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Reaction of 2,3-diaminomaleonitrile with diones

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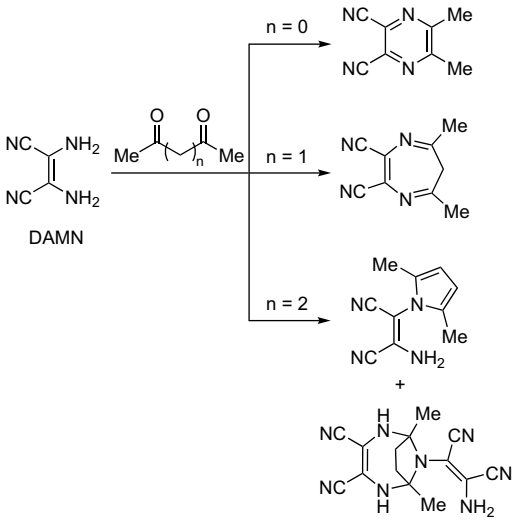
ABSTRACT

2,3-Diaminomaleonitrile (DAMN) was allowed to react with 2,6-heptanedione to produce (2*Z*)-2-amino-3-[(1*E*)-3-methylcyclohex-2-enylideneamino]but-2-enedinitrile and (2*Z*)-2-amino-3-[(1*Z*)-3-methylcyclohex-2-enylideneamino]but-2-enedinitrile. The reaction of DAMN with 2,7-octanedione yielded *trans*-5,8a-dimethyl-1,5a,6,7,8,8a-hexahydrocyclopenta[*e*]-1,4-diazepine-2,3-dicarbonitrile. DAMN reacted with 2,8-nonanedione to afford *trans*- and *cis*-5,9a-dimethyl-5a,6,7,8,9,9a-hexahydro-1*H*-benzo[*e*]-1,4-diazepine-2,3-dicarbonitrile. These compounds were characterized by X-ray crystallography, NMR spectroscopy, and DFT calculations.

1. Introduction

2,3-Diaminomaleonitrile[1] (DAMN), a tetramer of HCN, and its derivatives have received considerable attention as one of the versatile precursors of heterocycles. The synthesis of imidazoles,[2] triazoles,[2a] porphyrazines,[3] pyrimidines,[4] pyrazines,[5] diazepines,[6] and purines[7] has been reported. DAMN can also serve as a synthetic precursor of fluorescent dyes,[5e,g,j,6a–c,8] jet-printing inks,[9] hair dyes,[10] and biologically active compounds such as insecticides[11] and anticancer agents.[12] Furthermore, it has been recently observed that monoimine derivatives of DAMN have a great potential to realize hyperbranched polymers by thermal polymerization via a 1,4-conjugate addition.[13] Recently, a three-component reaction[14] using DAMN as well as a general two-component reaction and the application of green chemistry to the reaction between DAMN and aldehydes have also been reported.[15]

In addition, the reaction of DAMN with diketones has also been reported. DAMN reacts with 2,3-butanedione[5j,k] (n=0) and 2,4-pentanedione[5j,6d] (n=1) to yield a pyrazine and 6*H*-1,4-diazepine, respectively (Scheme 1). However, it is interesting to note that DAMN reacts with 2,5-hexanedione (n=2) to afford either (*Z*)-1-amino-1,2-dicyano-2-(2,5-dimethylpyroro)ethane or triazabicyclononene, depending on the reaction conditions.[16] Thus, the expected diimino derivative is not always obtained from the reaction between DAMN and diketones. To the best of our knowledge, the reaction of DAMN with 2,6-diones (n=3), 2,7-diones



Scheme 1. Previously reported reaction of DAMN with diketones.

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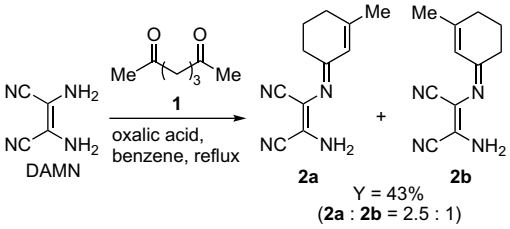
(n=4), and 2,8-diones (n=5) has not yet been investigated. We report herein the reaction of DAMN with 2,6-heptanedione (**1**), 2,7-octanedione (**6**), and 2,8-nonanedione (**10**).

2. Results and discussion

2.1. Reaction of DAMN with 2,6-heptanedione (1)

The reaction of DAMN with **1**[17] was examined in the presence of oxalic acid. From the ^{1}H NMR spectrum in $CDCl_3$, it was elucidated that two isomers were produced in a 2.5:1 ratio (Scheme 2, Fig. S1). The signal of the spectrum showed a series of large methylene (δ_H: 1.88, 2.23, and 2.67), methyl (δ_H: 1.95), amino (δ_H: 4.70), and methine (δ_H: 6.04) signals along with another series of small methylene (δ_H: 1.94, 2.28, and 2.48), methyl (δ_H: 1.99), amino (δ_H: 4.54), and methine (δ_H: 6.47) signals.



Scheme 2. Reaction of DAMN with 2,6-heptanedione (**1**).

Efforts to separate the two isomers by using column chromatography were unsuccessful. Therefore, we performed recrystallization using CH_2Cl_2 and hexane as solvents. X-ray crystallography was performed on the obtained crystalline precipitate. As a result, only **2a** was observed. The X-ray structure of the precipitate is shown in Figure 1. Surprisingly, the ^{1}H NMR spectra of the crystalline precipitate showed two isomers present in a ratio of 2.5:1 in $CDCl_3$. An identical ^{1}H NMR spectrum was obtained from the measurement of the mother liquor. These results suggest that a part of **2a** is isomerized to another isomer in solution. The three compounds shown in Figure 2 are considered to be isomers of **2a**.

In order to demonstrate the isomerization of **2a**, DFT calculations were performed on isomers **2a**–**2d** using the Gaussian 03 program package.[18] A density functional method was employed

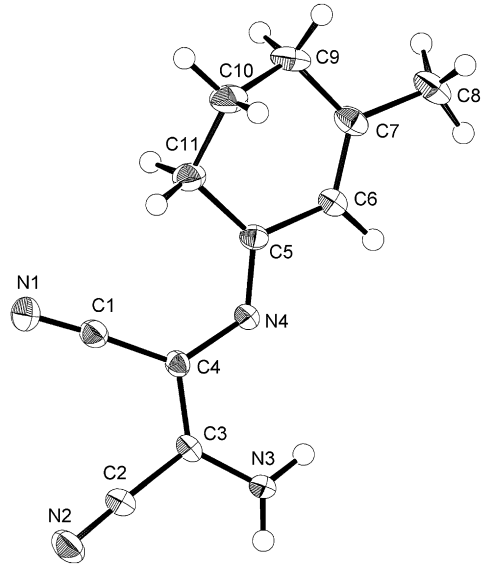


Figure 1. ORTEP drawing of **2a**.

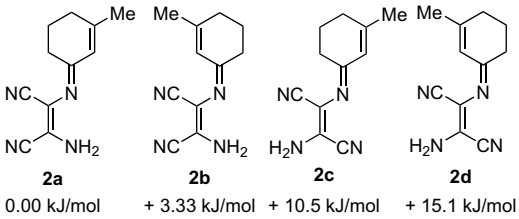


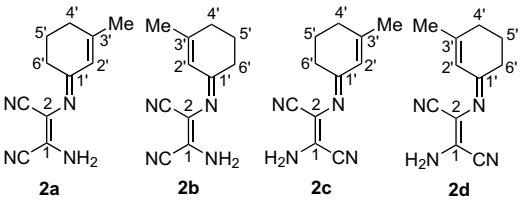
Figure 2. Relative energies of possible isomers calculated at the B3LYP/6-31G(d,p) level.

using the B3LYP[19] and 6-31G(d,p) basis sets. The optimized structures and relative energies of the isomers are shown in Figure S2 and Figure 2, respectively. The calculated stability order of these isomers is as follows: (most stable) **2a**>**2b**>**2c**>**2d** (least stable). It is considered that 2*Z*-isomers **2a** and **2b** are more stable than 2*E*-isomers **2c** and **2d** owing to an internal N–H···H hydrogen bond. This calculated result indicates that **2a** is isomerized to **2b**.

The complete assignment of the ^{1}H and ^{13}C NMR spectra of **2a** and **2b** was performed by DEPT, HMQC,[20] and HMBC[21] NMR experiments (Figs. S3 and S4). The observed ^{13}C NMR chemical shift values of C1 (122.5 and 121.4 ppm) and C2 (105.5 and 105.6 ppm) and the IR band (ν_{NH}=3407, 3289, 3180, 3148 cm^{-1}, ν_{CN}=2235, 2201 cm^{-1}) in the two isomers are close to the previously reported values of (2*Z*)-2-amino-3-[(arylmethylene)amino]but-2-enedinitriles[15] (Table 1). This provides additional evidence for the formation of 2*Z*-isomers **2a** and **2b**. In the ^{1}H NMR spectrum, a significant low-field shift of **2a** methylene signal at δ_H=2.67 and **2b** methine signal at δ_H=6.47 is observed in comparison with **2b** methylene signal at δ_H=2.48 and **2a** methine signal at δ_H=6.04, respectively. This may be attributed to the anisotropic deshielding effect of the adjacent cyano group.

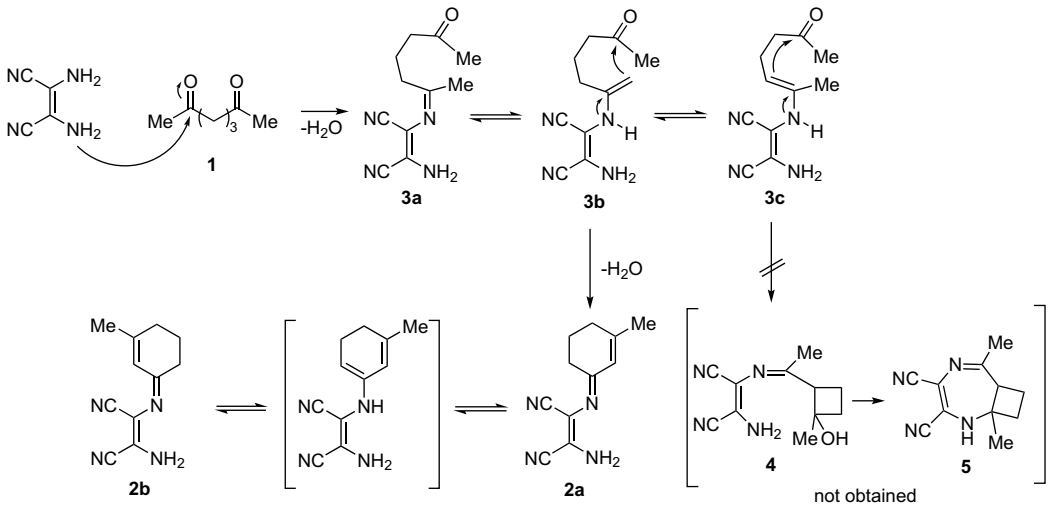
In order to obtain further evidence for the formation of **2a** and **2b**, a GIAO ^{13}C chemical shift calculation[22] (B3LYP/6-311+G(2d,p)) that is based on the optimized geometry of **2a**–**2d** was performed. The experimental and calculated ^{13}C NMR chemical shifts are listed in Table 1. The calculated values agree with the experimental results. A comparison of the observed ^{13}C chemical shift values of **2a** and **2b** reveals a significant difference at C2′ (**2a**: 126.8 ppm, **2b**: 118.3 ppm) and C6′ (**2a**: 29.3 ppm, **2b**: 34.7 ppm). This result is

Table 1
Experimental[a] ^{13}C shifts (ppm) for **2a**,**b** and calculated[b] ^{13}C shifts (ppm) for **2a**–**2d**



Entry	2a		2b		2c	2d
	Expt.	Calcd	Expt.	Calcd	Calcd	Calcd
C1	122.5	132.2	121.4	133.1	137.8	139.1
C2	105.5	113.1	105.6	112.1	113.2	119.3
C1′	170.5	173.8	170.1	170.9	169.7	168.5
C2′	126.8	135.2	118.3	124.3	136.2	122.2
C3′	156.3	165.5	159.5	168.3	161.3	168.3
C4′	30.4	34.1	31.4	35.4	33.7	35.4
C5′	22.2	27.1	22.4	27.4	26.7	27.5
C6′	29.3	33.1	34.7	40.1	30.7	39.7
Me	24.6	26.5	25.0	26.9	26.3	26.4
CN	114.1	119.8	114.1	120.2	122.0	120.2
CN	115.2	120.8	115.4	121.2	119.3	122.2

[a] Spectra were taken in $CDCl_3$.
[b] Chemical shift values were obtained relative to isotropic shielding of TMS as calculated at the same level.



Scheme 3. A plausible mechanism for the formation of **2a** and **2b**.

reproduced by the calculations. The results suggest that the reaction of DAMN with **1** produced **2a** and **2b**.

A plausible mechanism for the reaction of DAMN with **1** is shown in Scheme 3. The amino group of DAMN reacts with the carbonyl group of **1** to yield the monoimine intermediate **3a**, followed by tautomerization to yield the enamine intermediates **3b** and **3c**. The internal cyclization of **3b** produces **2a** and **2b**. However, the internal cyclization of **3c** that leads to the formation of the unstable four-membered ring product **4** was not observed.

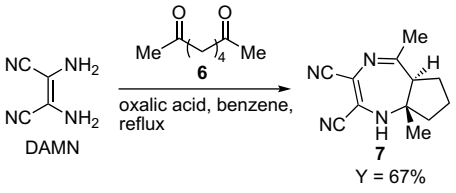
When a benzene solution of a product consisting of a mixture of **2a** and **2b** in the ratio of 2.5:1 was refluxed for 3 days, the ratio remained constant. This indicates that the mixture had already attained equilibrium. A plausible mechanism for the observed tautomerization between **2a** and **2b** in solution is shown in Scheme 3.

2.2. Reaction of DAMN with 2,7-octanedione (6)

DAMN was allowed to react with **6**[17] in the presence of oxalic acid to produce **7** in a 67% yield (Scheme 4). The structure of **7** was determined by X-ray crystallography. An ORTEP drawing of **7** is shown in Figure 3. Four pairs of enantiomers were observed in a unit cell (Fig. S5). Compound **7** yielded satisfactory analytical and spectroscopic data. The complete ^{1}H and ^{13}C NMR spectral assignment was carried out using a combination of DEPT, COSY, HMQC, and HMBC experiments (Fig. S6). Although *trans*-isomer **7** was confirmed by X-ray crystallographic analysis, *cis*-isomer **8** was not observed.

To analyze the diastereoselective formation of **7**, DFT calculations were performed at the B3LYP/6-31G(d,p) level. The calculated results are shown in Figure S7. According to the results, **8** is more stable than **7**, suggesting that the reaction is kinetically controlled.

A plausible mechanism for the formation of **7** is shown in Scheme 5. DAMN reacted with dione **6** to produce an enamine intermediate followed by an intramolecular nucleophilic attack to form a cyclopentyl ring. Then, protonation, dehydration, E1-elimination, and intramolecular ring closure occurred to yield intermediate **9**. When the 1,3-hydrogen shift of **9** occurs on the opposite side of the methyl group at 2-position of **9**, **7** is produced. On the other hand, when the 1,3-hydrogen shift occurs on the same side of the methyl group, **8** is produced. It is considered that owing to a steric repulsion between the adjacent methyl group on the diazepine ring, the 1,3-hydrogen shift of **9** occurred on the opposite side of the methyl group to produce only **7**. The optimized structure of **9**, calculated at the B3LYP/6-31G(d,p) level, is shown in Figure S8. In order to investigate the isomerization of **7** to a thermodynamically stable product **8**, refluxing a benzene solution of **7** was examined. However, **7** was decomposed on heating.



Scheme 4. Reaction of DAMN with 2,7-octanedione (**6**).

2.3. Reaction of DAMN with 2,8-nonanedione (10)

The benzene solution of DAMN and **10** was heated in the presence of oxalic acid at 80 °C for 2 days to yield a mixture of **11** and **12** in a ratio of 1:2 (Scheme 6, Fig. S9). The ratio between **11** to **12** was determined from the ^{1}H NMR spectra of the crude products by the integration of well-separated signals. The separation of diastereomers by column chromatography was unsuccessful. The ratio was maintained after purification by column chromatography. However, on heating a benzene solution of the diastereomeric

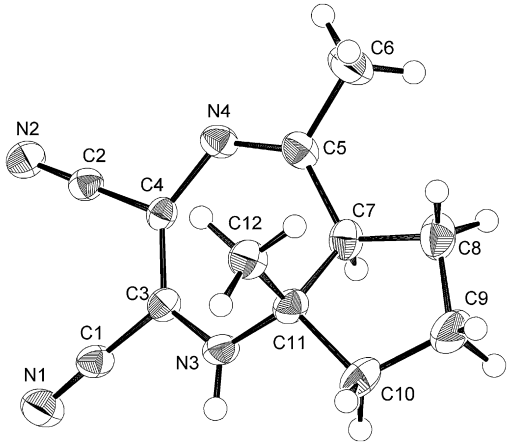
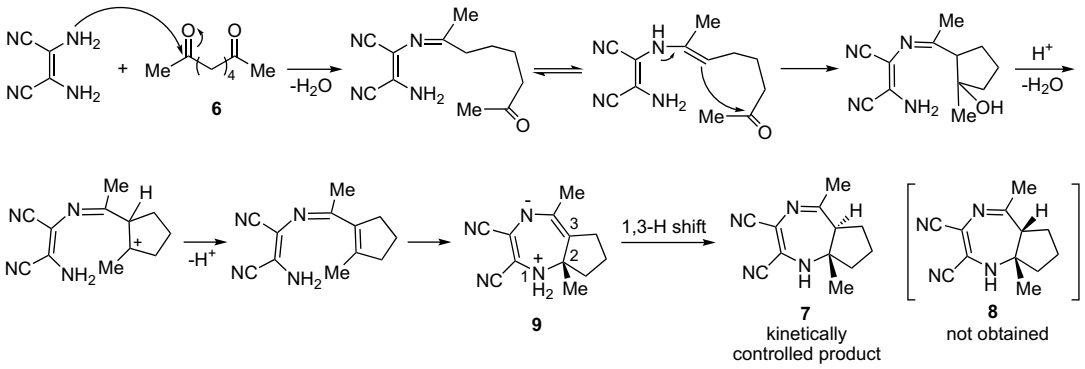
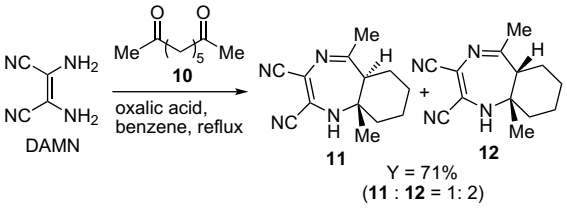


Figure 3. ORTEP drawing of **7**.



Scheme 5. A plausible mechanism for the formation of **7**.

mixtures at 80 °C for 5 days, only **12** was obtained. This indicates that **11** was isomerized to a thermodynamically stable **12**. This is supported by DFT calculation performed at the B3LYP/6-31G(d,p) level (Fig. S10). The diastereoselective formation of **12** was also confirmed by increasing the reaction time.



Scheme 6. Reaction of DAMN with 2,8-nonanedione (**10**).

The structure of **12** was confirmed by NMR, IR, MS, and X-ray crystallography. The ORTEP drawing and packing motif of **12** are shown in Figure 4 and Figure S11, respectively. Two pairs of enantiomers were observed in a unit cell (Fig. S11). The complete assignment of ^{1}H and ^{13}C NMR spectra of **12** is shown in Figure S12.

A reaction, similar to Scheme 5 occurs, thereby producing intermediate **13** (Scheme 7). The 1,3-hydrogen shift of **13** to yield **12** does not occur readily due to the steric repulsion between the adjacent methyl group on the diazepine ring (Fig. S13). Therefore, it is considered that **11** is a kinetically controlled product. On the other hand, **12** can be assumed to be a product that is thermodynamically stable. Therefore, the heating of **11** causes the imine–enamine tautomerization, which yields the thermodynamically stable **12**.

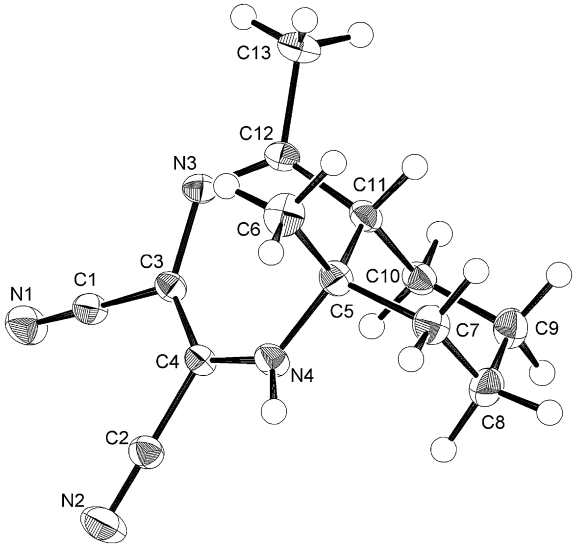


Figure 4. ORTEP drawing of **12**.

3. Conclusions

The reaction of DAMN with **1** yielded **2a** and **2b**. NMR spectroscopy revealed imine–enamine tautomerization between **2a** and **2b** in solution. The reaction between DAMN and **6** resulted in the diastereoselective formation of **7**. On the other hand, DAMN reacted with **10** to afford **11** and **12**. The diastereoselective formation of **12** was achieved by increasing the reaction time, suggesting that heating **11** results in an imine–enamine tautomerization, which yields thermodynamically stable **12**.

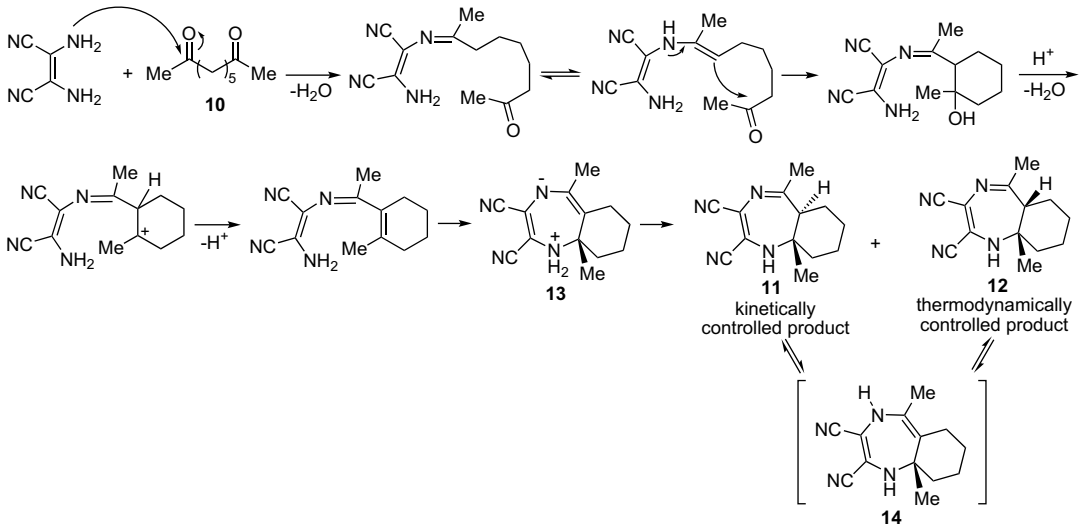
4. Experimental

4.1. Instrument

NMR spectra were recorded on ECX400P or ECA-600 spectrometer. Chemical shifts are referred to the internal standard tetramethylsilane, TMS. Infrared (IR) spectra were determined on a Perkin–Elmer 2000 FT-IR spectrometer. Mass spectra were recorded on a JEOL JMS-700 spectrometer. High Resolution Mass Spectra (HRMS) were obtained from the above instruments. Elemental analyses were performed on a Yanaco MT-6 CHN corder. Melting points were measured on a Yanagimoto MP-S2 micro-melting-point apparatus. Analytical thin-layer chromatography (TLC) was performed on pre-coated plates (Merck, silica gel 60 F_{254}). Silica gel (Wakogel C-200) was used for column chromatography. X-ray data were taken on a Rigaku AFC7R Mercury CCD. The structures were solved by direct methods, SIR97.[23] Geometry optimizations and energy evaluations were carried out with Gaussian 03, revision B.03 package.[18]

4.2. Materials

2,3-Diaminomaleonitrile (DAMN) was purchased from Sigma–Aldrich and used after recrystallization from ethyl acetate. Oxalic acid and benzene were purchased from Wako Pure Chemical Industries and used without further purification. 2,6-heptanedione (**1**), 2,7-octanedione (**6**), and 2,8-nonanedione (**10**) were prepared according to the previously reported procedure.[17]



Scheme 7. A plausible mechanism for the reaction of DAMN with **10**.

4.3. Reaction of DAMN with diketones

*4.3.1. Reaction of DAMN with 2,6-heptanedione (**1**)*

In a round-bottomed flask were placed 2,6-heptanedione (**1**) (323 mg, 2.52 mmol) and benzene (13 mL). 2,3-Diaminomaleonitrile (DAMN) (270 mg, 2.50 mmol) and oxalic acid (70 mg, 0.77 mmol) were added to the solution and the mixture was refluxed for 24 h. After cooling, the solvent was evaporated off. Chromatographic treatment of the residue on silica gel (ethyl acetate/dichloromethane=1:10) yielded a mixture of (2*Z*)-2-amino-3-[(1*E*)-3-methylcyclohex-2-enylideneamino]but-2-enedinitrile (**2a**) and (2*Z*)-2-amino-3-[(1*Z*)-3-methylcyclohex-2-enylideneamino]-but-2-enedinitrile (**2b**) in the ratio of 2.5:1 (216 mg, *Y*=43%).

*4.3.1.1. (2Z)-2-Amino-3-[(1E)-3-methylcyclohex-2-enylideneamino]-but-2-enedinitrile (**2a**).* ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.88 (tt, *J*=6.4, 6.4 Hz, 2H), 1.95 (s, 3H), 2.23 (t, *J*=6.4 Hz, 2H), 2.67 (t, *J*=6.4 Hz, 2H), 4.70 (br s, 2H), 6.04 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 22.2 (CH_2), 24.6 (CH_3), 29.3 (CH_2), 30.4 (CH_2), 105.5 (C), 114.1 (C), 115.2 (C), 122.5 (C), 126.8 (CH), 156.3 (C), 170.5 (C).

*4.3.1.2. (2Z)-2-Amino-3-[(1Z)-3-methylcyclohex-2-enylideneamino]-but-2-enedinitrile (**2b**).* ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.94 (tt, *J*=6.4, 6.4 Hz, 2H), 1.99 (s, 3H), 2.28 (t, *J*=6.4 Hz, 2H), 2.48 (t, *J*=6.4 Hz, 2H), 4.54 (br s, 2H), 6.47 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 22.4 (CH_2), 25.0 (CH_3), 31.4 (CH_2), 34.7 (CH_2), 105.6 (C), 114.1 (C), 115.4 (C), 118.3 (CH), 121.4 (C), 159.5 (C), 170.1 (C).

*4.3.1.3. Mixtures of **2a** and **2b** in the ratio of 2.5:1.* Mp 114–116 °C; IR (KBr) 3407 (NH), 3289 (NH), 3180 (NH), 3148 (NH), 2235 (C≡N), 2201 (C≡N) cm^{-1}; MS (EI, 70 eV) *m*/*z* (rel intensity) 200 (41, M^+), 172 (100, $[M-CH_2N]^+$). Found: C, 65.82; H, 6.03; N, 27.84%. Calculated for $C_{11}H_{12}N_4$: C, 65.98; H, 6.04; N, 27.98%.

*4.3.2. Reaction of DAMN with 2,7-octanedione (**6**)*

To a solution of 2,7-octanedione (**6**) (850 mg, 5.98 mmol) in benzene (20 mL) were added DAMN (667 mg, 6.17 mmol) and oxalic acid (70 mg, 0.77 mmol), and the reaction mixture was held at reflux overnight. The solvent was removed under vacuum pressure and the residue was purified by column chromatography (ethyl acetate/dichloromethane=1:2) to give *trans*-5,8a-dimethyl-1,5a,6,7,8,8a-hexahydrocyclopenta[*e*]-1,4-diazepine-2,3-dicarbonitrile (**7**) (849 mg, *Y*=67%).

*4.3.2.1. trans-5,8a-Dimethyl-1,5a,6,7,8,8a-hexahydrocyclopenta[e]-1,4-diazepine-2,3-dicarbonitrile (**7**).* Mp 153–155 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.03 (s, 3H), 1.77–1.89 (m, 3H), 1.97–2.04 (m, 1H), 2.11 (ddd, *J*=11.7, 7.6, 5.3 Hz, 1H), 2.17–2.21 (m, 1H), 2.20 (s, 3H), 2.51 (dd, *J*=11.7, 7.6 Hz, 1H), 5.17 (br s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 22.1 (CH_2), 26.0 (CH_3), 26.9 (CH_3), 28.1 (CH_2), 42.5 (CH_2), 59.4 (CH), 67.1 (C), 105.3 (C), 114.8 (C), 118.7 (C), 118.8 (C), 172.6 (C); IR (KBr) 3253 (NH), 3053 (NH), 2213 (C≡N) cm^{-1}; HRMS (EI, 70 eV) *m*/*z* calculated for $C_{12}H_{14}N_4$ $[M]^+$ 214.1219, found 214.1203.

*4.3.3. Reaction of DAMN with 2,8-nonanedione (**10**)*

DAMN (366 mg, 3.39 mmol) and oxalic acid (70 mg, 0.77 mmol) were added to a solution of 2,8-nonanedione (**10**) (445 mg, 2.85 mmol) in benzene (20 mL). The solution was refluxed for 2 days. After removal of the solvent in vacuo, the residue was chromatographed on silica with EtOAc/CH_2Cl_2 1:2, giving a mixture of *trans*-5,9a-dimethyl-5a,6,7,8,9,9a-hexahydro-1*H*-benzo[*e*]-1,4-diazepine-2,3-dicarbonitrile (**11**) and *cis*-5,9a-dimethyl-5a,6,7,8,9,9a-hexahydro-1*H*-benzo[*e*]-1,4-diazepine-2,3-dicarbonitrile (**12**) in a ratio of 1:2 (468 mg, *Y*=71%). The reaction mixture could not be separated by column chromatography. Heating the benzene solution of the mixture at 80 °C for 5 days produced only **12** (468 mg, *Y*=71%).

*4.3.3.1. trans-5,9a-Dimethyl-5a,6,7,8,9,9a-hexahydro-1H-benzo[e]-1,4-diazepine-2,3-dicarbonitrile (**11**).* ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.25–1.28 (m, 1H), 1.31 (s, 3H), 1.33–1.37 (m, 1H), 1.62–1.72 (m, 3H), 1.78–1.82 (m, 1H), 1.83–1.88 (m, 1H), 1.94–1.99 (m, 1H), 2.19 (s, 3H), 2.50 (dd, *J*=13.1, 4.1 Hz, 1H), 4.25 (br s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 22.3 (CH_2), 24.6 (CH_2), 25.0 (CH_2), 26.3 (CH_3), 26.5 (CH_3), 43.8 (CH_2), 51.0 (CH), 70.5 (C), 105.6 (C), 114.8 (C), 117.8 (C), 118.5 (C), 179.0 (C).

*4.3.3.2. cis-5,9a-Dimethyl-5a,6,7,8,9,9a-hexahydro-1H-benzo[e]-1,4-diazepine-2,3-dicarbonitrile (**12**).* ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.17 (s, 3H), 1.25–1.34 (m, 2H), 1.39 (ddd, *J*=14.1, 14.1, 4.6 Hz, 1H), 1.47–1.55 (m, 1H), 1.57–1.65 (m, 2H), 1.83 (d, *J*=14.1 Hz, 1H), 1.86–1.91 (m, 1H), 2.23 (s, 3H), 2.63 (d, *J*=10.8 Hz, 1H), 5.29 (br s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 21.2 (CH_2), 24.8 (CH_2), 26.1 (CH_2), 30.1 (CH_3), 30.9 (CH_3), 39.7 (CH_2), 57.0 (C), 59.3 (CH), 103.8 (C), 114.5 (C), 119.2 (C), 119.4 (C), 174.9 (C).

*4.3.3.3. Mixtures of **11** and **12** in the ratio of 1:2.* Mp 208–209 °C; IR (KBr) 3245 (NH), 3069 (NH), 2216 (C≡N) cm^{-1}; MS (EI, 70 eV) *m*/*z* (rel intensity) 228 (56, M^+), 81 (100, $[M-C_7H_7N_4]^+$). Found: C,

68.08; H, 6.99; N, 24.53%. Calculated for $C_{12}H_{14}N_4$: C, 68.39; H, 7.06; N, 24.54%.

5. X-ray crystallography

The single crystals of **2a**, **7**, and **12** were given by the slow diffusion of hexane to CH_2Cl_2 solution at room temperature. Crystal data for **2a**: $C_{11}H_{12}N_4$, M_w=200.25, monoclinic, $P2_1/n$, Z=4, a=12.142(6), b=7.083(3), c=13.245(7) Å, β=104.859(6)°, D_{calcd}=1.208 g/cm^3, 8703 reflections were collected, 2505 unique (R_{int}=0.0331), 2304 observed ($I>2\sigma(I)$), 145 parameters, R_1=0.0589, wR_2=0.118, GOF=1.177, refinement on F^2. Crystal data for **7**: $C_{12}H_{14}N_4$, M_w=214.27, orthorhombic, $Pbca$, Z=8, a=6.714(5), b=25.030(18), c=13.314(10) Å, D_{calcd}=1.272 g/cm^3, 16,610 reflections were collected, 2556 unique (R_{int}=0.0742), 2318 observed ($I>2\sigma(I)$), 147 parameters, R_1=0.1225, wR_2=0.221, GOF=1.365, refinement on F^2. Crystal data for **12**: $C_{13}H_{16}N_4$, M_w=228.3, monoclinic, $P2_1/n$, Z=4, a=6.903(4), b=13.005(7), c=14.325(8) Å, β=103.977(7)°, D_{calcd}=1.215 g/cm^3, 9744 reflections were collected, 2836 unique (R_{int}=0.0322), 2640 observed ($I>2\sigma(I)$), 202 parameters, R_1=0.0662, wR_2=0.131, GOF=1.203, refinement on F^2. Crystallographic data have been deposited at the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK and copies can be obtained on request, free of charge, by quoting the publication citation and the deposition numbers for **2a** (CCDC 686760), **7** (CCDC 686789), and **12** (CCDC 686862), respectively.

Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2009.01.053.

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