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# The preparation of dicyano-1,3,4-thiadiazole and tricyanothiazole via 1,2,3-dithiazole chemistry

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ABSTRACT

Treatment of 1,2-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)hydrazine **4** with benzyltriethylammonium iodide (1 equiv) affords dicyano-1,3,4-thiadiazole **3** and 5-cyano-1,3,4-thiadiazole-2-carboxamide **5** in 79 and 21% yields, respectively. By using polymer bound triphenylphosphine instead of benzyltriethylammonium iodide the dicyano-1,3,4-thiadiazole **3** can be isolated in 70% yield without chromatography. The reaction of DAMN with Appel salt **8** gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile **7** (14%), 2,3-bis-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)fumaronitrile **10** (14%), and 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile **11** (24%) together with other products. The maleonitrile **11** isomerizes into the fumaronitrile **10** on irradiation at 365 nm. Reaction of aminoacetonitrile with Appel salt **8** gives the (dithiazolylidene)acetonitrile **7** in 33% yield. Treatment of (dithiazolylidene)acetonitrile **7** with polymer bound triphenylphosphine gives tricyanothiazole **6** in 76% yield. A rational general mechanism for the transformation of bisdithiazoles to percyanoheteroles is proposed.



## 1. Introduction

4,5-Dichloro-1,2,3-dithiazolium chloride (Appel salt)[1,2] was prepared over 20 years ago and its chemistry has been exploited extensively to prepare many neutral 5*H*-1,2,3-dithiazoles. Several excellent reviews have appeared,[3–6] and some 1,2,3-dithiazoles show interesting biological activity as fungicides,[7–9] or as antibacterials.[10–12] 1,2,3-Dithiazolyls are also of interest in the materials sciences as potential conductors and/or organic magnets.[13,14]

Additionally, neutral 4-chloro-1,2,3-dithiazoles are useful for the preparation of difficult to access cyano substituted heteroarenes. In particular *N*-substituted 1,2,3-dithiazolimines have been converted via thermolysis to benzothiazoles,[15,16] benzimidazoles,[17] thiazolopyridines,[18] and benzoxazines,[19] while selected 1,2,3-dithiazolylidenes have been converted into isothiazoles[20–22] and the rare 3*H*-pyrrole system.[23] Acyclic functionalities such as isothiocyanates, and thiocyanoformamides can also be prepared from neutral 1,2,3-dithiazolimines.[24–26]

Several percyanoheteroles are known (e.g., pyrrole,[27,28] furan,[29] thiophene,[28,30] pyrazole,[31] imidazole,[32] thiazole,[33] 1,2,4-thiadiazole,[34] 1,2,5-thiadiazole,[35] and the 1,3,4-thiadiazole[36]). Furthermore, percyanoheteroacenes often show interesting electrochemistry,[37,38] and readily form charge transfer salts that can have interesting conducting[39] or magnetic properties,[40,41] or find uses as neutral organic π acceptors for anion recognition.[42] However, their synthesis was often laborious, and involved the dehydration of carboxamide precursors using $P_2O_5$. We considered the possibility that several percyanoheteroles could be more efficiently prepared via 1,2,3-dithiazole chemistry, thus further demonstrating their usefulness. Herein we report the preparation of 1,3,4-thiadiazole-2,5-dicarbonitrile and thiazole-2,4,5-tricarbonitrile via dithiazole precursors.

## 2. Results and discussion

### 2.1. Synthesis of 1,3,4-thiadiazole-2,5-dicarbonitrile 3

1,3,4-Thiadiazole-2,5-dicarbonitrile **3**, an excellent fungicide for aspergillus,[36] has been prepared in five-steps starting from the commercially available 2,5-dimethyl-1,3,4-thiadiazole **1**. The procedure involved chlorination, methoxylation, hydrolysis, and aminolysis followed by dehydration of 1,3,4-thiadiazole-2,5-dicarboxamide **2** using $P_2O_5$ at 200 °C at 2 mmHg (Scheme 1). This procedure was time-consuming, involved the use of hazardous chlorine gas, and had a moderate overall yield (38%).[36]

A retrosynthetic analysis of thiadiazole-2,5-dicarbonitrile **3** suggested the nitriles could be derived from the N-3 and C-4 atoms of two dithiazole units. ANRORC[18,43,44] type ring transformations of 1,2,3-dithiazoles often lead to cyano functionalized heteroarenes, where the nitrile is derived from the carbon–nitrogen backbone of

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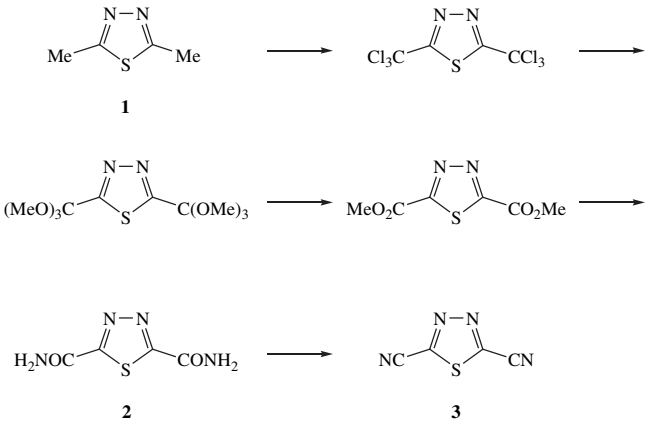
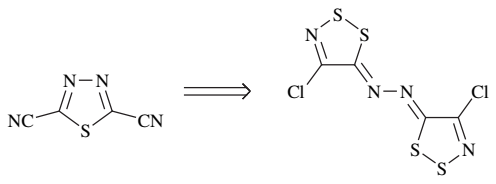



1 2 3

**Scheme 1.**

the dithiazole. An ideal precursor (synthon) for this reaction was identified to be the bisdithiazole **4**, which had been prepared by Oakley and Preuss in 33% yield.[45] To our knowledge, the use of a bisdithiazole to provide all the components of a monocyclic heteroarene via a ring transformation was new.



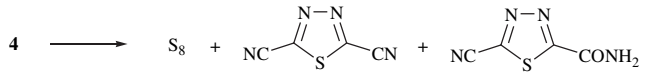

3 4

## 2.2. Preparation of bisdithiazole 4 and transformation into dicyanothiadiazole 3

The bisdithiazole **4** was synthesized according to the literature, by reacting anhydrous hydrazine with Appel salt (2 equiv) in 1,2-DCE.[45] By modifying the work-up, [the mixture was evaporated and the residue extracted (3 d, 1,2-DCE) in a Soxhlet apparatus] we were able to improve significantly the product yield from 33 to 58%.

The bisdithiazole **4** was then reacted with various tetraalkylammonium halides. While the ring transformation of (1,2,3-dithiazolylidene)malononitrile into 3-chloroisothiazole-4,5-dicarbonitrile using benzyltriethylammonium chloride (5 mol %) was almost quantitative,[20,22] the reaction of catalytic benzyltriethylammonium chloride with the bisdithiazole **4** could not be driven to completion. Nevertheless, the use of (1 equiv) of either benzyltriethylammonium chloride, bromide or iodide gave moderate to good yields of the desired thiadiazole **3** along with 5-cyano-1,3,4-thiadiazole-2-carboxamide **5** (Table 1). Performing the reactions under an argon atmosphere gave cleaner reaction mixtures and overall higher yields, presumably due to the hygroscopic nature of the tetraalkylammonium halides. Under these conditions benzyltriethylammonium iodide was superior and could be used in catalytic amount (0.25 equiv) despite a longer reaction time (6 h). Lower amounts of benzyltriethylammonium iodide (0.10 equiv) failed to drive the reaction to completion, even using microwave heating. The highest obtained yield of 1,3,4-thiadiazole-2,5-dicarbonitrile **3** (79%) was from the reaction of benzyltriethylammonium iodide (1 equiv) in refluxing PhCl, under an argon atmosphere. With the use of benzyltriethylammonium iodide (1 equiv) and microwave heating (ca. 160 °C) the reaction time was significantly reduced (5 min) as expected (Table 1).

**Table 1**
Transformation of the bisdithiazole 4 into the 1,3,4-thiadiazoles **3** and **5**




3 5

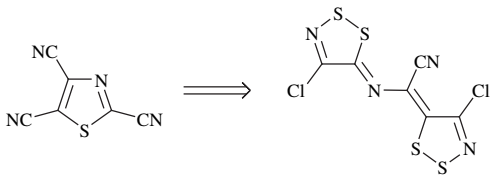
| Reagent (equiv) | Conditions | Yields (%) | |
|---|---|---|---|
| | | **3** | **5**[d] |
| $BnEt_3NCl$ (1) | PhCl, 132 °C, 14 h, air | 67 | 33 |
| $BnEt_3NBr$ (1) | PhCl, 132 °C, 51 h, air | 53 | 40 |
| $BnEt_3NI$ (1) | PhCl, 132 °C, 1 h, air | 55 | 27 |
| $BnEt_3NI$ (1) | PhCl, 132 °C, 0.67 h, Ar | 79 | 21 |
| $BnEt_3NI$ (1) | PhCl, 132 °C, 0.67 h, Ar | 60[c] | — |
| $BnEt_3NI$ (1) | PhCl, 160 °C (MW)[b], 5 min | 72 | 23 |
| $BnEt_3NI$ (0.50) | PhCl, 132 °C, 2 h, Ar | 78 | 19 |
| $BnEt_3NI$ (0.25) | PhCl, 132 °C, 6 h, Ar | 76 | 18 |
| $BnEt_3NI$ (0.25) | PhCl, 160 °C (MW)[b], 10 min | 55 | 24 |
| $BnEt_3NI$ (0.10) | PhCl, 132 °C, 72 h, Ar | [d] | — |
| $PPh_3$ (5)[a] | DCM, 20 °C, 24 h, air | [d] | — |
| $PPh_3$ (6)[a] | DCM, 20 °C, 0.5 h, air | 69 | — |
| $PPh_3$ (6)[a] | DCM, 20 °C, 1 h, air | 69 | — |
| $PPh_3$ (6)[a] | DCM, 20 °C, 0.5 h, Ar | 70 | — |
| $PPh_3$ (7)[a] | DCM, 20 °C, 0.5 h, air | 47 | — |

[a] $PPh_3$–polymer bound (3.2 mmol/g).
[b] Sealed tube reaction in Microwave reactor (MW, 250 W, 160 °C, 120 PSI).
[c] Isolated by Kugelrohr bulb-to-bulb distillation (60 °C, 4 mmHg).
[d] Incomplete reaction.

The formation of 5-cyano-1,3,4-thiadiazole-2-carboxamide **5** was caused by hydration of the dicyanothiadiazole **3** during chromatography; this reactivity on silica was confirmed by a 2D TLC study. Isolation of dicyanothiadiazole **3** directly from the reaction mixture by a Kugelrohr bulb-to-bulb distillation gave the product in only 60% yield. In a control study a pure sample of dicyanothiadiazole **3** was unstable towards benzyltriethylammonium iodide (1 equiv) in hot chlorobenzene and this could explain the reduced yields during the Kugelrohr distillation. Isolation of dicyanothiadiazole **3** could be simplified by the use of an alternative thiophile, polymer bound triphenylphosphine, that could also 'mop-up' any elemental sulfur formed. Treatment of the bisdithiazole **4** with polymer bound triphenylphosphine (6 equiv) afforded the desired product cleanly, by filtration, in 69% yield (Table 1). The use of less phosphine led to incomplete reactions, while extending the reaction time or using more triphenylphosphine (6 equiv) did not improve the product yield. Unlike the reactions with the tetraalkylammonium halides, there was no significant advantage in running the triphenylphosphine reactions under an argon atmosphere. Furthermore, the use of free triphenylphosphine led to incomplete reactions and gave only traces of the dicyanothiadiazole **3** (by TLC). Pure dicyanothiadiazole **3** in the presence of free triphenylphosphine (2 equiv) in DCM at reflux was surprisingly stable.

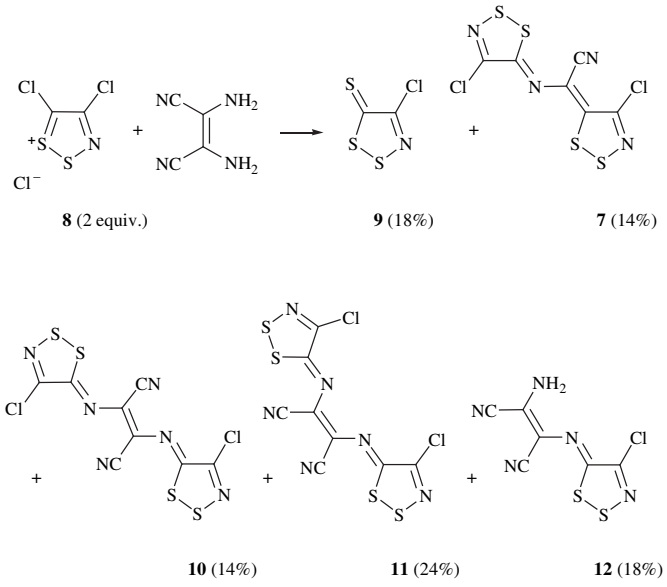
## 2.3. Synthesis of thiazole-2,3,4-tricarbonitrile 6

*2.3.1. Preparation of bisdithiazole **11**.* In view of the success of the synthesis of dicyanothiadiazole **3** via the bisdithiazole **4**, the analogous synthesis of thiazole-2,3,4-tricarbonitrile **6** was considered. Tricyanothiazole **6** has been prepared in the literature via a three-step process:[33] The reaction of diethyl 2-chloro-3-oxosuccinate and ethyl thiooxamate gave triethyl thiazole-2,4,5-tricarboxylate, aminolysis afforded thiazole-2,4,5-tricarboxamide and dehydration with $P_2O_5$ at 200 °C and $10^{-3}$ mmHg gave tricyanothiazole **6** in an overall yield of 14%. A retrosynthetic analysis of tricyanothiazole **6** gave the bisdithiazole **7** as a possible precursor.



6 7

The bisdithiazole **7** has been reportedly prepared in 39% yield by reacting Appel salt **8** with diaminomaleonitrile (DAMN).[46] However, in our hands product **7** could be obtained in only 14% yield and was surprisingly not the main reaction product (Scheme 2). Together with the typical Appel salt reaction minor byproduct 4-chloro-1,2,3-dithiazole-5(*H*)-thione **9**,[47] three other products were also isolated from the reaction mixture, the bisadducts **10** and **11** and the monoadduct **12** (Scheme 2). Efforts to improve the yield of the bisdithiazole **7** included: performing the reaction at ca. 39 °C (refluxing DCM), using excess Appel salt **8** (3 equiv), manipulating the reaction time, the concentration, using dry MeCN as solvent, and also starting from the monoadduct **12**.[46] However none of these efforts gave an increased yield of the bisdithiazole **7**. It was interesting though to investigate the structure of the other products **10** and **11**.



**8** (2 equiv.) **9** (18%) **7** (14%)

**10** (14%) **11** (24%) **12** (18%)

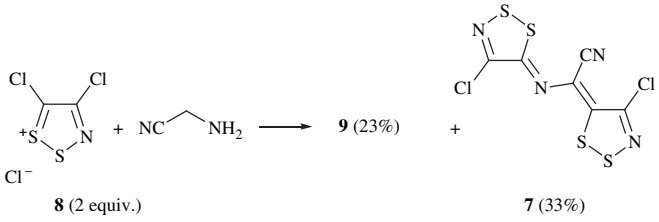
**Scheme 2.**

The major product **11** (24%) [mp (DSC onset) 212 °C (decomp.) (from 1,2-DCE)] was deep red in colour [$\lambda_{max}$(DCM) 502 nm (log $\varepsilon$ 3.30)] suggesting extended conjugation and possibly an intact dithiazole ring. Compound **11** gave a correct microanalysis for the formula $C_8Cl_2N_6S_4 \cdot C_2H_2Cl_2$ suggesting a 1:1 co-crystallization with 1,2-DCE. The sample on vacuum drying gave a correct analysis for $C_8Cl_2N_6S_4$ and LREI mass spectrometry gave a molecular parent ion of *m*/*z* 378 Da (15%) with an isotope pattern indicative of two chlorine atoms. IR spectroscopy supported the presence of a C≡N group ($\nu_{max}$ 2210 $cm^{-1}$) while $^{13}C$ NMR spectroscopy showed a total of 5 resonances, one sp hybridized ($\delta_C$ 113.2 ppm) corresponding to the C≡N group, and three $sp^2$ hybridized carbon resonances ($\delta_C$ 163.6, 147.2, and 120.4 ppm), typical of dithiazolimines. The data suggested a symmetrical structure. The remaining $sp^3$ carbon resonance corresponded to the co-crystallized 1,2-DCE and this was confirmed by $^1H$ NMR spectroscopy that showed the presence of one singlet resonance ($\delta_H$ 3.90 ppm).[48] The data suggested the bisdithiazole adduct of DAMN, however, the geometry of the ethene bond could not be determined.

Interestingly the second minor product **10** (14%) [mp (DSC onset) 274 °C (decomp.) (from PhCl)], was a highly insoluble, purple solid. Microanalysis gave the formula $C_8Cl_2N_6S_4$ and LREI mass spectrometry gave a molecular parent ion of *m*/*z* 378 Da (11%) with an isotope pattern indicative of two chlorine atoms, suggesting it was isomeric to compound **11**. Its UV/vis spectrum was more red-shifted [$\lambda_{max}$ (DCM) 524 nm (log $\varepsilon$ 3.46)] indicating more extensive conjugation than product **11** while IR spectroscopy again confirmed the presence of a C≡N group ($\nu_{max}$ 2197 $cm^{-1}$). Owing to the high insolubility of product **10** $^1H$ and $^{13}C$ NMR spectroscopic data could not be obtained.

Interestingly, heating a sample of isomer **11** gave some **10** raising the suspicion that compound **10** was in fact the *trans* isomer of **11**. Having in mind the *cis*–*trans* isomerization of DAMN,[49,50] we attempted the photochemical isomerization of isomers **10** and **11**. After irradiating a solution (DCM) of bisdithiazole **10** with UV/vis light of 365 nm for 12 h we observed no change (by TLC), however, irradiation of isomer **11** led to its complete transformation into the insoluble isomer **10**. This tentatively suggested that compound **10** was the *trans* isomer 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)fumaronitrile **10**, which would be expected to be the most thermodynamically stable and owing to the *trans* geometry more conjugated, while compound **11** should be the *cis* isomer 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile **11**.

Unable to get a respectable yield of the bisdithiazole **7** from the reaction with DAMN, a different approach was pursued. A retrosynthetic analysis of the bisdithiazole **7** revealed that it could be prepared from two molecules of Appel salt **8** and one molecule of aminoacetonitrile. The reaction of commercially available aminoacetonitrile hydrogen sulfate salt with Appel salt **8** (2 equiv), at ca. 20 °C for 24 h, followed by the addition of pyridine (6 equiv) gave the desired product **7** in only 8–10% yield. The use of free aminoacetonitrile,[51] however, and Appel salt **8** (2 equiv) in DCM at reflux for 24 h followed by the addition of pyridine (4 equiv) gave the desired product **7** in 33% yield (Scheme 3).



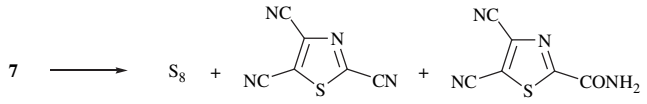
**8** (2 equiv.) **9** (23%) **7** (33%)

**Scheme 3.**

## 2.4. Ring transformation of bisdithiazole 7 into thiazoletricarbonitrile 6

The reaction of bisdithiazole **7** with benzyltriethylammonium chloride (1 equiv) in refluxing PhCl gave the tricyanothiazole **6** and the hydrated thiazole **13** in 70 and 15% yields, respectively. Good to moderate yields of the tricyanothiazole **6** were also achieved with benzyltriethylammonium bromide (1–0.1 equiv) and benzyltriethylammonium iodide (1 equiv). This data suggested that the bisdithiazole **7** was more reactive than bisdithiazole **4** and this could arise from the presence of the (dithiazolylidene)acetonitrile moiety, which was expected to show reactivity similar to that of (1,2,3-dithiazolylidene)malononitrile[20–22] and therefore more susceptible to the thiophiles. The use of polymer bound triphenylphosphine (5 equiv) allowed the chromatography-free isolation of the tricyanothiazole **6** in 76% yield. The use of less phosphine again led to incomplete reactions, while extending the reaction time or using

**Table 2**
Transformation of the bisdithiazole **7** into the thiazoles **6** and **13**



**6** **13**

| Reagent (equiv) | Conditions | Yields (%) | |
|---|---|---|---|
| | | **6** | **13** |
| $BnEt_3NCl$ (1) | PhCl, 132 °C, 1 h, Ar | 70 | 15 |
| $BnEt_3NCl$ (0.1) | PhCl, 132 °C, 48 h, Ar | [b] | |
| $BnEt_3NBr$ (1) | PhCl, 132 °C, 5 min, Ar | 63 | 11 |
| $BnEt_3NBr$ (0.5) | PhCl, 132 °C, 15 min, Ar | 68 | 20 |
| $BnEt_3NBr$ (0.1) | PhCl, 132 °C, 5 h, Ar | 63 | 17 |
| $BnEt_3NI$ (1) | PhCl, 132 °C, 35 min, Ar | 56 | 14 |
| $BnEt_3NI$ (0.1) | PhCl, 132 °C, 48 h, Ar | [b] | |
| $PPh_3$ (4)[a] | DCM, 20 °C, 24 h, air | [b] | — |
| $PPh_3$ (5)[a] | DCM, 20 °C, 2 h, air | 76 | — |
| $PPh_3$ (5)[a] | DCM, 20 °C, 4 h, air | 76 | — |
| $PPh_3$ (5)[a] | DCM, 20 °C, 2 h, Ar | 74 | — |
| $PPh_3$ (6)[a] | DCM, 20 °C, 1 h, air | 68 | — |

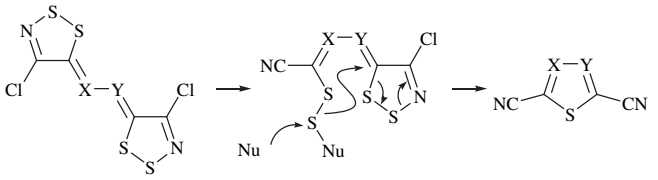
[a] $PPh_3$–polymer bound (3.2 mmol/g).
[b] Incomplete reaction.

more than 5 equiv did not improve the product yield. Again free triphenylphosphine gave only traces of the tricyanothiazole **6** (Table 2).

4,5-Dicyanothiazole-2-carboxamide **13**, mp 162–163 °C (from PhMe), has not been previously reported in the literature. The position of the carboxamide substituent was tentatively determined by mass spectroscopy. The LRMS-EI spectrum gave two characteristic peaks, which tentatively correspond to the loss of the SCC≡N (108 Da, 27%) and N=CCN fragments (126, 4%), and also five peaks, which correspond to the fragments NCC=CCN (76, 7%), N=CCONH$_2$ or SCC≡N (70, 23%), NC=CCN (64, 5%) and C=CC≡N (50, 4%). The fragments NCC=CCN (76, 7%) and NC=CCN (64, 5%) tentatively supported the formation of 4,5-dicyanothiazole-2-carboxamide **13**. Furthermore, the donor–acceptor concept concerning the general reactivity of the thiazole ring, supports that the C-2 position was the most electron-deficient while the C-5 position was electron-rich and the C-4 position was neutral.[52,53] As such, the reactivity of the substituents linked to carbon atoms of the thiazole ring depended on their position on the heterocyclic nucleus. The nitrile group that was linked to the C-2 carbon atom, the most electron deficient carbon, was therefore expected to hydrate preferentially.

### 2.5. Mechanistic rationale for the ring transformations

Soft thiophilic nucleophiles can cleave 1,2,3-dithiazoles to afford the disulfide intermediates **14**. These intermediates can be a source of both electrophilic and nucleophilic sulfur. As such, a second thiophile can attack the thiophile bound sulfur of the disulfide infusing nucleophilic character to the adjacent sulfur, which can then be trapped by the electrophilic C-5 ring carbon atom of the remaining 1,2,3-dithiazole unit affording the synthesis of percyanoheterocycles



**4** [X = Y = N] **14** **3** [X = Y = N]
**7** [X = C(CN), Y = N] **6** [X = C(CN), Y = N]

**Scheme 4.**

**3** or **6** (Scheme 4). Since the bisdithiazole **7** was more reactive than bisdithiazole **4** it could tentatively be surmised that the dithiazolylidene moiety of bisdithiazole **7** was more susceptible to ring cleavage owing to its more electrophilic character.

## 3. Summary

A remarkably short and chromatography free synthesis of 1,3,4-thiadiazole-2,5-dicarbonitrile **3** has been achieved using 1,2,3-dithiazole chemistry. The strategy also provided a route to thiazole-2,4,5-tricarbonitrile **6** although this synthesis required to the difficult to access bisdithiazole **7**. In an effort to obtain bisdithiazole **7** in higher yields, an alternative synthesis involving aminoacetonitrile and Appel salt **8** was developed to complement the known synthesis using DAMN.

## 4. Experimental section

### 4.1. General

DCM was freshly distilled from $CaH_2$ under argon. Anhydrous hydrazine was prepared by distillation of hydrazine monohydrate from KOH under argon and stored over 4 Å molecular sieves. Reactions were protected from atmospheric moisture by $CaCl_2$ drying tubes. Anhydrous $Na_2SO_4$ was used for drying organic extracts, and all volatiles were removed under reduced pressure. All reaction mixtures and column eluents were monitored by TLC using commercial glass backed thin layer chromatography (TLC) plates (Merck Kieselgel 60 $F_{254}$). The plates were observed under UV light at 254 and 365 nm. The technique of dry flash chromatography was used throughout for all non-TLC scale chromatographic separations using Merck Silica Gel 60 (less than 0.063 mm).[54] Melting points were determined using a PolyTherm-A, Wagner & Munz, Koefler–Hotstage Microscope apparatus. Decomposition points (decomp.) and mp >250 °C were determined using a TA Instruments DSC Q1000 with samples hermetically sealed in aluminium pans under an argon atmosphere; using heating rates of 5 °C/min. Solvents used for recrystallization are indicated after the melting point. UV spectra were obtained using a Perkin–Elmer Lambda-25 UV/vis spectrophotometer and inflections are identified by the abbreviation 'inf'. IR spectra were recorded on a Shimadzu FTIR-NIR Prestige-21 spectrometer with a Pike *Miracle* Ge ATR accessory and strong, medium and weak peaks are represented by s, m and w, respectively. $^1$H and $^{13}$C NMR spectra were recorded on a Bruker Avance 300 machine (at 300 and 75 MHz, respectively). Deuterated solvents were used for homonuclear lock and the signals are referenced to the deuterated solvent peaks. Low resolution (EI) mass spectra were recorded on a Shimadzu Q2010 GC–MS with direct inlet probe. Photochemical isomerizations were performed using a UVitec LF-204.LS (4 W) hand held UV lamp. 4,5-Dichloro-1,2,3-dithiazolium chloride **8**[1] was prepared according to the literature procedure.

### 4.2. 1,2-Bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)hydrazine 4

A solution of anhydrous hydrazine (1 mL, 32 mmol) in 1,2-dichloroethane (DCE) (60 mL) was added dropwise to an ice-bath cooled slurry of Appel salt **8** (12.5 g, 60 mmol) in DCE (200 mL). The reaction mixture was then stirred at ca. 20 °C for 18 h and heated to reflux for 4 h. The mixture was then allowed to cool to room temperature and the volatiles removed to afford a black residue. The residue was transferred to a Soxhlet apparatus (30 mL) and extracted with DCE (200 mL) for 72 h. Evaporation of the DCE extracts and crystallization gave the title compound **4** (5.28 g, 58%) as black-green plates, mp 246–247 °C (lit.,[46] 249 °C) (from PhCl); identical to an authentic sample.

### 4.3. 1,3,4-Thiadiazole-2,5-dicarbonitrile 3

To a stirred solution of 1,2-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)hydrazine **4** (100 mg, 0.33 mmol) in PhCl (3 mL) at ca. 20 °C, benzyltriethylammonium iodide (105.3 mg, 0.33 mmol) was added and the reaction was heated to reflux, under an argon atmosphere. The mixture was kept at reflux for 40 min, until no starting material remained (TLC). The reaction mixture was then allowed to cool to ca. 20 °C and adsorbed on silica. Chromatography (hexane) gave sulfur (31.7 mg, 100%). Further elution (hexane–DCM, 1:1) gave the title compound **3** (35.5 mg, 79%) as colourless plates, mp 118–119 °C (lit.,[36] 121 °C) (from cyclohexane); $R_f$ (hexane–DCM, 1:1) 0.30; $\nu_{max}$/cm$^{-1}$ 2249w and 2182w (C≡N), 1396w, 1366m, 1340w, 1302w, 1263w, 1227w, 1203s, 1181w, 1157s, 1101w, 892w; $\delta_C$(75 MHz; $CDCl_3$) 142.4, 108.2 (*C*≡N); *m*/*z* (EI) 136 ($M^+$, 100%), 108 (6), 84 (4), 82 (4), 72 (5), 71 (3), 70 (100), 58 (10), 56 (3), 52 (10). Further elution (hexane–EtOAc, 3:7) gave *5-cyano-1,3,4-thiadiazole-2-carboxamide* **5** (10.8 mg, 21%) as colourless plates, mp 207–208 °C (decomp.) (from PhH); $R_f$ (hexane–EtOAc, 3:7) 0.74; (Found: C, 31.3; H, 1.3; N, 36.3. $C_4H_2N_4OS$ requires C, 31.2; H, 1.3; N, 36.35); $\nu_{max}$/cm$^{-1}$ 3401m, 3324w, 3294w, 3270m and 3198w ($NH_2$), 2260 (C≡N), 1679s (C═O), 1600m, 1454w, 1388w, 1367m, 1330w, 1249w, 1197m, 1179w, 1126m, 1089m, 1081w, 803w; $\delta_H$(300 MHz; DMSO-$d_6$) 8.91 (1H, br s, N*H*), 8.48 (1H, br s, N*H*); $\delta_C$(75 MHz; DMSO-$d_6$) 170.0 (*C*═O), 158.1, 143.7, 110.8 (*C*≡N); *m*/*z* (EI) 154 ($M^+$, 23%), 126 (17), 111 (59), 84 (8), 82 (3), 70 (10), 59 (27), 58 (12), 53 (6), 52 (2).

### 4.4. 1,3,4-Thiadiazole-2,5-dicarbonitrile 3 using polymer bound triphenylphosphine

To a stirred solution of 1,2-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)hydrazine **4** (30 mg, 0.10 mmol) in dry DCM (3 mL) at ca. 20 °C, polymer bound triphenylphosphine 3.2 mmol/g (185.63 mg, 0.594 mmol) was added and the reaction was kept at ca. 20 °C until no starting material remained (TLC). The polymer bound triphenylphosphine was filtered from the reaction mixture and the solvent was evaporated to give the title compound **3** (9.3 mg, 69%) as colourless plates, mp 118–119 °C (lit.,[36] 121 °C) (from cyclohexane) identical to that described above.

## 5. Reaction of Appel salt 8 with DAMN

To a stirred solution of diaminomaleonitrile (107 mg, 1 mmol) in dry DCM (10 mL) at ca. 20 °C, 4,5-dichloro-1,2,3-dithiazolium chloride **8** (417 mg, 2 mmol) was added in one portion. After 24 h pyridine (323 μL, 4 mmol) was added and the mixture was stirred for a further 30 min. Then the reaction mixture was adsorbed on silica and chromatography (hexane–DCM, 8:1) gave 4-chloro-5*H*-1,2,3-dithiazole-5-thione **9** (30.5 mg, 18%) as red needles, mp 75–76 °C (lit.,[1] 78–79 °C) (from pentane); $R_f$ (hexane–DCM, 8:1) 0.52; identical with an authentic sample. Further elution (hexane–DCM, 2:1) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile **7** (45.8 mg, 14%) as a deep purple solid, mp 241–242 °C (lit.,[46] 244–245 °C) (from PhH); $R_f$ (hexane–DCM, 2:1) 0.48; identical to an authentic sample. Further elution (hexane–DCM, 1:1) gave 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)fumaronitrile **10** (53.1 mg, 14%) as purple needles, mp (DSC onset) 274 °C (decomp.) (from PhCl); $R_f$ (hexane–DCM, 1:1) 0.56; (Found: C, 25.3; N, 22.1. $C_8Cl_2N_6S_4$ requires C, 25.3; N, 22.2); $\lambda_{max}$ (DCM)/nm 228 (log ε 3.13), 269 (3.07), 389 (2.43), 482 inf (3.23), 524 (3.46), 550 (3.40); $\nu_{max}$/cm$^{-1}$ 2197w (C≡N), 1533s, 1518s, 1452s, 1283m, 1236w, 1198w, 1128w, 1094w, 1024w, 984w, 932m, 901m, 866s, 808m, 746w, 710s; *m*/*z* (EI) 382 ($M^+$+4, 3%), 380 ($M^+$+2, 9), 378 ($M^+$, 11), 281 (15), 279 (40), 125 (10), 102 (12), 93 (14), 76 (15), 70 (23), 64 (100). A further elution (hexane–DCM, 1:2) gave 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile **11** (91.0 mg, 24%) as black-green needles, mp (DSC onset) 212 °C (decomp.) (from DCE); $R_f$ (hexane–DCM, 1:2) 0.47; (Found: C, 25.2; H, 0.9; N, 17.6. $C_8Cl_2N_6S_4 \cdot C_2H_2Cl_2$ requires C, 25.1; H, 0.8; N, 17.6); after drying in a vacuum oven (24 h) at 60 °C (Found: C, 25.4; N, 22.1. $C_8Cl_2N_6S_4$ requires C, 25.3; N, 22.2); $\lambda_{max}$ (DCM)/nm 230 (log ε 3.03), 258 (2.89), 395 (2.93), 502 (3.30), 553 inf (3.02); $\nu_{max}$/cm$^{-1}$ 2210w (C≡N), 1549s, 1477s, 1236s, 1150m, 984m, 897w, 876s, 800s, 777w; $\delta_H$ (300 MHz; DMSO-$d_6$) 3.90 (s, Cl*CH*$_2$*CH*$_2$Cl, lit.,[48] 3.90); $\delta_C$ (75 MHz; $CDCl_3$) 163.6 (*C*-5), 147.2 (*C*-4), 120.4 (*C*═*C*), 113.2 (*C*≡*N*), 45.0 (Cl*CH*$_2$*CH*$_2$Cl, lit.,[48] 45.02); *m*/*z* (EI) 382 ($M^+$+4, 4%), 380 ($M^+$+2, 11), 378 ($M^+$, 15), 281 (23), 279 (53), 216 (11), 149 (8), 127 (7), 125 (14), 102 (12), 93 (15), 85 (10), 76 (19), 70 (30), 64 (100). A final elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene-amino)-3-aminomaleonitrile **12** (41.2 mg, 16%) as orange needles, mp 201–203 °C (lit.,[46] 205–207 °C) (from DCE); $R_f$ (DCM) 0.47; identical to an authentic sample.

### 5.1. Reaction of Appel salt 8 with 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-3-aminomaleonitrile 12

To a stirred solution of 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-3-aminomaleonitrile **12** (107 mg, 1 mmol) in dry DCM (10 mL) at ca. 20 °C, 4,5-dichloro-1,2,3-dithiazolium chloride **8** (208.5 mg, 1 mmol) was added in one portion. After 24 h pyridine (161 μL, 2 mmol) was added and the mixture was stirred for a further 30 min. Then the reaction was adsorbed on silica and chromatography (hexane–DCM, 8:1) gave 4-chloro-5*H*-1,2,3-dithiazole-5-thione **9** (25.5 mg, 29%) as red needles, mp 75–76 °C (lit.,[1] 78–79 °C) (from pentane); $R_f$ (hexane–DCM, 8:1) 0.52; identical to an authentic sample and further elution (hexane–DCM, 2:1) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile **7** (26.2 mg, 8%) as a deep purple solid, mp 241–242 °C (lit.,[46] 244–245 °C) (from PhH); $R_f$ (hexane–DCM, 2:1) 0.48; identical to an authentic sample. Further elution (hexane–DCM, 1:1) gave 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)fumaronitrile **10** (22.7 mg, 6%) as purple needles, mp (DSC onset) 274 °C (decomp.) (from PhCl); $R_f$ (hexane–DCM, 1:1) 0.56; identical to that described above. A further elution (hexane–DCM, 1:2) gave 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile **11** (98.5 mg, 26%) as black-green crystals, mp (DSC onset) 212 °C (decomp.) (from DCE); $R_f$ (hexane–DCM, 1:2) 0.47; identical to that described above. A final elution (DCM) gave recovered 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-3-aminomaleonitrile **12** (141.6 mg, 55%) as orange needles, 201–203 °C (lit.,[46] 205–207 °C) (from DCE); $R_f$ (DCM) 0.47; identical to an authentic sample.

### 5.2. Photochemical isomerization of 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile 11 to 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile 10

A solution of 2,3-bis(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)maleonitrile **11** (10 mg, 0.021 mmol) in DCM (5 mL) was radiated with UV light at 365 nm using a UV-lamp. After 12 h a purple precipitate was formed and TLC confirmed the complete consumption of **11**. After evaporation of the solvent, 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile **10** was isolated (7.5 mg, 96%) as purple needles mp (DSC onset) 274 °C (decomp.) (From PhCl) identical to that described above.

### 5.3. Reaction of Appel salt 8 with aminoacetonitrile

To a stirred solution of aminoacetonitrile (13.4 mg, 0.24 mmol) in dry DCM (3 mL) at ca. 20 °C, 4,5-dichloro-1,2,3-dithiazolium

chloride **8** (100 mg, 0.48 mmol) was added in one portion and the mixture was heated at ca. 39 °C. After 24 h pyridine (77 μL, 0.96 mmol) was added and the mixture was stirred for a further 30 min. Then the reaction mixture was adsorbed on silica and chromatography (hexane–DCM, 8:1) gave 4-chloro-5*H*-1,2,3-dithiazole-5-thione **9** (9.3 mg, 23%) as red needles, mp 75–76 °C (lit.,[1] 78–79 °C) (from pentane); $R_f$ (hexane–DCM, 8:1) 0.52; identical to an authentic sample and further elution (hexane–DCM, 2:1) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)acetonitrile **7** (25.9 mg, 33%) as a deep purple solid, mp 241–242 °C (lit.,[46] 244–245 °C) (from PhH); $R_f$ (hexane–DCM, 2:1) 0.48; identical to an authentic sample.

### 5.4. Thiazole-2,4,5-tricarbonitrile 6

To a stirred solution of 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)acetonitrile **7** (50 mg, 0.153 mmol) in PhCl (3 mL) at ca. 20 °C, benzyltriethylammonium chloride (34.9 mg, 0.153 mmol) was added and the reaction was kept at reflux, under an argon atmosphere for 1 h until no starting material remained (TLC). The reaction mixture was then allowed to cool to ca. 20 °C and adsorbed on silica. Chromatography (hexane) gave sulfur (12.5 mg, 100%). Further elution (hexane–DCM, 1:1) gave the title compound **6** (17.1 mg, 70%) as colourless plates, mp 122–123 °C (lit.,[33] 127 °C) (from PhH); $R_f$ (hexane–DCM, 1:1) 0.24; $\nu_{max}/cm^{-1}$ 2246w and 2236w (C≡N), 1477w, 1418m, 1333m, 1205w, 1183w, 1153s, 969w, 950w, 885w, 736w, 703m; $\delta_C$(75 MHz; $CDCl_3$) 142.4, 135.4, 119.7, 109.5 (*C*≡N), 109.4 (*C*≡N), 107.0 (*C*≡N); *m*/*z* (EI) 160 ($M^+$, 55%), 110 (5), 109 (6), 108 (100), 91 (4), 83 (3), 82 (26), 76 (9), 72 (3), 71 (5), 70 (57), 69 (3), 64 (11), 58 (9), 57 (8), 56 (13), 55 (5), 52 (8), 50 (10). Further elution (hexane–EtOAc, 3:7) gave *4,5-dicyanothiazole-2-carboxamide* **13** (4.1 mg, 15%) as colourless needles, mp 162–163 °C (from PhMe); $R_f$ (hexane–EtOAc, 3:7) 0.70; (Found: C, 40.3; H, 1.0; N, 31.3. $C_6H_2N_4OS$ requires C, 40.6; H, 1.1; N, 31.5%); $\lambda_{max}$ (DCM)/nm 229 (log ε 3.19), 266 (3.03), 276 (3.05); $\nu_{max}/cm^{-1}$ 3376w, 3297w, and 3174w ($NH_2$), 2247w (C≡N), 2241w (C≡N), 1689s (C═O), 1610w, 1481w, 1458w, 1386m, 1230w, 1130m, 791w, 744w, 735w; $\delta_H$(300 MHz; DMSO-$d_6$) 8.82 (1H, br s, N*H*), 8.43 (1H, br s, N*H*); $\delta_C$(75 MHz; DMSO-$d_6$) 171.0 (C═O), 158.7, 134.0, 120.3, 111.8 (*C*≡N), 110.0 (*C*≡N); *m*/*z* (EI) 178 ($M^+$, 36%), 162 (3), 135 ($M^+$-CONH, 50), 126 ($M^+$-N═CCN, 4), 108 ($M^+$-SCCN, 27), 83 (9), 82 (14), 77 (10), 76 (NCC═$CCN^+$, 7), 71 (5), 70 (N═$CCONH_2^+$ or $SCCN^+$, 23), 69 (N═$CCONH^+$, 3), 64 (NC═$CCN^+$, 5), 59 (10), 58 (N═$CS^+$, 17), 57 (8), 55 (3), 50 (C═$CCN^+$, 4).

### 5.5. Thiazole-2,4,5-tricarbonitrile 6 using polymer bound triphenylphosphine

To a stirred solution of 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)-2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)acetonitrile **7** (50 mg, 0.153 mmol) in dry DCM (3 mL) at ca. 20 °C, polymer bound triphenylphosphine 3.2 mmol/g (286.9 mg, 0.92 mmol) was added and the reaction was kept at ca. 20 °C until no starting material remained (TLC). The polymer bound triphenylphosphine was filtered off from the reaction mixture and evaporation of the solvent gave the title compound **6** (18.6 mg, 76%) as colourless plates, mp 122–123 °C (lit.,[33] 127 °C) (from PhH) identical to that described above.

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