Poly(N,N'-dichloro-N-ethyl-benzene-1, 3-disulfonamide) and N,N,N',N'-Tetrachlorobenzene-1,3-disulfonamide as Novel Catalytic Reagents for Synthesis of Bis-indolyl, Tris-indolyl, Di(bis-indolyl), Tri(bis-indolyl) and Tetra(bis-indolyl) Methanes under Solid-State, Solvent and Water Conditions

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Introduction

Indole derivatives are widely distributed in nature and are known to possess broad spectrum of biological and pharmaceutical activities.1 Bis(indolyl)methanes are found in cruciferous plants and are known to promote beneficial estrogen metabolism2 and induce apoptosis in human cancer cell. Thus, the development of facile and environmental friendly synthetic methods for the preparation of these compounds constitutes an active area of investigation in pharmaceutical and organic synthesis.3-5

Synthetically the reaction of 1H-indole with aldehydes or ketones produces azafulvenium salts that react further with a second 1H-indole molecule to form bis(indol-3-yl)methanes.6 In recent years, synthesis of this class of molecules under mild conditions have been reported, with promoters such as montmorillonite clay K-10,7 trichloro-1,3,5-triazine,8 AlPW12O409 sodium dodecyl sulfate (SDS),10 ZrCl411 H2NSO4H1213 zeolites,14 bentonite,15 In(OTf)/ionic liquid,16 CuBr217 Dy(OTf)3/ionic liquid,18 HClO4·SiO2,19 InCl3,20 MW/ Lewis acids (FeCl3, BiCl3, InCl3, ZnCl2, CoCl2),21 NaHSO4, and Amberlyst-15,22 sulfated zirconia,23 ZrOCl2/SiO2,24 silica sulfuric acid (SSA),25 TiO2,26 (NH4)2HPO4,27 acidic ionic liquid,28 NaBF4,29 metal hydrogen sulfates,30 tetrabutylammonium tribromide,31 superacid SO3/CF3SO332 NaHSO4/ionic liquid,33 NBS,34 PhCl,35 H3PW12O40,36 LiClO4,37 Zr(DS)438 and Bi(NO3)3·5H2O.39

Keywords: TCBDA, PCBS, bis(indolyl)methanes, catalytic reagents

Result and Discussion

In continuation of our interest in the synthesis of N-halo sulfonamide and application of these reagents in organic synthesis,40-43 we report the synthesis of poly (N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide) [PCBS] and N,N,N',N'-tetrachlorobenzene-1,3-disulfonamide [TCBDA] as novel catalytic reagents in organic reactions (Scheme 1).

Many of the methods described above involve the use of expensive reagents, high catalyst loading, long reaction times and environmentally hazardous reagents. Therefore, we studied the use of poly (N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide) and N,N,N',N'-tetrachlorobenzene-1,3-disulfonamide as novel catalysts in the electrophilic substitutions of indole with a variety of aldehydes and ketones under (i) solvent-free, (ii) solvent conditions (H2O and EtOH) to afford bis(indolyl)methanes (Scheme 1).
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Since TCBDA and PCBS contain chlorine atoms which are attached to nitrogen atoms, it is also possible that they release Cl\(^+\) \textit{in situ} which can act as Lewis acid to activate the carbonyl oxygen to form the bis-indole derivatives.

Initially, we carried out the reaction of indole with benzaldehyde in the presence catalytic amount of \(N,N,N',N'-\text{tetrachlorobenzene}-1,3\)-disulfonamide (TCBDA) in EtOH at room temperature. After 5 min the reaction completed with good yield (96%).

The applicability of the present methodology is further extended by performing the reaction in an aqueous media. In this reaction, we also found that, water in the presence of 5 mol\% CTAB (N-cetyl-N,N,N,N-trimethylammonium bromide) as surfactant is essential for this reaction using TCBDA at room temperature. However, this process is green, environmentally friendly, clean, and could be carried out easily at room temperature without undesirable side reactions.

In recent years, there has been an increasing interest in reactions that proceed in the absence of solvents due to their reduced pollution, low cost, simplicity in process and handling. Therefore, we decided to test this reaction under solvent-free conditions (grinding) with these reagents. We found that the reaction could be rapid with excellent yield, (98%, entry 1) using \(N,N,N',N'-\text{tetrachlorobenzene}-1,3\)-disulfonamide [TCBDA] (1 min) and using poly (\(N,N'-\text{dichloro-N-ethyl-benzene-1,3-disulfonamide}\) [PCBS] (1.5 min). In comparison to the reported methods, TCBDA and PCBS under solvent-free conditions were found to be efficient catalysts in terms of handling, temperature, yield and reaction times.

These results promoted us to investigate the scope and the generality of these new protocols for various aldehydes and ketones under optimized conditions. As shown in Table 1, a series of aromatic, aliphatic and heterocyclic aldehydes underwent electrophilic substitution reaction with indole smoothly to afford a wide range of substituted bis(indoly)methanes in good to excellent yields. The electron deficiency and nature of the substituents on the aromatic ring effect the conversion.

| Condition | Method | Temperature | Reaction Time | Yield |
|-----------|--------|-------------|---------------|-------|
| A         | TCBDA or PCBS, EtOH, 40 °C, 30 min | 95%          |
| B         | TCBDA or PCBS, solid-state, grinding | r.t., 10 min | 96%    |
| C         | TCBDA, CTAB, H\(_2\)O, 100 °C | 120 min | 90%    |

Scheme 1.

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\text{Condition A: TCBDA or PCBS, EtOH, 40 °C, 30 min, 95%} \\
\text{Condition B: TCBDA or PCBS, solid-state, grinding, r.t., 10 min, 96%} \\
\text{Condition C: TCBDA, CTAB, H\(_2\)O, 100 °C, 120 min, 90%}
\]

Scheme 2.
Table 1. Synthesis of bis(indolyl)methanes by the reaction of indole with aldehydes and ketones in various conditions

| Entry | Carbonyl compound | TCBDA (method A) | PCBS (method A) | TCBDA (method B) | PCBS (method B) | TCBDA (method C) |
|-------|-------------------|-------------------|-----------------|-------------------|-----------------|------------------|
|       |                   | time/min | yield (%) | time/min | yield (%) | time/min | yield (%) | time/min | yield (%) |
| 1     | CHO               | 5        | 96       | 10       | 90       | 1       | 98       | 1.5      | 98       | 2        | 90²¹ |
| 2     | MeCHO             | 10       | 92       | 15       | 90       | 1.5     | 96       | 2        | 96       | 2.5      | 80²¹ |
| 3     | CHO OMe           | 5        | 98       | 10       | 95       | 1       | 99       | 2        | 98       | 3        | 89²¹ |
| 4     | CHO Cl            | 8        | 96       | 12       | 90       | 1       | 98       | 1.5      | 96       | 4        | 78²¹ |
| 5     | CHO Br            | 15       | 92       | 15       | 87       | 2       | 92       | 2        | 92       | 3.5      | 75²⁰ |
| 6     | CHO Cl            | 15       | 89       | 16       | 85       | 1.5     | 95       | 2.5      | 90       | 3.5      | 80²⁰ |
| 7     | CHO Cl            | 10       | 96       | 20       | 90       | 1       | 96       | 2        | 96       | 2        | 82²⁰ |
| 8     | CHO               | 25       | 90       | 30       | 80       | 2.5     | 92       | 2.5      | 90       | 4        | 70²⁴ |
| 9     | CHO               | 15       | 92       | 20       | 90       | 1       | 96       | 2        | 96       | 2        | 79²¹ |
| 10    | CHO Cl            | 20       | 90       | 30       | 85       | 1       | 98       | 2        | 96       | 5        | 70²⁰ |
| 11    | CHO Cl            | 25       | 90       | 30       | 85       | 2       | 97       | 2.3      | 97       | 4        | 70²⁰ |
| 12    | CHO               | 30       | 78       | 40       | 75       | 2.5     | 96       | 3        | 96       | 5        | 75²¹ |
| 13    | CHO               | 25       | 95       | 35       | 90       | 2       | 95       | 4        | 94       | 4.5      | 72²¹ |
| 14    | CHO               | 2        | 92       | 5        | 90       | 1       | 98       | 2        | 96       | 2        | 82²⁰ |
| 15    | CHO               | 70       | 85       | 85       | 80       | 4       | 90       | 6        | 90       | 6        | 70²¹ |
| 16    | CHO               | 120      | 80       | 120      | 75       | 4       | 90       | 6        | 90       | 9        | 65²⁶ |
| 17    | CHO               | 100      | 85       | 100      | 85       | 4.5     | 85       | 5        | 80       | 7        | 75²¹ |
| 18    | CHO               | 110      | 78       | 120      | 70       | 5       | 80       | 6        | 80       | 6        | 70²¹ |

²Products were characterized from their physical properties, comparison with authentic samples and by spectroscopic methods.

rate; aromatic aldehydes having electron-withdrawing groups on the aromatic ring (Table 1, entries 10, 11) react slower than electron-donating groups (Table 1, entries 4, 8, 9, 12). Furthermore, unsaturated aldehydes, such as cinnamaldehyde, give the corresponding bis(indolyl) methanes without polymerization or halogenation under the above reaction conditions. Ketones required longer reaction times, which is most probably due to the electron-donating and steric effects of the methyl group.

This reaction was further explored for the synthesis of tri-indolylmethane by the condensation of indol-3-carbaldehyde or isatin with two equivalents of indole under similar conditions with our methods in good to high yields (Scheme 2 and 3).

Selective condensation of a dialdehyde, i.e., terephthalaldehyde to the corresponding bis-indolyl methane was achieved by controlling the molar ratio of indole (Scheme 3). The results showed that addition of 2
equivalents of indole to terephthaldialdehyde, gives (b) in good yield under various conditions (Scheme 3). Treatment of 4 equivalents of indole with terephthaldialdehyde gives the corresponding di(bis-indolyl methanes), (c) in excellent yield at room temperature under various conditions. 

This reaction was further explored for the synthesis of tri(bis-indolyl)methane (e) and tetra(bis-indolyl)methanes (g, h) as new triarylmethanes, by the condensation of aldehyde (d) with 6 equivalents indole and aldehydes (f, b) with 8 equivalents indole under similar condition (reflux in DMSO) in high yields (Scheme 4 and 5).

3-Substituted indoles were examined for this reaction under the above reaction conditions with aldehydes (Scheme 6). Since the more active site (C-3) in indole was blocked in this case electrophilic substitution took place at C-2 in indole giving the corresponding bis(indolyl)methane in high yield under various conditions. The results were summarized in Table 2.

Our experiments also indicated that TCBDA and PCBS were reusable catalysts and after four runs, the catalytic activities of the reagents were almost the same as those of fresh catalysts. Thus, after the successful synthesis of 2-methoxyphenyl-3,3-bis(indolyl)methane in first run (in solvent condition), which gave the corresponding product in 98% isolated yield (Table 1, entry 3), the N,N′-dichlorobenzene-1,3-disulfonamide (TCBDA) catalyst was subjected to a second run reaction from which it gave the product in 85% yield; the average chemical yield for four consecutive runs was 60%. The reusability of catalysts are shown in Figure 1.

The chemo selectivity of the present methods is also demonstrated by competitive reactions of indol with arylaldehydes in the presence of aliphatic ones and ketones. For example, when a 1:1 mixture of benzaldehyde and propionaldehyde was allowed to react with two equivalents of indole in the presence of TCBDA and PCBS under various conditions, it was found that the arylaldehydes was chemo selectively converted to the corresponding bis(indolyl) methane but the aliphatic ones was converted slightly. Also, in an equimolar mixture arylaldehyde and ketone, only arylaldehyde was converted to the corresponding bis(indolyl)methane, whereas ketone remained (Scheme 7). The reaction was clean and the products were obtained in high yields without the formation of any side products such as N-alkylated products.

In conclusion, we have introduced the novel catalytic reagents poly (N,N′-dichloro-N-ethyl-benzene-1,3-disulfonamide) [PCBS] and N,N,N′,N′-tetrachlorobenzene-1,3-disulfonamide [TCBDA] for the efficient preparation of bis-indolyl, tris-indolyl, di(bis-indolyl), tri(bis-indolyl) and tetra(bis-indolyl) methanes from indole with various aldehydes and ketones in ethanol, water and in solid-state conditions at room temperature with excellent yields. This method is applicable to a wide range of aldehydes, including aromatic, aliphatic, α,β-unsaturated, heterocyclic substrates, and ketones. In addition, efficiency, mild reaction conditions, easy work up, simplicity and chemoselectivity of this protocol provide a fast, green, and low cost procedure for the synthesis of these compounds.
Table 2. The reaction of aromatic aldehydes with 3-substituted indoles under various conditions

| Entry | Carbonyl compound | Indole | Product | Condition A | Condition B | Condition C |
|-------|-------------------|--------|---------|-------------|-------------|-------------|
|       |                   |        |         | time/min    | yield (%)   | time/min    | yield (%)   | time/min    | yield (%)   |
| 1     | MeO-CHO           |        |         | 30          | 95          | 10          | 96          | 120         | 90<sup>a</sup> |
| 2     | Me-CHO            |        |         | 30          | 92          | 10          | 90          | 150         | 80<sup>a</sup> |
| 3     | CHO               |        |         | 25          | 96          | 5           | 90          | 100         | 85<sup>a</sup> |
| 4     | CHO               |        |         | 60          | 75          | 10          | 70          | 180         | 50<sup>a</sup> |

<sup>a</sup>Products were characterized from their physical properties, comparison with authentic samples and by spectroscopic methods.
Poly(N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide) and N,N,N',N'-Tetrachlorobenzene-1,3-disulfonamide

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Experimental

Procedure for the preparation of poly (N,N'-dichloro-N-ethyl-benzene-1,3-disulfonamide) [PCBS] and N,N,N',N'-Tetrachlorobenzene-1,3-disulfonamide [TCBDA]

A sample of white finely powdered poly (N-ethyl-benzene-1,3-disulfonamide) (1 g) or benzene-1,3-disulfonamide (1 g) was dissolved in a solution of NaOCl (50 mL, 14%), at 25 °C for 30 min. The color of the solution did not change. After this time, acetic acid (20 mL, 50%) was added to the solution. The insoluble chlorinated reagent was removed by filtration and washed with water (5 mL).

Analytical data for N,N,N',N'-Tetrachlorobenzene-1,3-disulfonamide

White solid, mp: 145-147 °C. IR (KBr) $\nu_{max}$/cm$^{-1}$: 3050, 2950, 2900, 1570, 1462, 1417, 1377, 1304, 1167, 1082,
Synthesis of bis(indolyl)methanes in ethanol catalyzed by TCBD or PCBS

A mixture of indole (2.0 mmol), aldehyde or ketone (1.0 mmol) and catalyst PCBS (0.05 mmol, 0.04 g) in EtOH (3 mL) was stirred at room temperature for the appropriate time (Table 1). The progress of the reaction was monitored by TLC. After completion of the reaction, the solid which separated was filtered and then recrystallized from ethanol-water to afford pure products. The reaction mixture was filtered after 15 min. The residue was washed with EtOH (5 mL). Then, water (30 mL) was added to the filtrate, and the product was precipitated and filtered. The product was purified by washing with cold EtOH (2 × 5 mL).

Analytical data for compound e

Light red solid, mp: 208-210 °C. IR (KBr) ν\textsubscript{max}/cm\textsuperscript{-1}: 3421, 3295, 2950, 2900, 1635, 1506, 1457, 1377, 1216, 1173, 1082, 742. \textsuperscript{1}H NMR (300 MHz, DMSO-d\textsubscript{6}) δ (ppm) 5.01 (s, CH\textsubscript{2} benzylic, 6H), 5.72 (s, CH, 3H), 6.74-7.50 (m, CH aromatic, 46H), 10.71 (s, NH, 6H). \textsuperscript{13}C NMR (300 MHz, DMSO-d\textsubscript{6}) δ (ppm) 40.08, 69.48, 111.85, 114.67, 115.24, 118.54, 118.82, 119.58, 121.25, 123.87, 127.05, 129.66, 137.03, 137.73, 138.15, 156.91. Anal. Calc. for C\textsubscript{129.66}H\textsubscript{78}N\textsubscript{3}O\textsubscript{3}: C, 82.79; H, 5.31; N, 7.57. Found: C, 82.52; H, 5.21; N, 7.36.

Analytical data for compound f

Red solid, mp: 210-212 °C. IR (KBr) ν\textsubscript{max}/cm\textsuperscript{-1}: 3417, 2926, 2854, 1609, 1506, 1456, 1413, 1338, 1218, 1172, 1127, 1012, 743. \textsuperscript{1}H NMR (300 MHz, DMSO-d\textsubscript{6}) δ (ppm) 5.08 (s, CH\textsubscript{2} benzylic, 8H), 5.76 (s, CH, 4H), 6.82-7.65 (m, CH aromatic, 60H), 10.70 (s, NH, 8H). \textsuperscript{13}C NMR (300 MHz, DMSO-d\textsubscript{6}) δ (ppm) 41.05, 70.40, 111.45, 114.52, 115.12, 117.85, 118.85, 119.26, 120.85, 122.82, 126.65, 129.46, 136.19, 137.34, 137.74, 140.75, 151.24, 153.87. Anal. Calc. for C\textsubscript{129.26}H\textsubscript{78}N\textsubscript{3}O\textsubscript{3}: C, 82.95; H, 5.20; N, 7.35.

Analytical data for compound g

Red solid, mp: 255-257 °C. IR (KBr) ν\textsubscript{max}/cm\textsuperscript{-1}: 3420, 2912, 2860, 1612, 1510, 1435, 1403, 1327, 1218, 1170, 1118, 735. \textsuperscript{1}H NMR (300 MHz, DMSO-d\textsubscript{6}) δ (ppm) 5.10 (s, CH\textsubscript{2} benzylic, 8H), 5.71 (s, CH, 4H), 6.75-7.85 (m, CH aromatic, 46H), 10.70 (s, NH, 6H).
Supplementary Information

Supplementary characterization data and 1H NMR spectra are available, free of charge at http://jbscs.sbq.org.br, as a PDF file

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