Unexpected Formation of Benzaldehydes by the Reactions of Dithioacetals Derived from Cinnamaldehydes with 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone in Aqueous Solvents

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1,3-Dithianes **1**, 1,3-dithiolanes **2**, and diphenyl dithioacetals **3** derived from cinnamaldehydes reacted with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in aqueous solvents to give benzaldehydes **4**. Hydride transfer from **1-3** to 2,3-dichloro-5,6-dicyano-*p*-benzoquinone followed by hydrolysis and oxidative carbon-carbon bond cleavage would produce benzaldehydes **4**.

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Deprotection of dithioacetals using oxidizing agents has been extensively investigated [1] and a variety of dithioacetals including 2-styryl-1,3-dithiane (**1c**) (R = Ph) were converted into the corresponding carbonyl compounds in good yields [2-4]. Recently, deprotection of dithioacetals using 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in aqueous acetonitrile has been reported by other workers [5] and ourselves [6]. In the course of our investigations, we discovered that the unexpected product, benzaldehyde (**4c**) was obtained from the hydrolysis of dithiane **1c** with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone. We were interested in the formation of **4c** and examined this novel reaction.

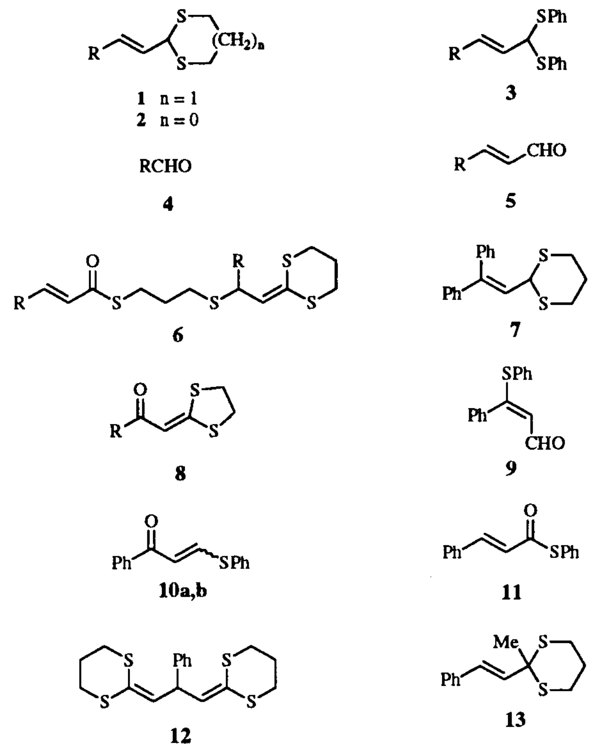
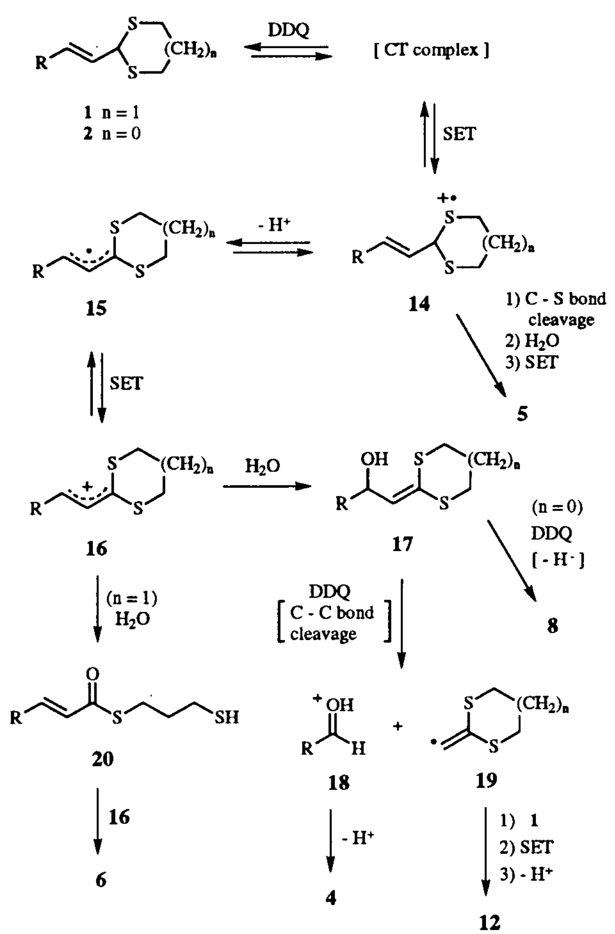


Figure 1.

Scheme 1



1,3-Dithiane **1c** was treated with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in acetonitrile-water (97:3) at room temperature for 15 minutes under nitrogen in the dark. Two equivalents of 2,3-dichloro-5,6-dicyano-*p*-benzoquinone were necessary for the complete conversion

Table 1

The Reactions of Dithioacetals **1-3** with 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone in Aqueous Solvents

Run	Substrate	R	Solvent [a]	Time, hours	Product (%) [b] 4	5	6	8
1	**1a**	4-$MeOC_6H_4$	A	0.25	38	0	18	—
2			C	0.25	33	0	10	—
3			D	1	50	0	17	—
4	**1b**	2-$MeOC_6H_4$	A	0.25	38	0	0	—
5			D	1	48	0	0	—
6	**1c**	Ph	A	0.25	41 [h]	5	0	—
7			B	0.2	23 [h]	0	19	—
8			C	0.5	25 [h]	0	0	—
9 [c]			D	1	40 [h]	0	11	—
10	**1d**	2-Furyl	A	0.25	20 [h]	0	0	—
11			D	1	25 [h]	0	0	—
12	**1e**	4-$NO_2C_6H_4$	A	0.25	7	17	0	—
13			D	1	5	0	0	—
14	**2a**	4-$MeOC_6H_4$	A	0.25	33	0	—	0
15			D	1	34	0	—	0
16	**2c**	Ph	A	0.25	25 [h]	10	—	42
17			D	1	22 [h]	0	—	31
18 [d]	**2e**	4-$NO_2C_6H_4$	A	1	0	7	—	37
19			D	3	21	0	—	33
20	**3a**	4-$MeOC_6H_4$	A	1	24	48	—	—
21			D	6	50	14	—	—
22 [e]	**3c**	Ph	A	2	0	49	—	—
23 [f]			D	6	2 [h]	11	—	—
24	**3e**	4-$NO_2C_6H_4$	A	2	0	73	—	—
25 [g]			D	6	18	43	—	—

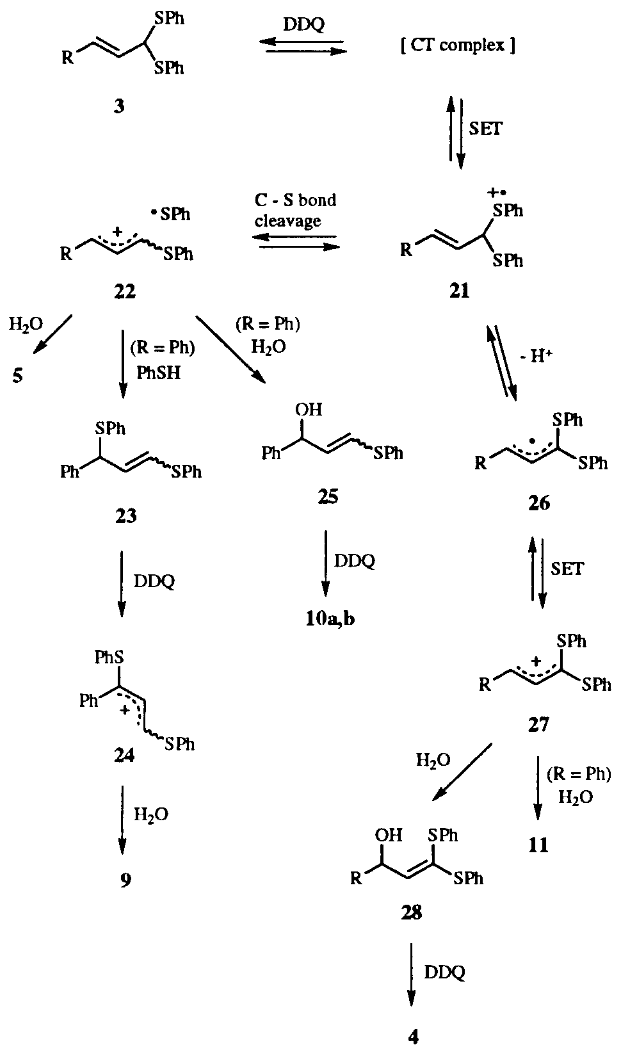
[a] A; acetonitrile-water (97:3), B; tetrahydrofuran-water (97:3), C; benzene-water (97:3), D; dichloromethane-water (97:3). [b] Isolated yields. [c] Compound **12** was obtained in 6% yield. [d] Compound **2e** (6%) was recovered. [e] Compounds **9**, **10a**, **10b**, and **11** were isolated in 14, 6, 8, and 14% yields, respectively. [f] Compound **9** was isolated in 42% yield. [g] Compound **3e** (11%) was recovered. [h] Determined by ^1H nmr spectroscopy.

of **1c** and changed to 2,3-dichloro-5,6-dicyanohydroquinone quantitatively. Surprisingly, benzaldehyde (**4c**) (41%) was obtained with a small amount of cinnamaldehyde (**5c**) (5%) (Table 1, Run 6). Similarly, various dithianes **1a-e** reacted with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in aqueous solvents to give benzaldehydes **4**, small amounts of cinnamaldehydes **5**, and rearranged thioesters **6** (Runs 1-13). When 2-(2,2-diphenylvinyl)-1,3-dithiane **7** was treated with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in acetonitrile-water (97:3) for 1 hour, deprotection occurred exclusively to give 3,3-diphenyl-2-propenal (90%). In dichloromethane-water (97:3) for 24 hours, benzophenone (4%) was produced with the deprotected product (58%). In the cases of dithiolanes **2**, benzaldehydes **4** and 2-phenacylidene-1,3-dithiolanes **8** were obtained together with small amounts of cinnamaldehydes **5** (Runs 14-19). From the reactions of cinnamaldehydes diphenyl dithioacetal **3**, benzaldehydes **4**, cinnamaldehydes **5**, and diphenyl disulfide (9-79%) were isolated (Runs 20-25). In the case of **3c**, some by-products, *i.e.*, (*E*)-3-phenyl-3-phenylsulfanyl-2-propenal (**9**) (14%), (*E*)-1-phenyl-3-phenylsulfanyl-2-propen-1-one (**10a**) (6%), (*Z*)-**10b** (8%), and *S*-phenyl 3-phenyl-2-propenethioate (**11**) (14%), were formed together with the deprotected **5c** (49%) (Run 22). Only a complex mixture was obtained from the reactions of 2-alkenal dithioacetals **1-3** (R = CH_3 and *n*-C_9H_{19}).

Although the exact path is not clear now, the mechanisms of the formation of benzaldehyde **4** are shown in Schemes 1 and 2. Hydride transfer from **1** or **2** to 2,3-dichloro-5,6-dicyano-*p*-benzoquinone, which consists of consecutive single electron transfer, proton transfer, and the second single electron transfer steps, would generate cation **16** which is hydrolyzed to give **17**. Oxidative carbon-carbon bond cleavage of **17** induced by 2,3-dichloro-5,6-dicyano-*p*-benzoquinone would produce benzaldehyde **4**. On the other hand, hydrolysis of cation **16** would afford **20**. The resulting thiol **20** is converted into **6** by the reaction with stabilized cation **16** rather than oxidized to disulfide [6]. 2-Phenacylidene-1,3-dithiolanes **8** would be produced by hydride transfer from **17** to 2,3-dichloro-5,6-dicyano-*p*-benzoquinone.

These mechanisms would be supported by the following results. (i) A dark red coloration due to the formation of charge transfer complex was observed during the reaction. The λ max (charge transfer) = 547 and 587 nm for **1c**, 543 and 583 nm for **2c**, and 542 and 580 nm for **3c**. (ii) Bis(dithiane) **12** (6%), which might be produced *via*

Scheme 2



addition of radical **19** to the starting **1**, was isolated from the reaction of **1c** with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone in dichloromethane-water (97:3) (Run 9). (iii) Dithioacetals bearing a methoxy group on the benzene ring increased the yields of benzaldehydes **4**, since the benzylic cation **16** was stabilized. In contrast, a nitro group suppressed the formation of **4** markedly. (iv) When 2-methyl-2-styryl-1,3-dithiane **13** was treated with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone for 15 minutes in acetonitrile-water (97:3), only deprotection occurred (77%). In dichloromethane-water (97:3), no reaction was observed. These results suggest that hydride transfer from the 2-position of 1,3-dithiane **1** to 2,3-dichloro-5,6-dicyano-*p*-benzoquinone would be involved in the first stage of benzaldehyde formation. (v) Compound **8** was stable under these conditions and was not converted into benzaldehyde **4**.

A plausible mechanism for the formation of compounds **9-11** is shown in Scheme 2. The first step is a single electron transfer process from **3** to 2,3-dichloro-5,6-dicyano-*p*-benzoquinone. The subsequent steps of the resulting cation radical **21** involving carbon-sulfur bond cleavage, the attack by benzenethiol [7] which is generated during the reaction, hydride transfer, and the attack by water, lead to **9**. Hydrolysis of **22** followed by further oxidation by 2,3-dichloro-5,6-dicyano-*p*-benzoquinone would form **10a,b**. The sequence of deprotonation, single electron transfer, and hydrolysis steps from **21** would lead to thioester **11**.

EXPERIMENTAL

The melting points are uncorrected. The ir spectra were recorded on a Hitachi I-3000 spectrophotometer. The nmr spectra (^{1}H and ^{13}C nmr) were measured on a JEOL JNM-FX 90Q or a Hitachi R-24B spectrometer using tetramethylsilane as an internal standard. The uv spectra were recorded on a Hitachi Model 320 spectrophotometer. Column chromatography was performed on Merck silica gel 60 (70-230 mesh). 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone was recrystallized from benzene-hexane. Dithioacetals **1-3**, **7**, and **13** were synthesized according to the literature procedure [8]. All reactions were carried out under nitrogen in the dark.

General Procedure for the Reaction of Dithioacetals **1-3** with 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone in Acetonitrile-Water (97:3).

To a mixture of dithiane **1a** (252 mg, 1.0 mmole) in acetonitrile (3.28 ml) and water (0.57 ml) was added a solution of 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (454 mg, 2.0 mmoles) in acetonitrile (15.15 ml). After stirring at room temperature for 15 minutes, the mixture was quenched with saturated sodium hydrogen carbonate (50 ml) and extracted with ether. The extracts were washed with water, dried, and evaporated and the residue was chromatographed on silica gel with 10:1 hexane-acetone to give benzaldehyde **4a** (52 mg, 38%) and thioester **6a** (46 mg, 18%) (Table 1, Run 1).

General Procedure for the Reaction of Dithioacetals **1-3** with 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone in Dichloromethane-Water (97:3).

To a mixture of dithiane **1a** (252 mg, 1.0 mmole) in dichloromethane (3.28 ml) and water (0.57 ml) was added a solution of 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (454 mg, 2.0 mmoles) in dichloromethane (15.15 ml). After stirring at room temperature for 1 hour, the mixture was worked up as described above except for extraction with dichloromethane to give benzaldehyde **4a** (68 mg, 50%) and thioester **6a** (44 mg, 17%) (Table 1, Run 3).

Thioester **6a** (R = 4-$MeOC_6H_4$).

This compound was obtained as a colorless oil; ir (neat): 1666 cm^{-1} (COS); ^{1}H nmr (deuteriochloroform): δ 1.75-2.34 (m, 4H, CH_2), 2.56 (t, J = 7.0 Hz, 2H, CH_2), 2.88 (t, J = 6.0 Hz, 4H, CH_2), 3.09 (t, J = 7.0 Hz, 2H, CH_2), 3.73 (s, 3H, OCH_3), 3.80 (s, 3H, OCH_3), 5.06 (d, J = 10.1 Hz, 1H, CH), 6.11 (d, J = 10.1 Hz, 1H, CH=C), 6.55 (d, J = 15.8 Hz, 1H, ArCH=C*H*), 6.62-7.83 (m, 9H, ArH and ArC*H*=CH); ^{13}C nmr (deuteriochloroform): δ

24.8 (t), 27.9 (t), 29.6 (t), 29.6 (t), 29.9 (t), 30.3 (t), 46.7 (d), 55.2 (q), 55.3 (q), 114.0 (d), 114.4 (d), 122.7 (d), 128.1 (s), 128.7 (d), 130.0 (d), 131.8 (s), 131.9 (s), 132.0 (d), 140.1 (d), 158.7 (s), 161.6 (s), 189.4 (s).

Anal. Calcd. for $C_{26}H_{30}O_3S_4$: C, 60.20; H, 5.83. Found: C, 60.43; H, 5.97.

Thioester **6c** (R = Ph).

This compound was obtained as colorless needles, mp 87-88° (from benzene-hexane); ir (potassium bromide): 1674 (COS), 1656 cm^{-1} (C=C); ^{1}H nmr (deuteriochloroform): δ 1.79-2.30 (m, 4H, CH_2), 2.58 (t, J = 7.0 Hz, 2H, CH_2), 2.88 (t, J = 6.0 Hz, 4H, CH_2), 3.10 (t, J = 7.0 Hz, 2H, CH_2), 5.10 (d, J = 10.1 Hz, 1H, CH), 6.14 (d, J = 10.1 Hz, 1H, CH=C), 6.68 (d, J = 15.8 Hz, 1H, PhCH=C*H*), 7.14-7.60 (m, 10H, ArH), 7.60 (d, J = 15.8 Hz, 1H, PhC*H*=CH); ^{13}C nmr (deuteriochloroform): δ 24.8 (t), 28.0 (t), 29.5 (t), 29.6 (t), 29.9 (t), 30.4 (t), 47.6 (d), 125.1 (d), 127.3 (d), 127.7 (d), 128.3 (d), 128.6 (d), 128.9 (d), 129.8 (s), 130.5 (d), 131.4 (d), 134.2 (s), 140.2 (s), 140.4 (d), 189.3 (s).

Anal. Calcd. for $C_{24}H_{26}OS_4$: C, 62.84; H, 5.71. Found: C, 63.10; H, 5.98.

2-Phenacylidene-1,3-dithiolane (**8c**) [6b].

This compound was obtained as pale yellow prisms, mp 79-80° (from benzene-hexane); ir (potassium bromide): 1610 cm^{-1} (C=O); ^{1}H nmr (deuteriochloroform): δ 3.36-3.49 (m, 4H, CH_2), 7.24-7.54 (m, 4H, ArH and C=CH), 7.89-7.99 (m, 2H, ArH); ^{13}C nmr (deuteriochloroform): δ 35.4 (t), 38.9 (t), 108.1 (d), 127.7 (d), 128.5 (d), 131.9 (d), 138.3 (s), 168.3 (s), 185.6 (s).

2-(4-Nitrophenacylidene)-1,3-dithiolane (**8e**).

This compound was obtained as yellow prisms, mp 230-231° (from acetone); ir (potassium bromide): 1620 (C=O), 1518, 1346 cm^{-1} (NO_2); ^{1}H nmr (deuteriodimethyl sulfoxide): δ 3.53 (s, 4H, CH_2), 7.55 (s, 1H, C=CH), 7.28 (s, 4H, ArH).

Anal. Calcd. for $C_{11}H_9NO_3S_2$: C, 49.42; H, 3.39. Found: C, 49.70; H, 3.66.

(*E*)-3-Phenyl-3-phenylsulfanyl-2-propenal (**9**) [9].

This compound was obtained as yellow prisms, mp 134-135° (from hexane); ir (potassium bromide): 1660 cm^{-1} (CHO); ^{1}H nmr (deuteriochloroform): δ 5.68 (d, J = 7.9 Hz, 1H, 2-H), 7.48 (s, 10H, ArH), 9.27 (d, J = 7.9 Hz, 1H, CHO); ^{13}C nmr (deuteriochloroform): δ 123.5 (d), 127.7 (s), 128.5 (d), 129.0 (d), 129.4 (d), 129.9 (d), 130.1 (d), 134.6 (s), 135.2 (d), 168.3 (s), 189.3 (d).

(*E*)-1-Phenyl-3-phenylsulfanyl-2-propen-1-one (**10a**) [10].

This compound was obtained as pale yellow needles, mp 71-73° (from hexane); ir (potassium bromide): 1644 cm^{-1} (C=O); ^{1}H nmr (deuteriochloroform): δ 6.85 (d, J = 14.8 Hz, 1H, 2-H), 7.35-7.58 (m, 8H, ArH), 7.79-7.90 (m, 2H, ArH), 8.02 (d, J = 14.8 Hz, 1H, 3-H).

(*Z*)-1-Phenyl-3-phenylsulfanyl-2-propen-1-one (**10b**) [10].

This compound was obtained as pale yellow needles, mp 79-80° (from hexane); ir (potassium bromide): 1638 cm^{-1} (C=O); ^{1}H nmr (deuteriochloroform): δ 7.14 (d, J = 9.7 Hz, 1H, 2-H), 7.33-7.60 (m, 8H, ArH), 7.58 (d, J = 9.7 Hz, 1H, 3-H), 7.95-8.05 (m, 2H, ArH).

S-Phenyl 3-phenyl-2-propenethioate (**11**) [11].

This compound was obtained as yellow needles, mp 90-91° (from hexane) (lit mp 85-86°); ir (potassium bromide): 1682 cm^{-1} (C=O); ^{1}H nmr (deuteriochloroform): δ 6.77 (d, J = 15.8 Hz, 1H, 2-H), 7.35-7.59 (m, 10H, ArH), 7.68 (d, J = 15.8 Hz, 1H, 3-H).

1,3-Bis(1,3-dithian-2-ylidene)-2-phenylpropane (**12**).

This compound was obtained as colorless prisms, mp 129-130° (from benzene-hexane); ^{1}H nmr (deuteriochloroform): δ 1.92-2.40 (m, 4H, CH_2), 2.90 (t, J = 6.0 Hz, 8H, CH_2), 5.17 (dd, J = 9.0 and 9.0 Hz, 1H, CH), 6.02 (d, J = 9.0 Hz, 2H, C=CH), 7.21 (s, 5H, ArH); ^{13}C nmr (deuteriochloroform): δ 25.0 (t), 29.6 (t), 30.1 (t), 45.2 (d), 126.4 (d), 127.4 (d), 128.2 (s), 128.6 (d), 132.8 (d), 142.3 (s).

Anal. Calcd. for $C_{17}H_{20}S_4$: C, 57.91; H, 5.72. Found: C, 58.11; H, 5.85.

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