Available online at www.sciencedirect.com
ScienceDirect
Tetrahedron
Tetrahedron 63 (2007) 1842–1848

Redoxactive derivatives of the betaine-alkaloid Punicin from *Punica granatum*. Synthesis and cyclovoltammetry

Andreas Schmidt,[a,*] Markus Topp,[a] Thorsten Mordhorst[a] and Oliver Schneider[b]

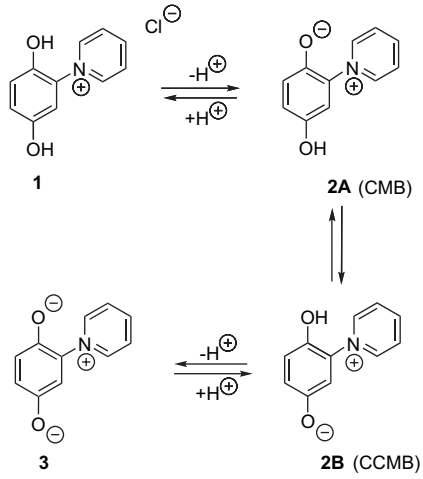
[a]*Clausthal University of Technology, Institute of Organic Chemistry, Leibnizstrasse 6, D-38678 Clausthal-Zellerfeld, Germany*
[b]*Clausthal University of Technology, Institute of Metallurgy, Robert-Koch-Strasse 42, D-38678 Clausthal-Zellerfeld, Germany*

Received 15 November 2006; revised 30 November 2006; accepted 11 December 2006
Available online 8 January 2007

Abstract—Hydroquinone- and naphthoquinone-substituted pyridinium, 2,4′-bipyridinium and 4,4′-bipyridinium salts were prepared. These compounds deprotonate to heterocyclic mesomeric betaines in aqueous solution, which can form conjugated or cross-conjugated tautomers. The redox behavior was studied by cyclovoltammetry.

1. Introduction

Investigations of the alkaloid **1** from *Punica granatum* L.[1] revealed that this product is a representative of the class of heterocyclic mesomeric betaines, depending on the reaction or measurement conditions.[2] Thus, the salt **1** is an acid in aqueous solutions, which are yellow-orange in color. NMR-investigations revealed that the natural product exists as a mixture of heterocyclic mesomeric betaines **2A** and **2B** in equilibrium (Punicin, Scheme 1). Interestingly, the betaine **2A** belongs to the class of conjugated mesomeric betaines (CMB), but its tautomer **2B** is a member of the class of cross-conjugated mesomeric betaines (CCMB). At higher pH values, deprotonation to the monoanionic species **3** occurs.[2]



Scheme 1. Punicin from *Punica granatum*.

The differences between these types of conjugation, which were defined in 1985 for heterocyclic mesomeric betaines,[3] are as follows. In the valence bond approach, common atoms for either charge in the canonical formulae exist in the conjugated mesomeric betaine **2A**, whereas the positive and the negative charges in the cross-conjugated system **2B** are restricted to separated parts of the molecule (Fig. 1).[4]

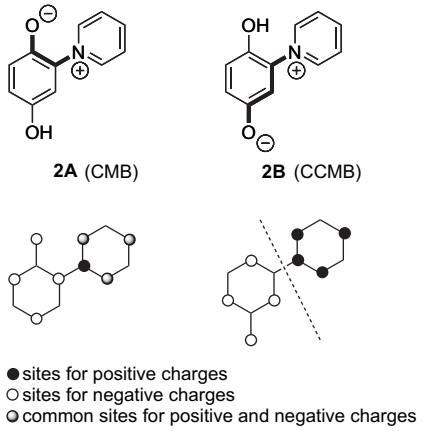


Figure 1. Conjugated (CMB) and cross-conjugated tautomers (CCMB).

In CCMB such as **2B** the cationic partial structure is always joined by a *union* bond to an unstarred position of the isoconjugated equivalent of the anionic moiety, i.e. the phenolate **I**. In the mesomeric betaine **2**, the isoconjugate equivalent is the benzyl anion **II** (Fig. 2). This position is a nodal position of the highest occupied molecular orbital (HOMO) **III** of **2**, which represents an 'isolator' between the charges. Thus, CMB as well as CCMB can be constructed by joining the cationic partial structure to starred or unstarred positions

* Corresponding author. Tel.: +49 5323 723861; fax: +49 5323 722858; e-mail: schmidt@ioc.tu-clausthal.de

0040–4020/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2006.12.023

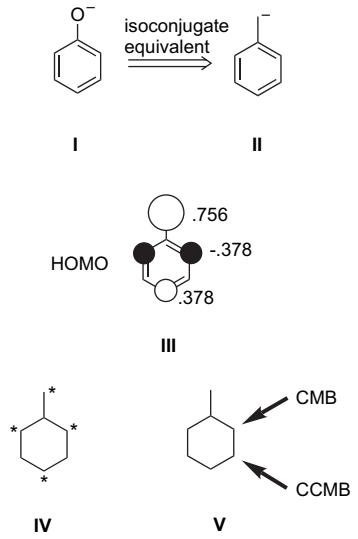
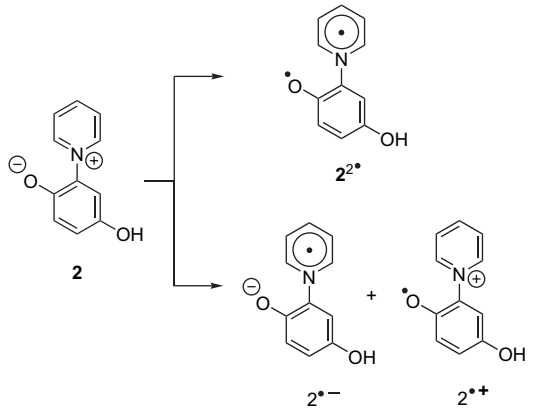


Figure 2. Characteristics of CMB and CCMB.

(**IV**, **V**). The chemical, physical, and biological consequences of the distinct types of conjugation in heterocyclic mesomeric betaines, including natural products such as alkaloids and nucleobases,[5] have been surveyed recently.[6]

Moreover, Punicin **2** possesses oxidizing (pyridinium) and reducing (benzene-1,4-diolate) partial structures. Internal electron transfers, i.e. disproportionation, resulted in diradicals $\mathbf{2}^{2\bullet}$, whereas an intermolecular redox reaction gave a radical anion $\mathbf{2}^{\bullet-}$ and a radical cation $\mathbf{2}^{\bullet+}$ (Scheme 2). Indeed, the natural product **1** gave an intense signal in ESR spectroscopy at g=2.00468. In triethylamine solution, in which the mesomeric betaine **2A/B** is formed from its protonated precursor **1**, the intensity of the signal is significantly enhanced.[7]



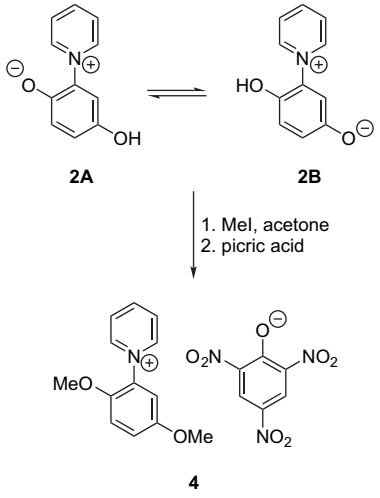
Scheme 2. Radicals from Punicin.

Considerable attention has been paid to heterocyclic mesomeric betaines as photoactive compounds with interesting physical properties such as photoinduced change of polarity, refractive index, and density.[8] New materials such as polyphenols,[9] polystyrenes,[10] methacryls[11] functionalized with mesomeric betaines, as well as polymers with mesoions in the main chain[12] have been prepared and examined. Conjugated mesomeric betaines such as *N*-oxides and their radicals aroused interest as structure elements of magnetic and conducting materials.[13] We found that derivatives of Punicin can be used in coupled photocatalytic electron transfers[7] and prepared the first modified polymers containing these interesting compounds.[14] In this paper we describe methylations of the betaine **2** and a cycloaddition reaction in order to study the properties of **2** as a hybrid of two types of conjugation. In addition, we were interested in derivatives of the natural product, studied deprotonations, and performed cyclovoltammetric examinations of 2,4′-bipyridine and naphthoquinone derivatives of Punicin **2**.

2. Results and discussion

2.1. Syntheses and spectroscopic features

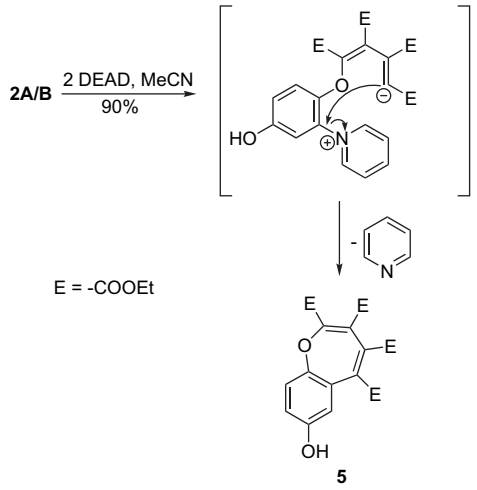
In order to gain knowledge about the alkylation site we treated the mesomeric betaine **2** with methyl iodide in anhydrous acetone. The NMR of the crude reaction mixture revealed that a mixture of 2′- and 5′-monomethylated products and the dialkylated derivative were formed under these conditions. The dimethyl derivative was smoothly separated from the reaction mixture by crystallization as picrate (Scheme 3).



Scheme 3. Methylation of Punicin.

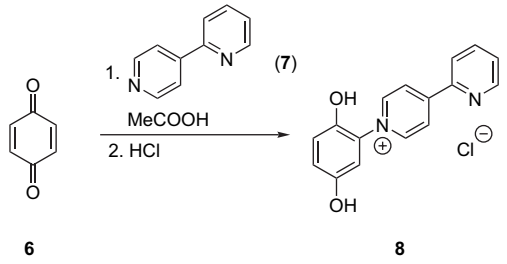
Two molecules of diethyl acetylenedicarboxylate (DEAD) reacted in acetonitrile with the betaines **2A/B** to afford the benzo[*b*]oxepine **5** in 90% yield. Obviously, the conjugated tautomer **2A** attacks the triple bond to form a terminal anion, which in turn adds a second molecule of DEAD. Ring closure to **5** is accomplished by extrusion of pyridine (Scheme 4). In accordance with the assigned structure, only three aromatic protons are detectable in ^{1}H NMR spectroscopy, in addition to four ethyl groups. In the ^{13}C NMR spectra, the seven-membered ring produces four signals of a push–pull-substituted diene with alternating downfield (C-2, C-4) and upfield shifts (C-3, C-5) of the resonance frequencies.

We next focussed our attention on variations of the benzoquinone and the pyridinium moieties of the original alkaloid from *P. granatum*. Thus, reaction of *p*-benzoquinone (**6**) with 2,4′-bipyridine (**7**) in glacial acetic acid resulted in the formation of 4-(2-pyridyl)-pyridinium chloride **8** as



Scheme 4. Cycloaddition of Punicin.

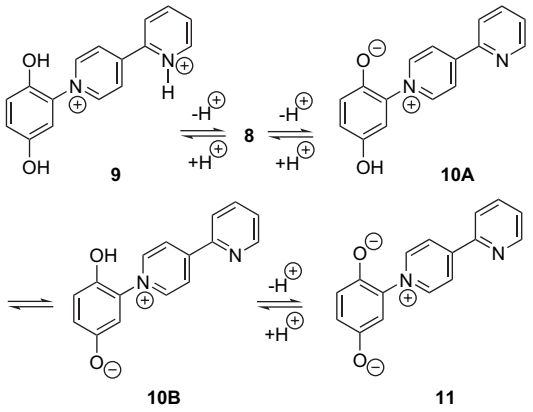
orange-colored solid in 84% yield (Scheme 5). The substitution site was proved by considerable downfield shifts of the resonance frequencies of the 4-substituted pyridine ring in comparison to the 2′-pyridine ring on conversion into the salt **8** ($\Delta\delta_H$=0.81/0.57 ppm). Two H/D-exchangeable resonance frequencies at δ=9.86 ppm and 10.63 ppm are detectable by ^{1}H NMR spectroscopy in DMSO-d_6. In analogy to the protonated Punicin **1**[2] we assigned the former mentioned signal to 2′-OH, and the latter to 5′-OH.



Scheme 5. Synthesis of 2,4′-bipyridine derivatives.

The salt **8** is protonated in solutions <pH 2 to give a yellow solution of the dication **9**. Deprotonation of **8**, which is orange in color, by treatment with the anion exchange resin Amberlite IRA-96 in its hydroxy form gave a red mixture of the conjugated mesomeric betaine **10A** and its cross-conjugated derivative **10B** (Scheme 6). However, partial decomposition on the resin occurred on trying to isolate the betaine, so that some amounts of 2,4′-bipyridine were isolated as well. On addition of strong bases a violet solution was formed, presumably due to deprotonation of the second OH group to anion **11**. However, as no compound could be isolated from the mixture due to decomposition, we cannot exclude the formation of ring-opened products—as previously observed[2]—from consideration. In solution under an inert atmosphere, however, these protonation/deprotonation processes are reversible. Results of a titration of **8** with 0.1 m NaOH and 0.1 m HCl, respectively, are summarized in Table 1.

The (naphthoquinon-3-yl)pyridinium salt **13** was prepared according to modified literature procedures, as in our hands the original procedure gave no isolable product.[15] Thus,



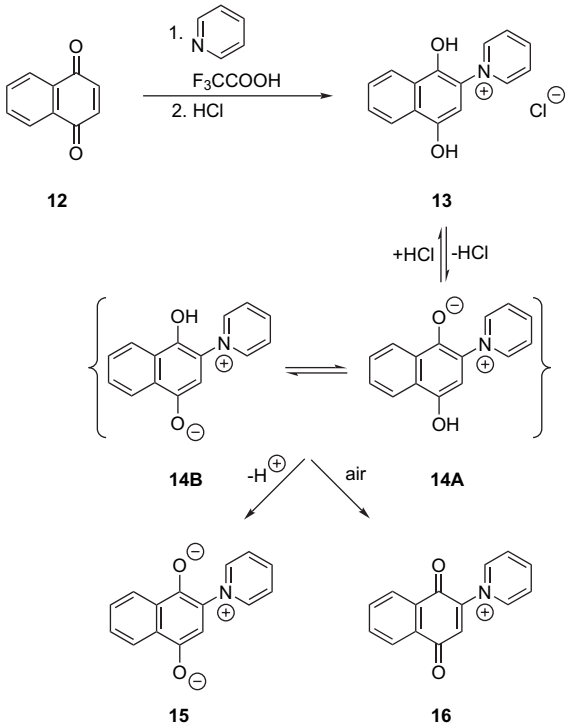
Scheme 6. Acid–base properties.

Table 1. Acid–base parameters

Compound	pH_0	$pK_a(1)$	$pK_a(2)$	$pK_a(3)$	c_o[a]	K_c	α
8	4.12	9.8	7.3	n.d.[b]	10.0	5.8×10^{-7}	7.6×10^{-3}
13	3.19	10.4	6.0	—	10.0	4.2×10^{-5}	6.5×10^{-2}
17	3.70	10.8	5.2	n.d.[b]	10.0	4.0×10^{-6}	2.0×10^{-6}
18	2.53	10.2	5.0	—	10.0	8.7×10^{-4}	3.0×10^{-1}
				—		2.2×10^{-4}[c]	1.5×10^{-1}[c]

[a] Initial concentration=10.0 mmol/L.
[b] n.d.=not detectable.
[c] Corrected values (half concentration of free H^+).

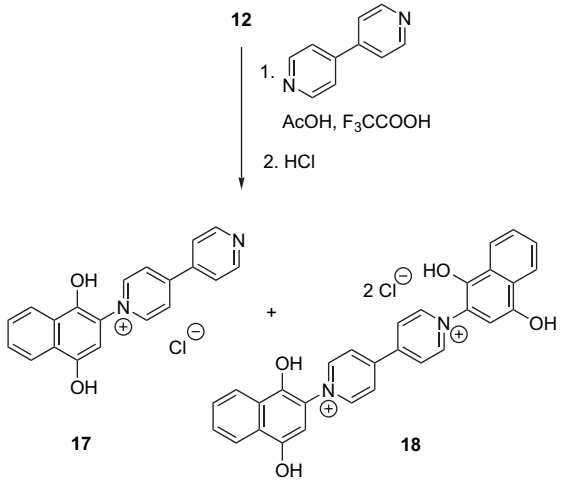
naphthoquinone (**12**) reacted with pyridine in the presence of trifluoroacetic acid in chloroform to give **13** as a brownish solid in 63% yield (Scheme 7). On deprotonation, the mixture of mesomeric betaines **14A/B** forms as a dark brown solid, which decomposed rapidly on the anion exchange resin. The pK_a values and acid–base parameters of **13** are



Scheme 7. Synthesis of naphthoquinone derivatives.

presented in Table 1. The values suggest the formation of the anionic species **15** on addition of excess base. Attempts to isolate these species, however, failed. Spraying a sample of the salt **13** in methanol gave a peak at *m*/*z* 236 under electrospray ionization conditions at 0 V fragmentor voltage in the cation detection mode. Obviously, the salt **13** is too acidic to be detected at *m*/*z* 238 under these very mild conditions. Instead, the prominent molecular peak of the cationic quinone **16** is found. In a solution of **13** in DMSO-d_6, however, no resonance frequencies of **16** can be detected in ^{1}H NMR spectroscopy. Our attempts to isolate **16** after oxidation under several conditions failed.

A solvent screening revealed that a mixture of acetic acid and trifluoroacetic acid is the best medium for the reaction of naphthoquinone (**12**) with 4,4′-bipyridine. Acetone precipitates a mixture of the monosubstituted salt **17**, which is brownish-red in color and the disubstituted dark violet 4,4′-bipyridinium salt **18**, which can smoothly be separated by recrystallization from acids (Scheme 8). Again, the salt **17** can exclusively be detected as its oxidized product at *m*/*z* 313 under ESI as well as MALDI-TOF conditions in mass spectrometry, as it forms a betainic species in water, which cannot be found in the cation or anion detection mode (cf. Table 1). In the ^{1}H NMR spectra in DMSO-d_6, however, the OH groups are clearly detectable, and carbonyl groups—which would hint at a quinone—are not visible in the IR spectra.



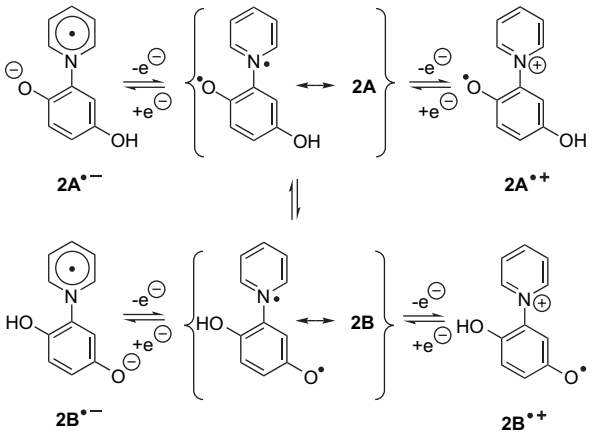
Scheme 8. Synthesis of 4,4′-bipyridinium salts of naphthoquinone.

The acid–base parameters of dication **18** prove that deprotonation occurs in aqueous solutions. In theory, monocations, three distinct types of mesomeric betaines (CMB/CMB, CMB/CCMB, CCMB/CCMB combinations), monoanions, and dianionic species can be formulated. Two pK_a values were determined due to the symmetry of the molecule (Table 1). Attempts to isolate deprotonated species after treatment of **17** and **18** with the anion exchange resin Amberlite IRA-402 in its hydroxy form failed due to decomposition on the resin. Instead, 4,4′-bipyridine was isolated in all cases.

2.2. Electrochemical characterizations

Electrochemical techniques allow the characterization of the redox behavior of electroactive species, the determination of redox potentials, reaction mechanisms, and the lifetime of reactive intermediates like radicals. For a characterization of the redox behavior, the salts **1**, **8**, and **13** were dissolved in an aqueous solution of 0.5 M NaCl as supporting electrolyte. Cyclovoltammetry was performed in these solutions at various scan rates and in different potential ranges. Measurements in pure NaCl without addition of any organic salt were carried out in order to distinguish effects from the supporting electrolyte and from the species of interest.

Unsubstituted hydroquinone can be oxidized reversibly to quinone with a standard potential of 0.899 V versus NHE (0.658 V vs SCE).[16] The compounds described in this paper are more complex and should show more than a single redox transition. The tautomers of Punicin **2** cannot only be oxidized forming a radical species, it also can be reduced at the pyridinium functionality, as shown in Scheme 9. Naphthoquinone derivatives have been reported to show two pairs of redox peaks during cyclovoltammetry in non-aqueous solution.[17]



Scheme 9. Potential reductions and oxidations of Punicin.

In cyclovoltammetry the electrode potential of a working electrode (measured current-less against a reference electrode) is varied at a constant sweep rate between a lower and an upper potential limit, and the resulting current (between working electrode and an auxiliary electrode, the counter electrode) is recorded as a function of applied potential. Oxidation processes (anodic reactions) manifest themselves in positive current peaks, and reduction processes (cathodic reactions) in negative peaks.

Figure 3 shows the voltammograms of Punicin **2** at sweep rates between 10 and 100 mV/s. There is a characteristic anodic peak at potentials of 0.15–0.20 V versus SCE and a characteristic cathodic peak at potentials between 0.078 and 0.09 V versus SCE (and some less clear cathodic features at lower potentials). In addition the current strongly increases when approaching the upper potential limit of 0.8 V. The cathodic peak at very low potentials cannot be clearly assigned to Punicin. All currents increase with sweep rate, only the anodic peak shows a somewhat erratic behavior. The potential variation of the cathodic peak is rather low, and the current scales linearly with the square root of sweep rate. This suggests at first sight that anodic and cathodic peaks correspond to the same redox reaction, and that these

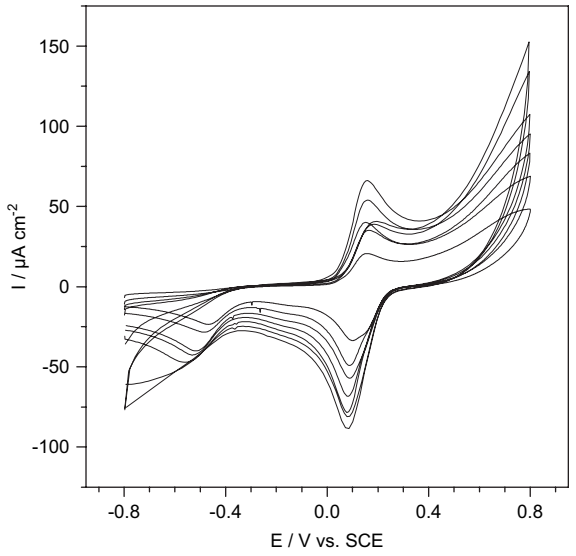


Figure 3. Cyclic voltammograms measured in a solution of 0.001 mol/L Punicin and 0.5 mol/L NaCl at sweep rates between 10 and 100 mV/s.

peaks are reversible. However, a variation of Punicin concentration showed that the cathodic peak current and the anodic current at 0.8 V scale linearly with Punicin content in solution—and are therefore clearly connected to its redox behavior—whereas the anodic current is invariant. In addition an increase of the upper potential limit to 1.0 V increases the cathodic currents indicating that the reduction reaction is correlated with the second rise in anodic current and not with the anodic peak.

Compound **8** shows similar CV characteristics like Punicin. At low sweep rates the cathodic currents are flat over a large potential range. Cathodic peak potentials range between 0.067 and 0.11 V versus SCE, whereas the anodic peak potential is close to 0.25 V. This indicates that for **2** and **8** the basic features in the voltammogram are those of the hydroquinone moiety, but that the pyridinium and 4-(2-pyridyl)-pyridinium chloride groups influence the redox transitions.

Compound **13** behaves differently. There is a very broad anodic wave at peak potentials between 0.04 and 0.07 V. The major cathodic feature is a broad peak at potentials between −0.5 and −0.6 V, which might be related to the reduction of the *N*-(2,7-dihydroxynaphthyl)pyridinium chloride. The cyclovoltammetric data for all compounds are summarized in Table 2.

In summary we present additional features of the unusual alkaloid Punicin **2** from *P. granatum*. Some derivatives possessing 2,4′-bipyridine, 4,4′-bipyridine, and naphthoquinone moieties are presented and studies of their quite complicated acid–base properties, their tautomerism (leading to two distinct types of heterocyclic mesomeric betaines), and their redox behavior are described. It can be stated from the cyclovoltammetric measurements that all compounds investigated show electroactive behavior.

Table 2. Peak potentials of different redoxactive species based on Punicin

Compound	$E_{p,a}$ (v)	$E_{p,c1}$ (v)	$E_{p,c2}$ (v)
1	0.196 (100)	0.086 (100)	—
	0.160 (50)	0.078 (50)	—
8	0.265 (100)	0.067 (100)	—
	0.241 (50)	0.051 (50)	—
13	0.066 (100)	−0.15 (100)	−0.586 (100)
	0.043 (50)	−0.146 (50)	−0.549 (50)

Potentials are given in volts versus SCE, and sweep rates v in mV/s.

3. Experimental

3.1. General

The ^{1}H and ^{13}C NMR spectra were recorded on a Bruker Avance 400 and DPX 200 at 400 and 200 MHz, respectively. The chemical shifts are reported in parts per million relative to internal tetramethylsilane (δ=0.00 ppm). FTIR spectra were obtained on a Bruker Vector 22 in the range of 400–4000 cm^{-1} (2.5% pellets in KBr). The GC–MS spectra were recorded on a GC Hewlett–Packard 5980, Serie II in combination with an MS Hewlett–Packard 5989 B, and on a Varian GC3900 with SAT2100T mass spectrometer. Melting points are uncorrected. Cyclovoltammetry was performed with an electrochemical interface by Solartron. A simple electrochemical cell made from glass and Teflon was used for these experiments. A glassy carbon electrode served as working electrode, which was polished prior to use. A Pt-coated Ti-wire was used as a counter electrode, and a saturated calomel electrode (SCE, E=0.241 V vs normal hydrogen electrode) as a reference electrode. Measurements were controlled using an SI1287 Electrochemical Interface. The measuring volume was 10 mL and the concentration of the analyte was 1 mmol/L.

3.2. Syntheses

3.2.1. *N*-(2′,5′-Dimethoxyphenyl)-pyridinium picrate 4. A suspension of mesomeric betaine **2A/B** (0.3 mmol, 50.0 mg) in anhydrous acetone and methyl iodide (3 mmol, 400 mg) was heated at reflux temperature for 5 h and then poured into water. Evaporation to dryness yielded a mixture of compounds, which was dissolved in ethanol, and poured into a saturated solution of picric acid in the same solvent. On cooling the heated solution a brown precipitate formed, which was collected by filtration, yield 40 mg (60%), mp 133 °C (found: C, 49.25; H, 4.02; N, 11.96. $C_{19}H_{16}N_4O_9 \cdot H_2O$ requires C, 49.36; H, 3.92; O, 12.12); δ_H (DMSO-d_6) 9.18 (m, 2H; α-H), 8.77 (t, J=7.8 Hz, 1H; γ-H), 8.59 (s, 2H; picrate), 8.29 (m, 2H; β-H), 6.90–7.30 (m, 3H; $H_{Ar.}$), 3.80 (s, 3H), 3.75 (s, 3H); δ_C (DMSO-d_6) 156.0, 150.3, 150.0, 148.1, 143.7, 129.1, 125.1, 124.3, 117.0, 59.4, 58.5; ν_{max} (KBr) (cm^{-1}): 1558, 1490, 1441, 1348, 1275, 1017, 843, 778; m/z (ESIMS)=216 (M^+, 100).

3.2.2. Tetraethyl 7-hydroxy-benzo[*b*]oxepine-2,3,4,5-tetracarboxylate 5. A sample of mesomeric betaine **2A/B** (2.2 mmol, 0.4 g) in 10 mL of anhydrous acetonitrile was treated with DEAD (8.8 mmol, 1.5 g) and then the solution was heated at reflux for 1 h. Acetonitrile was then distilled off in vacuo. Water (2 mL) was added to the residue, and the mixture was then extracted with dichloromethane. The solvent was distilled off, and the residue was again treated with water, which was then washed with toluene. The

aqueous phase was finally evaporated to dryness to give an orange-colored solid, yield 0.4 g (90%) (found: C, 52.33; H, 5.48. $C_{22}H_{24}O_{10}\cdot 3H_2O$ requires C, 52.59; H, 6.02); δ_H ($CDCl_3$) 1.00–1.50 (m, 12H; CH_3), 4.00–4.32 (m, 8H; CH_2), 6.00–7.60 (m, 3H; $H_{Ar.}$); δ_C (DMSO-d_6) 164.6, 159.8, 157.4, 150.0, 142.0, 132.2, 130.7, 124.2, 121.7, 113.3, 108.8, 62.2, 61.9, 61.7, 61.0, 13.6; ν_{max} (KBr) (cm^{-1}): 3441, 1735, 1637, 1260, 1025; *m/z* (ESIMS)=449 (MH^+, 80), 471 ($M+Na^+$, 30).

3.2.3. *N*-(2,5-Dihydroxyphenyl)-4-(2-pyridyl)-pyridinium chloride 8. Benzoquinone (1.38 g, 12.8 mmol) was dissolved in 4 mL of glacial acetic acid before 2 g (12.8 mmol) of 2,4′-bipyridine was added. The resulting solution was diluted with 3 mL of 18% hydrochloric acid and heated for 2 h to 45 °C. After cooling to room temperature the mixture was slowly neutralized with sodium hydrogencarbonate whereupon an orange solid precipitated, which was filtered off and washed subsequently with cold saturated sodium hydrogencarbonate solution and diethylether. Recrystallizing from ethanol/water/ethylacetate yielded 3.25 g (10.8 mmol; 84%) of an orange solid, mp 276 °C (dec) (found: C, 60.02; H, 4.20; N, 8.76. $C_{16}H_{15}ClN_2O_3$ requires C, 60.29; H, 4.74; N, 8.79); δ_H (DMSO-d_6) 7.10 (m, 3H), 7.71 (m, 1H), 8.15 (m, 1H), 8.57 (d, *J*=7.9 Hz, 1H), 8.89 (d, *J*=6.5 Hz, 3H), 9.27 (d, *J*=6.5 Hz, 2H), 9.86 (s, 1H), 10.63 (s, 1H); δ_C (DMSO-d_6) 156.0, 150.3, 150.0, 148.1, 143.7, 129.1, 125.1, 124.3, 117.0, 59.4, 58.5, C_q not detectable; ν_{max} (KBr) (cm^{-1}): 3059, 1633, 1515, 1202, 789.

3.2.4. Deprotonation of the salt 8 to the betaine 9A/B. Amberlite IRA-96 (30 mL) was filled into a column, washed with water (400 mL), and then treated with 20 mL of 4% NaOH for 15 min. Then, the resin was subsequently washed with water to pH 7, and 40 mL of water/EtOH (3:1). The salt **8** was dissolved in the same solvent mixture, and this solution was given on the resin. The elute was collected and evaporated to dryness. δ_H (200 MHz, DMSO-d_6) 9.23 (d, *J*=6.8 Hz, 2H, 4-*H*), 8.91–8.82 (m, 3H, 5-*H*+6-*H*), 8.52 (d, *J*=7.9 Hz, 1H, 8-*H*), 8.13 (m, 1H, 9-*H*), 7.69 (m, 1H, 7-*H*), 7.02 (m, 3H, 1-*H*+2-*H*+3-*H*) ppm. The product was isolated in impure form.

3.2.5. *N*-(2,7-Dihydroxynaphthyl)-pyridinium chloride 13. Naphthoquinone (5.78 g, 36.5 mmol) was dissolved in 20 mL of chloroform. Then, 5 mL of trifluoroacetic acid followed by 2.94 mL (36.5 mmol) of pyridine was added to the solution. The mixture was refluxed for 3 h. After cooling to room temperature, 3 mL of concentrated hydrochloric acid was added and the mixture was stirred for 2 h. The brown precipitate was filtered off and washed with chloroform. Drying in vacuo yielded 6.32 g (23.1 mmol; 63%) of a brownish solid, mp 213 °C (found: C, 63.29; H, 4.32; N, 4.73. $C_{15}H_{12}ClNO_2\cdot 2H_2O$ requires C, 63.05; H, 4.70; N, 4.90); δ_H (DMSO-d_6) 7.07 (s, 1H), 7.64–7.69 (m, 2H), 8.21–8.41 (m, 4H), 8.74–8.83 (m, 1H), 9.27 (dd, 2H), 10.20 (s, 1H), 10.70 (s, 1H); δ_C (DMSO-d_6) 122.4, 123.4, 126.4, 126.8, 127.0, 127.1, 128.1, 138.5, 146.5, 146.9, 147.4; ν_{max} (KBr) (cm^{-1}): 3133, 2899, 1591, 1388, 1076, 781.

3.2.6. *N*-(2,7-Dihydroxynaphthyl)-4-(4-pyridyl)-pyridinium chloride 17. A sample of 1.13 g (7.15 mmol) of **12** was dissolved in a mixture of 2 mL of glacial acetic acid and 2 mL of trifluoroacetic acid. 4,4′-Bipyridine (1.23 g, 7.87 mmol) was added slowly and the reaction mixture was stirred for 20 h at room temperature. Addition of 1 mL concentrated hydrochloric acid was followed by another 4 h of stirring. On dilution with 25 mL of acetone the product was crystallized at 8 °C. The crude reaction product was recrystallized from aqueous acidic media. After drying in vacuo 1.10 g (3.40 mmol) of **17** was isolated (44%), mp 176 °C (found: C, 63.78; H, 3.95; N, 7.38. $C_{20}H_{15}ClN_2O_2\cdot H_2O\cdot HCl$ requires C, 63.54; H, 4.40; N, 7.41); δ_H (DMSO-d_6) 7.14 (s, 1H), 7.65–7.69 (m, 2H), 8.17 (d, 2H), 8.20–8.44 (m, 2H), 8.79 (d, 2H), 8.92 (d, 2H), 9.45 (d, 2H), 10.30 (s, 1H), 10.77 (s, 1H); δ_C (DMSO-d_6) 122.3, 122.4, 123.5, 126.0, 126.4, 126.8, 127.0, 127.2, 138.6, 141.1, 147.5, 150.8, 152.9; ν_{max} (KBr) (cm^{-1}): 3364, 3030, 1595, 1397, 1213, 1082, 814; *m/z* (MALDI-TOFMS)=313 (quinone structure), 315 (M^+).

3.2.7. *N*,*N*′-(Bis-2,7-dihydroxynaphthyl)-4,4′-dipyridinium dichloride 18. Compound **12** (1.13 g, 7.15 mmol) was dissolved in a mixture of 2 mL of glacial acetic acid and 2 mL of trifluoroacetic acid. 4,4′-Bipyridine (0.56 g, 3.56 mmol) was added slowly and the reaction mixture was stirred for 20 h at room temperature. Addition of 1 mL of concentrated hydrochloric acid was followed by another 4 h of stirring. On dilution with 25 mL of acetone the product crystallized on storage at 8 °C. The crude reaction product was recrystallized from aqueous acidic media. After drying in vacuo, 1.26 g (2.31 mmol) of **18** was isolated (65%), mp 186 °C (dec) (found: C, 64.50; H, 3.74; N, 4.70. $C_{30}H_{22}Cl_2N_2O_4\cdot H_2O$ requires C, 63.95; H, 4.29; N, 4.97); δ_H (DMSO-d_6) 7.14 (s, 2H), 7.68–7.73 (m, 4H), 8.23–8.44 (m, 4H), 9.06 (d, 4H), 9.65 (d, 4H), 10.35 (s, 2H), 10.72 (s, 2H); δ_C (DMSO-d_6) 104.4, 122.5, 123.5, 126.0, 126.6, 126.7, 126.8, 127.2, 127.4, 138.7, 147.5, 148.0, 149.3; ν_{max} (KBr) (cm^{-1}): 3423, 3116, 1634, 1391, 1078.

Acknowledgements

The Deutsche Forschungsgemeinschaft (DFG) is gratefully acknowledged for financial support. Marcel Albrecht is gratefully acknowledged for some experiments.

References and notes

1. Nawwar, M. A. M.; Hussein, S. A. M.; Merfort, I. *Phytochemistry* **1994**, *37*, 1175; The substance was described earlier: Ortoleva, G.; di Stefano, G. *Gazz. Chim. Ital.* **1901**, *31*, 256; Buchta, E. *Chem. Ber.* **1937**, *70*, 2339; Diels, O.; Kassebart, R. *Liebigs Ann. Chem.* **1937**, *530*, 51.
2. Schmidt, A.; Mordhorst, T.; Nieger, M. *Nat. Prod. Res.* **2005**, *19*, 541.
3. Ollis, W. D.; Stanforth, S. P.; Ramsden, C. A. *Tetrahedron* **1985**, *85*, 2239.
4. Schmidt, A.; Mordhorst, T. *ARKIVOC* **2003**, *XIV*, 233.
5. Schmidt, A. *Adv. Heterocycl. Chem.* **2003**, *85*, 67.
6. Schmidt, A. *Curr. Org. Chem.* **2004**, *8*, 653.
7. Schmidt, A.; Mordhorst, T.; Fleischhauer, H.; Jeschke, G. *ARKIVOC* **2005**, *X*, 150 and unpublished results.

8. (a) Koch, A.; Jonas, U.; Ritter, H.; Spiess, H.-W. *Tetrahedron* **2004**, *60*, 10011; (b) Deutschmann, T.; Ritter, H. *Macromol. Chem. Phys.* **2000**, *201*, 1200; (c) Theis, A.; Ritter, H.; Böhme, F.; Klinger, C.; Mittler, S.; Menges, B. *Chem. Mater.* **2002**, *14*, 2109.
9. Tonami, H.; Uyama, H.; Kobayashi, S.; Menges, B.; Mittler, S.; Theis, A.; Ritter, H. *Macromol. Chem. Phys.* **2003**, *204*, 1079.
10. See Ref. 8b; Ritter, H.; Sperber, R. *Macromol. Rapid Commun.* **1995**, *16*, 407; Ritter, H.; Sperber, R.; Weißhuhn, C. M. *Macromol. Chem. Phys.* **1994**, *195*, 3823.
11. Theis, A.; Ritter, H. *Des. Monomers Polym.* **2001**, *4*, 177.
12. Deutschmann, T.; Ritter, H. *Macromol. Rapid Commun.* **1996**, *17*, 723; See Ref. 8c.
13. Zakrassov, A.; Shteiman, V.; Sheynin, Y.; Tumanskii, B.; Botoshansky, M.; Kapon, M.; Keren, A.; Kaftory, M.; Vos, T. E.; Miller, J. S. *J. Mater. Chem.* **2004**, *14*, 1827; Stroh, C.; Ziessel, R.; Raudaschl-Sieber, G.; Köhler, F. H.; Turek, P. *J. Mater. Chem.* **2005**, *15*, 850; Lahti, P. M.; Esat, B.; Walton, R. *J. Am. Chem. Soc.* **1998**, *120*, 5122; Inoue, K.; Iwamura, H. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 927; Shultz, D. A.; Vostrikova, K. E.; Bodnar, S. H.; Koo, H.-J.; Whangbo, M.-H.; Kirk, M. L.; Depperman, E. C.; Kampf, J. W. *J. Am. Chem. Soc.* **2003**, *125*, 1607.
14. Fleischhauer, H.; Frormann, L.; Schmidt, A. *Int. Mag. Extrusion* **2005**, *5*, 50.
15. de Barry Barnett, E.; Cook, J. W.; Driscoll, E. P. *J. Chem. Soc.* **1923**, *123*, 503; Koenigs, E.; Greiner, H. *Chem. Ber.* **1931**, *64*, 1045.
16. Bard, A. J.; Faulkner, L. R. *Electrochemical Methods: Fundamentals and Applications*, 2nd ed.; Wiley: New York, NY, 2001.
17. Bodini, M. E.; Arancibia, V. *Transition Met. Chem.* **1997**, *22*, 150; Tonholo, J.; Freitas, L. R.; de Abreu, F. C.; Azevedo, D. C.; Zani, C. L.; de Oliveira, A. B.; Goulart, M. O. F. *J. Braz. Chem. Soc.* **1989**, *9*, 163.