased. No sign of accumulation of a non-electroactive compound, such as the thiadiazolidine di-addition intermediate postulated as **Int1** in Scheme 1, was observed.

Although **4a** was stable in well-degassed DMF solutions (Fig. 6a, solid line), it was slowly oxidized to pyrazine, observed through its CV cathodic peak at *ca* −2.5 V (Fig. 6a, dashed line), particularly in the basic media provided by an excess of **EDA**. The process is shown in Fig. 6a (dotted line). As a result, a mixture of **4a** and its corresponding pyrazine was obtained in non-degassed solutions with a high **[EDA]/[1a]** molar ratio. Fig. 6b illustrates this situation for **[EDA]/[1a]** = 15. Similar reactions were also observed in other systems, but we have no explanation for these slow oxidations in solution. We can only offer further information: Given the following three solutions: (1) **4a** in DMF without degassing, (2) **4a** + **EDA** in degassed DMF, (3) **4a** + **EDA**

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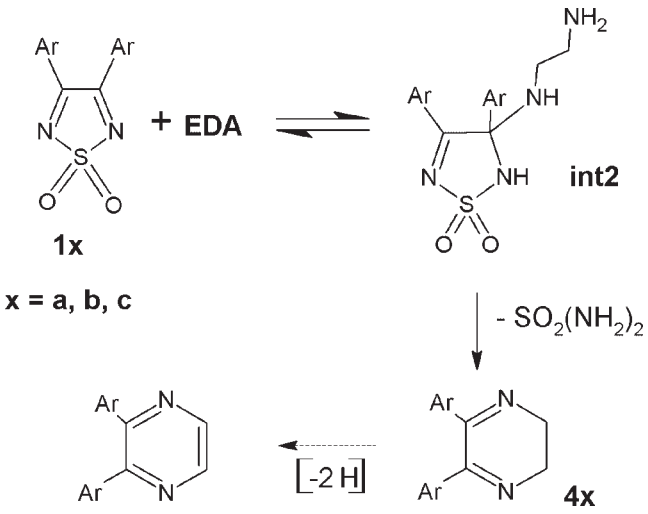


Scheme 3. Addition reaction of **EDA** to **1** to give the corresponding dihydropyrazines and pyrazines

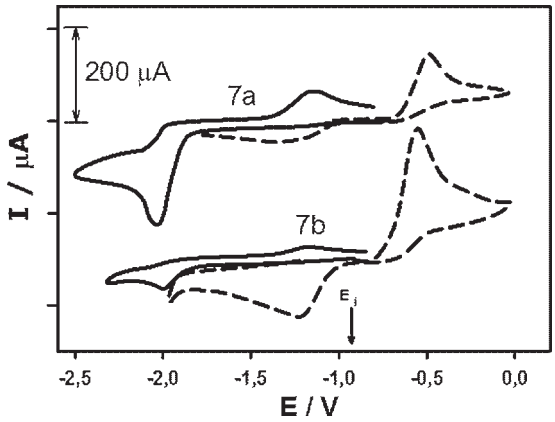


Figure 7. CVs of DMF solutions of 1b and EDA at low and high [EDA]/[1b] molar ratios. (a) 7.60 mM 1b, 37 mM EDA; (-) cathodic scan. (- - -) anodic scan. (b) 7.60 mM 1b, 135 mM EDA; (-) cathodic scan, (- - -) anodic scan. All scans were registered 1 day after solution preparation. Supporting electrolyte: 0.3 M $NaClO_4$, Sweep rate: 0.2 Vs^{-1}. E_i: rest potential, used as the initial potential of all scans

in DMF without degassing; it was experimentally observed that **4a** remained unaltered in (1), but transformed into pyrazine in (2) and (3). If several 'type 2' solutions are prepared with different **EDA** concentrations, the rate of the transformation of **4a** into pyrazine increased with the increase in **EDA** concentration. It is also known that molecular oxygen is only slightly soluble in DMF to begin with. Only a few microliters of **EDA** are added, so oxygen could not have been incorporated as an **EDA** dissolution. It might also be noted that the anions of **4b** and **5a** (shown below) disappear rapidly when its solution is exposed to the air. However, they can be kept indefinitely in DMF-**EDA** solutions prepared essentially as solution (2) above, which therefore cannot contain more than a negligible amount of oxygen.

The reaction of **1b** with **EDA** was similar to its reaction with **1a**. The CV cathodic peak of **4b** at −1.74 V was observed in the reaction of **1b** with **EDA** at a molar ratio **[EDA]/[1b]** *ca* 1, after the

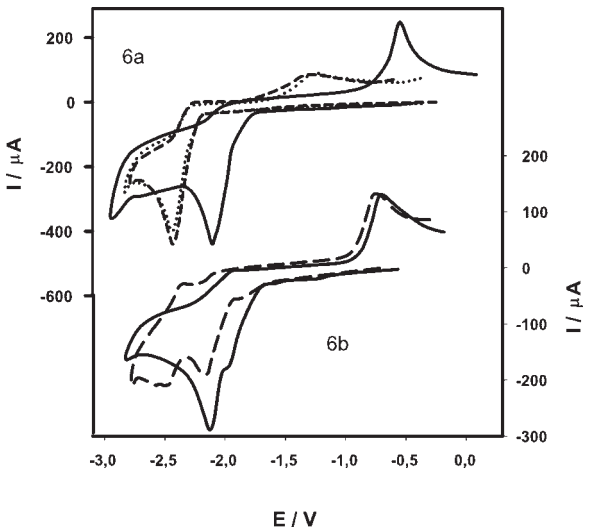


Figure 6. (a) (–) CV of 7.41 mM 4a; (- - -) CV of 6.94 mM 2,3-diphenylpyrazine; (●●●) CV of 7.49 mM 4a and 40 mM EDA scanned 13 days after EDA addition. (b) (–) CV of 7.51 mM 1a and 115 mM EDA scanned 1 day after EDA addition; (- - -) idem after a month. Solvent: DMF Supporting electrolyte: 0.1 M $NaClO_4$; sweep rate: 0.2 Vs^{-1}

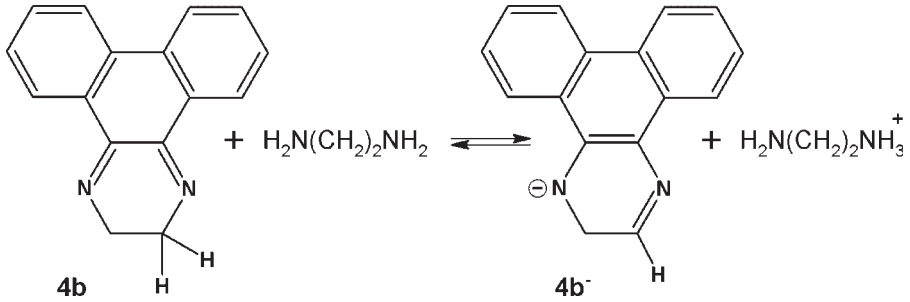
disappearance of the **1b** reversible CV couples (at *ca* −0.7 and −1.3 V). However, upon exposure to the atmosphere, the peak at −1.74 V disappeared and was replaced by the phenanthro [9,10-b]-pyrazine CV peak at −2.04 V (irreversible, identical to that of synthesized sample), which was the final product. The dihydropyrazine intermediate **4b** was identified through the NMR spectrum of the solution before work-up (experimental Section).

The reaction was also studied at larger **[EDA]/[1b]** molar ratios. At a molar ratio **[EDA]/[1b]** = 5, a CV scanned at the end of the reaction (Fig. 7a; solid line) shows the pyrazine peak at −2.04 V. An anodic peak at −0.55 V was also observed in the same solution if the scan was started in the anodic direction from its equilibrium potential E_i (Fig. 7a, broken line).

For even larger molar ratios (Fig. 7b, **[EDA]/[1b]** ≈ 18), the solution acquired a dark violet color and the CVs showed that the anodic peak at −0.55 V has grown larger (Fig. 7b, broken line) while the cathodic pyrazine peak at −2.04 V has decreased (Fig. 7b, solid line). The color disappeared upon exposure of the solution to the atmosphere.

We assigned the violet color and the anodic peak at −0.55 V to the anion $\mathbf{4b}^-$ (Scheme 4) on the basis of the following NMR data: the ^{1}H NMR spectrum of 0.15 mmol **4b**, 1.2 mmol **EDA** in 0.761 g DMF-d7, registered 2 h after solution preparation, presented signals corresponding to phenanthro [9,10-b]-pyrazine, sulfamide, and **EDA** in excess. In addition, a triplet at δ (TMS) = 4.41, 1H and a doublet at δ = 3.43, 2H were assigned to the —CH_2—CH=N— group in the $\mathbf{4b}^-$ anion. The signals of protonated **EDA** appeared as two multiplets partially superimposed on the solvent signal at *ca* δ (TMS) = 2.7–2.9. In the ^{13}C NMR spectrum, the signals of $\mathbf{4b}^-$ appeared at δ (TMS) = 64.4, 49.1, and 46.9. Both NMR spectra are included as supplementary material (figures SM2a and 2b).

The reaction of **1c** with **EDA** was somewhat analogous to those of **1a** or **b**, although surprisingly fast in comparison. The $\mathbf{1c}/\mathbf{1c}^{\bullet-}$ and $\mathbf{1c}^{\bullet-}/\mathbf{1c}^{2-}$ reversible couples (at *ca* −0.9 and −1.5 V), initially observed for a 6.73 mM **1c** solution in DMF solvent, disappeared almost instantaneously when **EDA** was added to the solution even in a [**EDA**]/[**1c**] molar ratio slightly larger than 1. An almost flat CV was observed for a very short time (*ca* 90 s). An irreversible



Scheme 4. $4b^-$ formation reaction

cathodic peak at −1.92 V, and a couple at *ca* −2.50 V appeared and remained thereafter. The final CV was identical to that obtained for a solution of **4c** and sulfamide.

As it was the case for **1b**, a solution of **1c** in a large excess of **EDA** ([**EDA**]/[**1c**] *ca* 18) developed a dark violet color that rapidly disappeared in the presence of air. We believe that an anion of **4c** was responsible for the color, but it could not be detected by NMR spectroscopy because the very large excess of **EDA** blocked other signals.

Reaction of 2a with EDA

Given that thiadiazolines have only one C=N double bond, a nucleophilic addition to give thiadiazolidines was their expected reaction with a strong nucleophile, such as **EDA**. This was in fact initially observed in the reaction of **2a** with **EDA** in DMF solution, as indicated by CV and NMR spectra. The thiadiazolidine underwent further reaction as mentioned below.

CV showed that the initial cathodic signal of **2a** at −2.11 V decreased with time without being replaced by any other CV peak. As it is shown in Fig. 8, for a DMF solution with [**EDA**]/[**2a**] = 4.4, the initial **2a** peak (Fig. 8a, solid line) showed an appreciably decreased current intensity 2 days after solution preparation (Fig. 8a, dashed line), and had practically disappeared 7 days later (Fig. 8a, dotted line), without being replaced by any other CV signal. As it was mentioned above, this behavior suggested the formation of an electroinactive thiadiazolidine **5a** (Fig. 9).

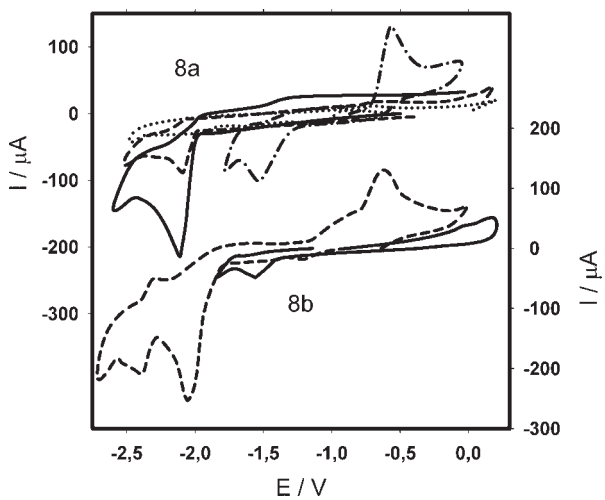
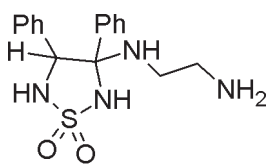


Figure 8. CVs of a solution of 2a (7.34 mM) and EDA (32 mM); ([EDA]/[2a] = 4.4). The scans were run immediately after dilution with DMF of a concentrated reaction solution ([2a] = 0.15 M; [EDA] = 0.66 M) in DMF, at the following times after reactants mixture: 8(a) (-) $t = 0$, (- - -) $t = 2$ days; (●●●) $t = 7$ days; (-●-) $t = 43$ days, anodic scan. 8b: (-) 2.5 h after exposure to the atmosphere, anodic scan; (- - -): 2.5 h after exposure to the atmosphere, cathodic scan. Sweep rate: 0.2 Vs^{-1}, supporting electrolyte: 0.45 M $NaClO_4$

In the ^{13}C NMR spectrum of a similar solution (figure SM3a, supplementary material) the signal of the single heterocyclic sp^3 C-atom of **2a** (at δ (TMS) = 75.6) (figure SM3b, supplementary material) was replaced by two signals of similar intensity (at δ (TMS) = 87.8 and 77.3) corresponding to the two different sp^3 C-atoms of **5a**. The single ^1H NMR resonance of **EDA** (δ (TMS) = 2.59) decreased and two triplets centered at δ (TMS) *ca* 3.2 and 2.7, assigned to the methylene protons in the **EDA** substituent of **5a** appeared (figure SM3c, supplementary material), and the **2a** 1H signal at $\delta = 6.05$ (H bonded to heterocyclic sp3 C-atom) (figure SM3d, supplementary material) was displaced to higher field ($\delta = 5.0$), as its adjacent sp^2 C-atom, double-bonded to N, was changed into the **EDA**-substituted sp^3 C-atom of **5a**.

However, it was observed that after the disappearance of the **2a** CV peak, an anodic signal appeared and grew. Fig. 8a (dash-dot line) shows this signal at its full strength, 43 days after solution preparation. The NMR spectra (see figures SM4a and SM4b, supplementary material) also changed: new signals (at δ (TMS) = 138.5 and 43.5) developed in the ^{13}C NMR and in the ^1H NMR (at δ (TMS) = 3.6) spectrum. The anodic CV signal suggested the formation of an anion derived from **5a**. A simulation of the ^{13}C-NMR of possible anions of **5a** agreed with that assumption, but could not decide among them.

In carefully degassed solutions, kept in well-stoppered vessels, the spectra remained unchanged thereafter. But if the vessel was opened and exposed to the atmosphere, the anion reacted to yield **4a** as could be observed in CV scans by the disappearance of the anodic peak of the anion (Fig. 8b, solid line), and its replacement by the cathodic peaks of **4a** and that of the pyrazine (Fig. 8b, dashed line). On continuing the exposure, only the pyrazine peak remained (not shown).



5a

Figure 9. Product of the EDA addition to 2a

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CONCLUSIONS

While the addition of unsubstituted or adequately substituted ureas and thioureas to 3,4-diphenyl-1,2,5-thiadiazole 1,1-dioxide was found to give stable five-five fusion bicyclic compounds (Fig. 1), the addition of α-diamines did not produce the expected five-six fusion bicyclic products. Instead, sulfamide loss was observed and dihydropyrazines or quinoxalines were formed in the reactions with **EDA** or *o*-**PDA**. The experimental results only allowed the conjecture of an unstable intermediate with the five-six fusion bicyclic structure for the reactions of **1a** and **1b** with *o*-**PDA** (**int1** in Scheme 2). The new compound: acenaphtho [5,6-b]-2,3-dihydropyrazine was synthesized and characterized.

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