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Synthesis and transformations of tetrazolylacroleins

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Abstract—1-Methoxy-4-aryltetrazolyldienes have been subjected to oxidative degradation to yield tetrazolyl acroleins. These compounds when reacted with 1,1-dimethylhydrazine gave 1-dimethylamino-4-aryltetrazolyl-1-azadienes. Both the acroleins and the new 1-azadienes underwent ring transformation in reaction with fumaronitrile to afford pyrazolyl derivatives.

1. Introduction

In the course of our extensive research[1–4] on ring opening of azolopyridinium salts (**1**) we found that reaction of these compounds with nucleophiles can result in ring opening of the pyridine moiety to afford azolyldienes (**2**) (Scheme 1).

We have also reported that related heteroaromatic triazolium salts containing a diazine ring instead of the pyridine moiety can also be transformed to the corresponding azadienes. Thus, [1,2,3]triazolopyrimidinium salts (**3** and **7**) gave the 1- and 2-azadienes **4** and **8**, respectively,[5] whereas the pyrazine-fused azolium salt **5** afforded the 2-azadiene **6** (Scheme 2).[2]

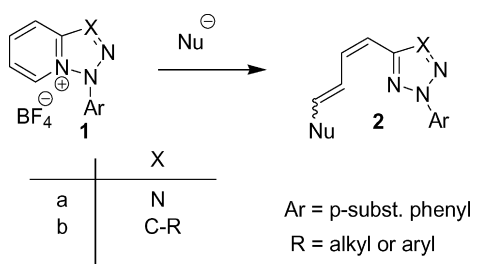
Realization of a fourth variation of the position of the nitrogen atom in the diene chain (i.e. the synthesis of **10**) seemed of further interest, but our synthetic strategy (i.e. the nucleophilic attack on the azine ring) was obviously not applicable for this desired synthesis as the appropriate pyridazine-fused salt (**9**) contains a nitrogen atom at the particular position.[6]

2. Discussion

Recently we have found that a different pathway seems fairly straightforward in order to prepare the missing 1-azadiene of type **10** in the area of tetrazolylazadienes. The key to this new strategy was the observation that 1-methoxy-4-(2-aryltetrazolyl-5)butadienes (**11**) readily obtainable by the reaction of 3-aryltetrazolopyridinium salt (**1a**) with sodium methoxide[7] (isolable as a mixture of 1-*cis*–3-*trans* and 1,3-*cis*–*cis* isomers) proved to be unstable in crystalline state upon storage on air and, in several days, underwent a spontaneous decomposition to yield aryltetrazolyl-acroleins (**12**) (Scheme 3).

Photodegradations analogous to this unexpected transformation can be found in the literature and are mainly interpreted by action of singlet oxygen to yield a dioxethane intermediate and a subsequent decomposition. Thus, transformation of olefins to two different oxo compounds can be carried out[8] and similar reaction of 1,4-bis-alkoxydiene has also been reported[9] to yield methyl formate and 3-methoxypropenal.

Because of the preparative importance of this finding a well executable procedure convenient also for multigram scale transformations seemed to be necessary. Furthermore, based on the above mechanistic considerations (i.e. the supposition that singlet oxygen is the effective reagent) use of a



Scheme 1.

Keywords: ring transformation; 1-azadiene; photooxidation; 1,3-dipolar cycloaddition.

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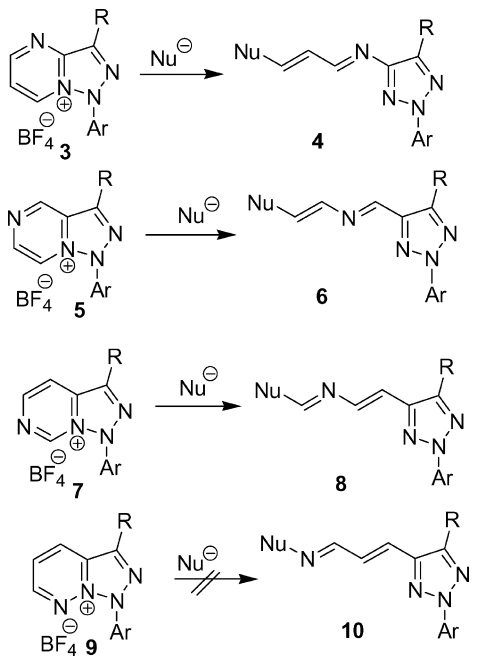


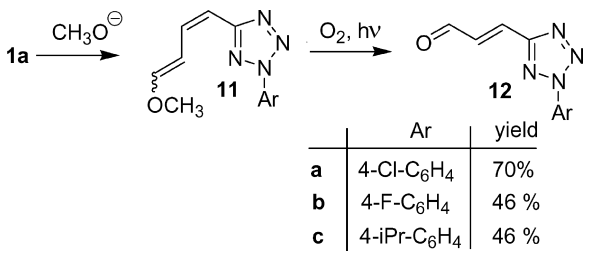
Scheme 2.

photosensitiser was studied. For this purpose, a solution of the starting methoxydiene (**11**) in dichloromethane was irradiated by a common lamp in the presence of tetraphenylporphyrin and a continuous introduction of air at room temperature for a prolonged period. As expected, the acrolein product **12** was obtained in medium to good yield. Structure elucidation revealed that the crude product was still a mixture of *cis* and *trans* isomers, but after recrystallization from isopropanol the isomerization to the *trans* product (**12**) seemed to be complete (Scheme 4).

We have found that the new acrolein derivatives (**12**) readily participated in a condensation reaction with 1,1-disubstituted hydrazines to give hydrazones. Thus, a smooth reaction of **12** with 1,1-dimethylhydrazine gave the desired 1-dimethylamino-1-azadiene (**13**) in good yield.

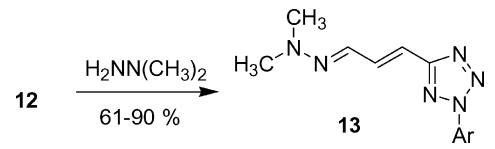
Although some of the earlier synthesized tetrazolyldieneamines as well as some azadieneamines proved to be reactive towards dienophiles in Diels–Alder type transformations, our efforts to observe such a reactivity of **13** failed in the most cases (e.g. no reaction could be detected with *N*-phenylmaleinimide, dimethyl acetylene dicarboxylate, etc.).

Fumaronitrile, interestingly however, proved to be one of



	Ar	yield
a	4-Cl-C_6H_4	70%
b	4-F-C_6H_4	46 %
c	4-iPr-C_6H_4	46 %

Scheme 3.



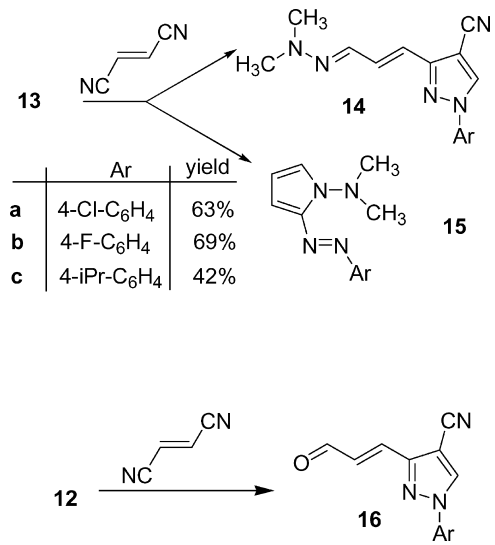
Scheme 4.

the exceptions in this respect, and simultaneous formation of two compounds (**14** and **15** in a ratio of 4:1, respectively) was experienced under fairly forced conditions (Scheme 5).

Although this finding provided a synthetically valuable approach to a new type of (i.e. to pyrazole-substituted) dieneamines (**14**), it has also shown that the new 1-azadienes (**13**) do not participate in a common Diels–Alder reaction as expected. Instead, the tetrazole ring undergoes nitrogen elimination under the forced conditions applied to yield a nitrilimine (a reactive 1,3-dipole), and this reactive intermediate can undergo further transformations as well documented in the literature.[10–12] Either this intermediate reacts with the dipolarophile via the well known [1,3] dipolar cyclization route (i.e. to give a dihydropyrazole intermediate followed by hydrogen cyanide elimination) to the pyrazole **14** or, more interestingly, an intramolecular ring closure involving the azadiene chain takes place and a [1,5] dipolar cyclization yields **15**.

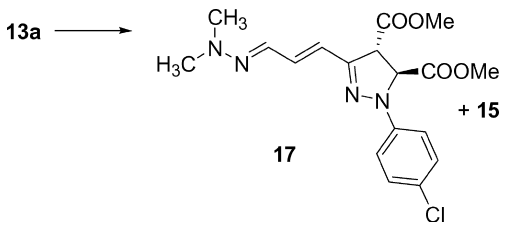
Similar to the reactivity of **13**, the acrolein compound **12** also underwent ring transformation in the presence of fumaronitrile to yield pyrazolyl-acroleins (**16**). It is interesting to note that in both cases (i.e. with formation of both **14** and **16**) the elimination was totally selective as supported by the ^{1}H NMR (HMBC and HetCor) experiments of these products.

Besides fumaronitrile, fumaric ester was also successfully applied in 1,3-dipolar cycloaddition reaction with **13**. In this case, the starting compound **13a** afforded a dihydropyrazole product **17** which, unlike the previous case, could be isolated in this dihydro form and no spontaneous aromatization took place. Work up of the reaction mixture revealed



	Ar	yield
a	4-Cl-C_6H_4	63%
b	4-F-C_6H_4	69%
c	4-iPr-C_6H_4	42%

Scheme 5.



Scheme 6.

that the intramolecular cyclization also took place to form the same byproduct as above (**15**) in traces (Scheme 6).

3. Conclusion

These findings reveal that our new approach provides a relatively facile access to new hetarylazadienes and hetarylacroleines. Elaboration of further synthetic tools exploiting the reactivity of the aldehyde function of tetrazolylacroleines is in progress and will be published elsewhere.

4. Experimental

Melting points were determined by a Büchi apparatus and are uncorrected. The IR spectra were recorded with a Nicolet Magna 750 FT-IR, spectrophotometer; the NMR spectra were recorded with Varian UNITY INOVA spectrometer (200 and 400 MHz for ^{1}H and 100 MHz for ^{13}C).

4.1. Synthesis of 1-tetrazolyl-4-methoxybutadienes (11)

The synthetic procedure for 2-(4-chlorophenyl)-5-(4-methoxy-buta-1,3-dienyl)-2*H*-tetrazole (**11a**) was reported earlier.[7] The *p*-fluoro and *p*-isopropyl substituted derivatives (**11b** and **11c**, respectively) were also prepared according to this literature procedure.

4.1.1. 2-(4-Fluorophenyl)-5-(4-methoxybuta-1,3-dienyl)-2*H*-tetrazole (a mixture of 1*Z*,3*E* and 1*Z*,3*Z* isomers, 11b). Starting from 3-(4-fluorophenyl)tetrazolo[1,5-*a*]pyridinium fluoroborate (**1**, Ar=4-fluorophenyl, 0.95 g, 3 mmol) colorless crystals were obtained: 0.34 g, 46%; mp 60–68°C (*i*PrOH). Anal. calcd for $C_{12}H_{11}FN_4O$ (246.24), C: 58.53, H: 4.50, N: 22.75; found C: 58.44, H: 4.67, N: 22.53.

4.1.2. 2-(4-Isopropylphenyl)-5-(4-methoxybuta-1,3-dienyl)-2*H*-tetrazole (a mixture of 1*Z*,3*E* and 1*Z*,3*Z* isomers, 11c). This compound was obtained from 3-(4-isopropylphenyl)tetrazolo[1,5-*a*]pyridinium fluoroborate (**1**, Ar=4-isopropylphenyl, 0.98 g, 3 mmol). Yellow oil, 0.48 g, 59%; HRMS (EI): M^+, found 269.1456. $C_{15}H_{17}N_4O$ requires 269.1402.

4.2. Synthesis of tetrazolylacroleins (12)

The appropriate 2-aryl-5-(4-methoxy-buta-1,3-dienyl)-2*H*-tetrazole (**11**, 10 mmol) was dissolved in dichloromethane (150 mL), catalytic amount of tetraphenylporphyrin (30 mg, approximately) was added, the reaction mixture was illuminated by a 60 W electric bulb, and air was bubbled through the reaction mixture at room temperature. The progress of the reaction was monitored by TLC. After completion of the reaction (4–7 days) the solvent was removed in vacuo, the residue was purified by column chromatography (Kieselgel 60H, dichloromethane/hexane (1:1) as an eluent), and the main fraction was recrystallized from isopropanol.

4.2.1. 2-(4-Chlorophenyl)-5-[(1*E*)-3-oxoprop-1-en-1-yl]-2*H*-tetrazole (12a). 1.64 g, 70%. Pale yellow crystals; mp 99°C; ν_{max} (KBr) 1686, 1493, 1418, 1113, 1100, 1003, 987, 833 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.85 (1H, d, J=7.7 Hz, C*H*O), 8.10–8.14 (AA′), 7.48–7.67 (3H, m, BB′, 1′-H), 7.29 (1H, dd, J=7.7, 16.2 Hz, 2′-H); δ_C (100 MHz, $CDCl_3$) 192.7, 162.4, 136.6, 135.7, 135.3, 135.2, 130.4, 121.5. Anal. calcd for $C_{10}H_7ClN_4O$ (234.64), C: 51.19, H: 3.01, N: 23.88; found C: 51.44, H: 2.81, N: 23.73.

4.2.2. 2-(4-Fluorophenyl)-5-[(1*E*)-3-oxoprop-1-en-1-yl]-2*H*-tetrazole (12b). 1.00 g, 46%. Colorless crystals; mp 97–99°C; ν_{max} (KBr) 1687, 1507, 1233, 1113, 1002, 839 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.85 (1H, d, J=7.7 Hz, C*H*O), 8.13–8.20 (AA′), 7.64 (1H, d, J=16.2 Hz, 1′-H), 7.22–7.34 (3H, m, AA′, 2′-H); δ_C (100 MHz, $CDCl_3$) 192.4, 165.8, 161.9, 160.8, 134.8, 121.8 ($J_{C,F}$=8.7 Hz), 117.1, 116.7 ($J_{C,F}$=23.5 Hz). Anal. calcd for $C_{10}H_7FN_4O$ (218.19), C: 55.05, H: 3.23, N: 25.68; found C: 54.82, H: 3.17, N: 25.67.

4.2.3. 2-(4-Isopropyl)-5-[(1*E*)-3-oxoprop-1-en-1-yl]-2*H*-tetrazole (12c). 1.11 g, 46%. Pale yellow crystals; mp 78–80°C (*i*PrOH); ν_{max} (KBr) 2964, 1687, 1515, 1106, 1004, 983, 838 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.85 (1H, d, J=7.7 Hz, C*H*O), 8.03–8.07 (AA′), 7.65 (1H, d, J=16.1 Hz, 1′-H), 7.41–7.45 (BB′), 7.28 (1H, dd, J=16.1, 7.7 Hz, 2′-H), 3.01 (1H, m, C*H*), 1.32 (6H, d, J=6.8 Hz, CH_3); δ_C (100 MHz, $CDCl_3$) 192.8, 162.0, 151.9, 135.7, 134.9, 134.7, 128.1, 120.3, 34.3, 24.1. Anal. calcd for $C_{13}H_{14}N_4O$ (242.28), C: 64.45, H: 5.82, N: 23.13; found C: 64.67, H: 5.71, N: 22.96.

4.3. General procedure for the synthesis of *N*,*N*-dimethyl-hydrazones (13)

A mixture of the appropriate tetrazolylacrolein **12** (1 mmol), sodium sulfate (0.3 g) and 1,1-dimethyl-hydrazine (0.61 g, 1.1 mmol, 0.78 mL) and dichloromethane (5 mL) was allowed to stand at room temperature for 3 h. After completion of the reaction the sodium sulfate was filtered off, washed several times with dichloromethane, and the solvent was removed in vacuo. The residue was purified by recrystallisation from acetonitrile.

4.3.1. 2-(4-Chlorophenyl)-5[(1*E*,3*E*)-5-(dimethylhydrazono)-prop-1-en-1-yl]-2*H*-tetrazole (13a). 0.25 g, 90%. Yellow crystals; mp 161–163°C (CH_3CN); ν_{max} (KBr) 1630, 1549, 1492, 1417, 1350, 1203, 1092, 1059, 995, 830 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 8.03–8.09 (AA′), 7.49–7.64 (3H, m, BB′, 2′-H), 7.06 (1H, d, J=9.2 Hz, 3′-H), 6.63 (1H, d, J=16.1 Hz, 1′-H), 3.03 (6H, s, N–C*H*$_3$); δ_C

(100 MHz, $CDCl_3$) 164.8, 136.2, 135.3, 135.1, 130.9, 129.8, 120.8, 113.4, 42.4 (N–*C*H_3). Anal. calcd for $C_{12}H_{13}ClN_6$ (276.72), C: 52.08, H: 4.74, N: 30.37; found C: 52.11, H: 4.67, N: 30.33.

4.3.2. 2-(4-Fluorophenyl)-5[(1*E*,3*E*)-5-(dimethylhydrazono)-prop-1-en-1-yl]-2*H*-tetrazole (13b). 0.19 g, 76%. Pale yellow crystals; mp 127–128°C (CH_3CN); 1627, 1552, 1510, 1050, 998, 836 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 8.08–8.15 (AA′), 7.56 (1H, dd, *J*=15.9, 9.1 Hz, 2′-H), 7.20–7.30 (3H, m, BB′, 3′-H), 6.70 (1H, d, *J*=15.9 Hz, 1′-H), 3.04 (6H, s, N–C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 165.3, 160.3, 135.5, 121.6, 121.5 ($J_{C,F}$=8.6 Hz), 116.8, 116.4 ($J_{C,F}$=23.1 Hz), 114.7, 42.7 (N–*C*H_3). Anal. calcd for $C_{12}H_{13}FN_6$ (260.27), C: 55.38, H: 5.03, N: 32.29; found C: 55.38, H: 4.95, N: 32.11.

4.3.3. 2-(4-Isopropylphenyl)-5[(1*E*,3*E*)-5-(dimethylhydrazono)-prop-1-en-1-yl]-2*H*-tetrazole (13c). 0.17 g, 61%. Beige crystals; mp 105–106°C (CH_3CN); ν_{max} (KBr) 2967, 1630, 1552, 1513, 1471, 1420, 1350, 1197, 1056, 998, 974, 833 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 7.99–8.04 (AA′), 7.59 (1H, dd, *J*=9.2, 16.1 Hz, 2′-H), 7.36–7.40 (BB′), 7.09 (1H, d, *J*=9.2 Hz, 3′-H), 6.68 (1H, d, *J*=16.1 Hz, 1′H), 3.02 (7H, m, N–C*H*$_3$, C*H*), 1.30 (6H, d, *J*=7.0 Hz, C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 164.5, 150.5, 135.6, 134.8, 131.3, 127.5, 119.6, 119.0, 42.4 (N–*C*H_3), 33.8 (*C*H), 23.8 (*C*H_3). Anal. calcd for $C_{15}H_{20}N_6$ (284.36), C: 63.36, H: 7.09, N: 29.55; found C: 63.45, H: 7.18, N: 29.49.

4.4. General procedure for the ring transformation of the 4-tetrazolyl-1-dimethylamino-1-azadienes to pyrazolyl derivatives 14 and 16

A mixture of the appropriate tetrazolylazadiene or tetrazolylacrolein (**13** or **12**, respectively, 0.5 mmol), fumaronitrile (0.23 g, 2.93 mmol) in xylene (10 mL) was stirred under an argon atmosphere at 140 or 130°C, and the reaction was monitored by TLC. After completion of the reaction, the solvent was removed in vacuo, and the residue was purified by preparative layer chromatography, (hexane/ethyl acetate (2:1) as an eluent). The separation allowed also the detection of the pyrrol derivative **15** in traces (higher R_f value), and in case of transformation of **13c**, [2-(4-isopropyl-phenylazo)-pyrrol-1-yl]-dimethyl-amine (**15c**) was also isolated by chromatography, and identified by ^1H- and ^{13}C NMR spectroscopy.

4.4.1. 1-(4-Chlorophenyl)-3-[(1*E*,3*E*)-3-(dimethyl-hydrazono)prop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (14a). 94.4 mg, 63%. Pale yellow crystals (130°C, 72 h); mp 162–163°C (iPrOH); ν_{max} (KBr) 3129, 2225, 1626, 1533, 1499, 1421, 1352, 1288, 1221, 1054, 955, 822 cm^{-1}; δ_H (400 MHz, $CDCl_3$) 8.22 (1H, s, 3-H), 7.64 (AA′), 7.46 (BB′), 7.44 (1H, dd, *J*=16.0, 9.0 Hz, 2′-H), 7.05 (1H, d, *J*=9.0 Hz, 3′-H), 6.58 (1H, d, *J*=16.0 Hz, 1′-H), 3.00 (6H, s, N–C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 153.2 (5-C), 137.3 (1′-C), 133.6 (4′-C), 133.7 (2′-C), 132.3 (3-C), 131.7 (3′-C), 129.8 (3′, 5′-C), 120.6 (2′, 6′-C), 117.2 (1′-C), 113.3 (*C*≡N), 92.4 (4-C), 42.4 (N–*C*H_3). Anal. calcd for $C_{15}H_{14}ClN_5$ (299.76), C: 60.10, H: 4.71, N: 23.36; found C: 60.12, H: 4.64, N: 23.36.

4.4.2. 1-(4-Fluorophenyl)-3-[(1*E*,3*E*)-3-(dimethyl-hydrazono)prop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (14b). 98 mg, 69%. Yellow crystals (130°C, 30 h); mp 150–153°C (CH_3CN); ν_{max} (KBr) 2222, 1624, 1537, 1516, 1420, 1347, 1218, 1062, 965. 836 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 8.17 (1H, s, 5-H), 7.62–7.68 (AA′), 7.43 (1H, dd, *J*=16.1, 9.2 Hz, 2′-H), 7.02–7.22 (3H, m, BB′, 3′-H), 6.58 (1H, d, *J*=16.1 Hz, 1′-H), 3.00 (6H, s, N–C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 164.3, 153.1, 135.0, 133.4, 132.5, 131.9, 121.3 ($J_{C,F}$=8.3 Hz), 117.4, 116.4 ($J_{C,F}$=23.2 Hz), 113.5 (*C*≡N), 92.1, 42.5 (N–*C*H_3). Anal. calcd for $C_{15}H_{14}FN_5$ (283.30), C: 63.59, H: 4.98, N: 24.72; found C: 63.29, H: 4.78, N: 24.90.

4.4.3. 1-(4-Isopropylphenyl)-3-[(1*E*,3*E*)-3-(dimethyl-hydrazono)prop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (14c). 65 mg, 42%. Yellow crystals (140°C, 40 h); mp 101–102°C (diisopropylether); ν_{max} (KBr) 3137, 2959, 2228, 1626, 1533, 1517, 1422, 1346, 1046, 970, 957, 839 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 8.18 (1H, s), 7.55–7.59 (AA′), 7.44 (1H, dd, *J*=16.1, 9.0 Hz), 7.30–7.37 (BB′), 7.06 (1H, d, *J*=9.0 Hz), 6.61 (1H, d, *J*=16.1 Hz), 2.99 (6H, s, N–C*H*$_3$), 2.93 (1H, m, C*H*), 1.27 (6H, d, *J*=6.5 Hz, C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 152.8, 149.0, 133.0, 132.3, 132.2, 127.6, 119.6, 117.8, 91.7, 42.4, 33.7, 23.8. Anal. calcd for $C_{18}H_{21}N_5$ (307.39), C: 70.33, H: 6.89, N: 22.78; found C: 70.29, H: 6.91, N: 22.89.

4.4.4. [2-(4-Isopropylphenylazo)-pyrrol-1-yl]-dimethyl-amine (15c). Yellow oil, yield: 10% (140°C, 40 h); δ_H (200 MHz, $CDCl_3$) 7.72–7.77 (AA′), 7.30–7.34 (BB′), 7.05 (1H, dd, *J*=3.1, 2.5 Hz, pyrrol β-*H*), 6.58 (1H, dd, *J*=4.0, 2.5 Hz, pyrrol δ-*H*), 6.12 (1H, dd, *J*=4.0, 3.1 Hz, pyrrol γ-*H*), 3.15 (6H, s, N–C*H*$_3$), 2.97 (1H, m, C*H*), 1.28 (6H, d, *J*=7.0 Hz, C*H*$_3$); δ_C (100 MHz, $CDCl_3$) 150.2, 146.8, 133.2, 127.0, 124.8, 122.1, 107.1, 97.9, 48.1, 34.0, 23.9; HRMS (EI): M^+, found 256.3466. $C_{15}H_{20}N_4$ requires 256.3461.

4.4.5. 1-(4-Chlorophenyl)-3-[(1*E*)-3-oxoprop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (16a). 69.6 mg, 54%. Beige crystals (140°C, 22 h); mp 146–149°C (CH_3CN); ν_{max} (KBr) 2235, 1691, 1534, 1499, 1215, 1113, 1058, 977, 958, 827 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.78 (1H, d, *J*=7.6 Hz, C*H*O), 8.36 (1H, s, 5-H), 7.65–7.69 (AA′), 7.48–7.56 (3H, m, BB′, 1′-H), 7.16 (1H, dd, *J*=16.3, 7.6 Hz, 2′-H); δ_C (100 MHz, $CDCl_3$) 192.9 (*C*=O), 149.8, 138.6, 136.8, 134.7, 133.4, 132.4, 130.1, 121.0, 112.1 (*C*≡N), 94.6. Anal. calcd for $C_{13}H_8ClN_3O$ (257.68), C: 60.60, H: 3.13, N: 16.31; found C: 60.50, H: 3.19, N: 16.45.

4.4.6. 1-(4-Fluorophenyl)-3-[(1*E*)-3-oxoprop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (16b). 39.8 mg, 33%. Colorless crystals (140°C, 22 h); mp 126–129°C (CH_3CN); ν_{max} (KBr) 3123, 2234, 1678, 1513, 1374, 1248, 1224, 1161, 1128, 1065, 980, 833 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.79 (1H, d, *J*=7.3 Hz, C*H*O), 8.31 (1H, s, 5-H), 7.66–7.73 (AA′), 7.54 (1H, d, *J*=16.5 Hz, 1′-H), 7.10–7.28 (3H, m, BB′, 2′-H); δ_C (100 MHz, $CDCl_3$) 193.2, 150.1, 139.0, 135.0, 133.9, 132.7, 122.2 ($J_{C,F}$=8.3 Hz), 117.1 ($J_{C,F}$=23.5 Hz), 112.5 (*C*≡N), 94.8. Anal. calcd for $C_{13}H_8FN_3O$ (241.22), C: 64.73, H: 3.34, N: 17.42; found C: 64.56, H: 3.23, N: 17.15.

4.4.7. 1-(4-Isopropylphenyl)-3-[(1*E*)-3-oxoprop-1-en-1-yl]-1*H*-pyrazole-4-carbonitrile (16c). 49.1 mg, 37%. Pale yellow crystals (140°C, 25.5 h); mp 125–126°C (CH_3CN); ν_{max} (KBr) 2925, 2240, 1678, 1534, 1507, 1368, 1125, 1050, 980, 836 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 9.77 (1H, d, J=7.7 Hz, C*H*O), 8.33 (1H, s, 5-H), 7.49–7.63 (3H, m, AA′, 1′-H), 7.36–7.40 (BB′), 7.16 (1H, dd, J=7.7, 16.1 Hz, 2′-H), 2.99 (1H, m, C*H*), 1.29 (6H, d, J=7.0 Hz, CH_3); δ_C (100 MHz, $CDCl_3$) 192.9, 150.1, 149.4, 139.0, 136.3, 133.4, 132.1, 127.8, 119.9, 112.4, 94.0, 33.8, 23.8. Anal. calcd for $C_{16}H_{15}N_3O$ (265.31), C: 72.43, H: 5.70, N: 15.84; found C: 72.36, H: 5.71, N: 15.86.

4.4.8. Dimethyl (4*S*,5*R*)-*rel*-1-(4-chlorophenyl)-3[(1*E*,3*E*)-3-dimethylhydrazono)prop-1-en-1-yl]-4,5-dihydro-1*H*-pyrazole 4,5-dicarboxylate (17). A mixture of tetrazolylazadiene **13a** (0.140 g, 0.5 mmol), dimethylfumarate (0.28 g, 2 mmol) and xylene (12 mL) was stirred under an argon atmosphere at 130°C for 46 h. The solvent was removed in vacuo, and the residue was purified by column chromatography (silica, hexane/ethyl acetate (2:1) as an eluent). The product was recrystallized from a mixture of diethyl ether–hexane to give the title compound (0.080 g, 41%); mp 131–132°C; ν_{max} (KBr) 2953, 1741, 1596, 1497, 1396, 1296, 1225 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 7.10–7.30 (AA′), 6.8–7.0 (3H, m, BB′, 1′-H), 6.74 (1H, dd, J=16.0, 8.3 Hz, 2′-H), 6.54 (1H, d, J=16.0 Hz, 3′-H), 4.79 (1H, d, J=4.4 Hz, 5-H), 4.02 (1H, d, J=4.4 Hz, 4-H), 3.49 (6H, s, COOCH_3), 2.69 (6H, s, N–CH_3); δ_C (100 MHz, $CDCl_3$) 169.6, 168.9, 145.5, 141.9, 133.2, 132.6, 129.0, 125.1, 120.8, 114.4, 65.3, 54.7, 53.1, 53.0, 42.5. Anal. calcd for $C_{18}H_{21}ClN_4O_4$ (392.84), C: 55.03, H: 5.39, N: 14.26; found C: 55.10, H: 5.37, N: 14.23.

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