[3+2]-Cycloaddition of α-Diazo carbonyl Compounds with Arenediazonium Salts Catalyzed by Silver Nitrate Delivers 2,5-Disubstituted Tetrazoles

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Abstract [3+2]-Cycloaddition of arenediazonium salts with diazo compounds (earlier exemplified only for trimethylsilyldiazomethane and 2,2,2-trifluorodiazoethane) has been developed to include a wide range of readily available α-diazo carbonyl compounds. The resulting 2-aryl-5-acyl-2H-tetrazoles are of high value in medicinal chemistry.

Key words α-diazo carbonyl compounds, arenediazonium tosylates, tetrazoles, [3+2]-cycloaddition, silver nitrate

Tetrazoles are important representatives of the azole family of heterocycles with much utility in medicinal chemistry. In particular, 5-substituted 1H-tetrazoles are considered classical carboxylic acid isosteres. Disubstituted tetrazoles can be considered suitable amide bond replacements. Moreover, replacement of other five-membered nitrogen heterocyclic cores with tetrazole may significantly alter such molecular characteristics as total polar surface area and hydrophilicity, thus transitioning a compound’s properties (in particular, solubility) into a more favorable range. In order to be able to exercise such scaffold-hopping options with facility, there must be a versatile arsenal of synthetic methods to construct tetrazoles with a broad substituent variation. Methods reported to date include azide–nitrile and azide–isocyanide cycloadditions, dimerization of α-diazo carbonyl compounds, diazotization–cyclization of imidohydrazides or amidines, cyclocondensation of acyl hydrazides with arenediazonium salts, and cyclization of amides or imidoyl compounds with azides. A novel approach to constructing 2-aryltetrazoles was presented in 2015/2016 by Ma and Kamenecka and their coworkers. It involves silver-catalyzed cycloaddition of arenediazonium salts with 2,2,2-trifluorodiazoethane (CF₃CHN₂) and trimethylsilyldiazomethane (Me₃SiCHN₂), respectively (Scheme 1).

While the method displayed a broad scope with respect to the aromatic groups at N₂, the substitution at position 5 attainable by this approach has so far been limited to either a trifluoromethyl group (in compounds 1) or hydrogen (in compounds 2). It is worth noting that while preparation of compounds 1 was achieved with a catalytic amount of the silver salt, more than a stoichiometric amount of the latter was required to prepare compounds 2. We thought it surprising this cycloaddition-based entry into tetrazoles has not been explored further to include other diazo compounds, which would dramatically broaden the range of substituents on the tetrazole carbon atom. Considering, in particular, the diversity of α-diazo ketones available, the resulting 2-aryl-5-acyltetrazoles 3 (EWG = RC(O)) would be a very valuable chemotype to access (Scheme 1). Such cores have been utilized in the design of mGlur5 receptor modulators, fatty acid amide hydrolase inhibitors, antiviral compounds, and compounds endowed with hypoglycemic activity. Thus, we became interested in the opportunity to fill the above-mentioned void in synthetic methodology toward 2,5-disubstituted tetrazoles. Herein, we present the results of our investigation in this regard.

For the initial optimization studies, we selected commercially available benzenediazonium tosylate (4a) and 2-diazo-4'-methylacetophenone (5a). Our preference for the tosylate counterion was motivated by the recently reported convenient preparation and use of arenediazonium tosylates. Not only are they more stable toward chemical decomposition and explosion compared to conventionally used tetrafluoroborates, they are more clearly prepared by diazotization of the respective anilines in the presence of p-toluenesulfonylic acid in a variety of polar organic solvents, and even water. As the silver catalyst, we initially selected the readily available silver nitrate. The initial testing of the
conditions described by Ma and co-workers\(^7\) (employing a twofold excess of the diazo compound relative to the diazonium salt) gave, gratifyingly, a 48% yield of the anticipated product \(3a\) (Table 1, entry 1). The yield of \(3a\) was improved to 66% by altering the reagent ratio and doubling the amount of the catalyst (Table 1, entry 4).

Having identified the optimal reagent and catalyst ratio, we screened for a possible better solvent, base or catalyst (Table 2). The only improvement, however, that we were able to achieve was the replacement of the base with equally workable (yet significantly less expensive and easier to dose) DABCO. THF/DMF mixture and silver nitrate were only confirmed to be the best catalysts for the transformation.

With the optimized reaction conditions at hand, we proceeded to investigate the scope of the tetrazole synthesis for a range of substituted arenediazonium tosylates (\(4a–k\), prepared by diazotization of the respective anilines) and (hetero)aromatic (\(5a–g, Si–k, 5n–q\)) and aliphatic (\(5h\)) diazo ketones, as well as \(\alpha\)-diazo acetamides (\(5l, 5m\)), all of which are commercially available and can be conveniently prepared by the literature protocols (Figure 1).

As follows from the results presented in Scheme 2, the silver-catalyzed, DABCO-promoted cycloaddition of diazo compounds with arenediazonium salts (\(4a–k\), prepared by diazotization of the respective anilines) and (hetero)aromatic (\(5a–g, Si–k, 5n–q\)) and aliphatic (\(5h\)) diazo ketones, as well as \(\alpha\)-diazo acetamides (\(5l, 5m\)), all of which are commercially available and can be conveniently prepared by the literature protocols (Figure 1).
particularly sensitive to substituent effects in the diazonium portion. However, the yields were markedly lower for \(\alpha\)-diazo acetamides (cf. 3r, 3s, 3x, 3y) compared to diazo ketones. Reassuringly, the yields for aromatic and heteroaromatic ketones were comparable, thus allowing access to intriguing combinations of three different aromatic motifs in a single molecule (e.g., benzene/tetrazole/pyridine in 3o).

To conclude, we have described a novel variant of the [3+2]-cycloaddition of arenediazonium tosylates with structurally diverse \(\alpha\)-diazo carbonyl compounds which employs the readily available silver nitrate as a catalyst and significantly expands the range of druglike tetrazoles accessible from a broader range of reagents than has been reported to date. We are in the process of investigating other diazo compounds as partners in these reactions and will report the results in due course.

Scheme 2  Tetrazoles 3a–y prepared in this work
were determined in open capillary tubes with a Stuart SMP50 instrument. Mass spectra were recorded with a Bruker maXis HRMS-ESI-qTOF spectrometer (electrospray ionization mode).

Diazonium Tosylates 4a–k; General Procedure
To a stirred ice-cooled solution/suspension of the corresponding aniline (15.0 mmol) in THF (5 mL), a solution of p-toluenesulfonic acid monohydrate (3.043 mg, 16.0 mmol) in glacial acetic acid (15 mL) was added. The resulting suspension was stirred for 5 min and t-BuONO (2.44 mL, 22.5 mmol) was added in one portion. The mixture was stirred at 0 °C for 20 min, then the ice bath was removed and stirring was continued for 50 min at ambient temperature. The resulting solution was poured into Et₂O (150 mL) and the mixture was stirred for 30 min. The precipitate was collected by filtration, washed with Et₂O (2 × 50 mL) and dried under reduced pressure at 30 °C. The obtained arenediazonium tosylates were used without any further purification.

Benzenediazonium 4-Methylbenzenesulfonate (4a)
White solid; yield: 3.39 g (82%).

1H NMR (400 MHz, DMSO-d₆): δ = 8.73–8.65 (m, 2 H), 8.30–8.21 (m, 1 H), 8.02–7.93 (m, 2 H), 7.50 (d, J = 8.1 Hz, 2 H), 7.13 (d, J = 7.8 Hz, 2 H), 2.30 (s, 3 H).

4-Fluorobenzenediazonium 4-Methylbenzenesulfonate (4b)
White solid; yield: 4.01 g (91%).

1H NMR (400 MHz, DMSO-d₆): δ = 8.84 (dd, J = 9.4, 4.5 Hz, 2 H), 7.89 (dd, J = 9.3, 8.3 Hz, 2 H), 7.49 (d, J = 8.0 Hz, 2 H), 7.11 (d, J = 7.9 Hz, 2 H), 2.29 (s, 3 H).

4-Methoxybenzenediazonium 4-Methylbenzenesulfonate (4c)
Pale purple solid; yield: 4.15 g (86%).

1H NMR (400 MHz, DMSO-d₆): δ = 8.64 (dd, J = 9.4 Hz, 2 H), 7.52–7.44 (m, 4 H), 7.11 (d, J = 7.8 Hz, 2 H), 4.04 (s, 3 H), 2.29 (s, 3 H).

4-Nitrobenzenediazonium 4-Methylbenzenesulfonate (4d)
White solid; yield: 4.15 g (86%).

1H NMR (400 MHz, DMSO-d₆): δ = 9.86 (d, J = 9.2 Hz, 2 H), 8.70 (d, J = 9.1 Hz, 2 H), 7.47 (d, J = 7.9 Hz, 2 H), 7.11 (d, J = 7.7 Hz, 2 H), 2.29 (s, 3 H).

4-(Methoxycarbonyl)benzenediazonium 4-Methylbenzenesulfonate (4e)
White solid; yield: 4.81 g (96%).

1H NMR (400 MHz, DMSO-d₆): δ = 8.82 (d, J = 9.0 Hz, 2 H), 8.42 (d, J = 9.0 Hz, 2 H), 7.48 (d, J = 8.0 Hz, 2 H), 7.11 (d, J = 7.9 Hz, 2 H), 3.96 (s, 3 H), 2.29 (s, 3 H).

2-Methoxybenzenediazonium 4-Methylbenzenesulfonate (4f)
Pale beige solid; yield: 3.86 g (84%).

1H NMR (400 MHz, DMSO-d₆): δ = 8.55 (dd, J = 8.4, 1.6 Hz, 1 H), 8.22 (dd, J = 9.0, 7.5, 1.7 Hz, 1 H), 7.69 (d, J = 8.8 Hz, 1 H), 7.48 (d, J = 7.9 Hz, 2 H), 7.44 (dd, J = 8.3, 7.4, 0.7 Hz, 1 H), 7.12 (d, J = 7.8 Hz, 2 H), 4.18 (s, 3 H), 2.29 (s, 3 H).

4-(Trifluoromethyl)benzenediazonium 4-Methylbenzenesulfonate (4g)
White solid; yield: 4.9 g (95%).
Dried over Na2SO4. After filtration, the solution was concentrated unrestirred for 16 h at ambient temperature. The resulting suspension was White solid; yield: 5.42 g (88%).

Prepared from 2-diazo-1-(p-tolyl)ethan-1-one-1 (5a)4 and 4-fluorobenzenediazonium tosylate (4b).

Yellow solid; yield: 49 mg (58%); mp 122.7–123.9 °C.

**1H NMR (400 MHz, CDCl3):** δ = 8.38–8.30 (m, 2 H), 8.30–8.21 (m, 2 H), 7.38 (d, J = 8.0 Hz, 2 H), 7.35–7.27 (m, 2 H), 2.49 (s, 3 H).

**13C NMR (101 MHz, CDCl3):** δ = 181.8, 164.8, 162.7, 162.3, 145.6, 133.0, 132.7, 130.9, 129.4, 122.5, 122.4, 117.1, 116.8, 21.9.

HRMS-ESI: m/z calcd for C13H11FN4ONa [M + Na]: 305.0809; found: 305.0814.

**1H NMR (400 MHz, CDCl3):** δ = 8.38–8.32 (m, 2 H), 8.16 (d, J = 9.1 Hz, 2 H), 7.38 (d, J = 8.0 Hz, 2 H), 7.09 (d, J = 9.1 Hz, 2 H), 3.92 (s, 3 H), 2.49 (s, 3 H).

**13C NMR (101 MHz, CDCl3):** δ = 182.0, 162.5, 161.2, 145.4, 133.1, 130.9, 129.9, 124.9, 119.4, 55.7, 21.9.

HRMS-ESI: m/z calcd for C13H11FN4ONa [M + Na]: 317.1009; found: 317.1014.

**1H NMR (400 MHz, CDCl3):** δ = 8.38–8.30 (m, 2 H), 8.21–8.16 (m, 2 H), 7.39 (d, J = 8.0 Hz, 2 H), 7.29 (s, 3 H), 7.11 (d, J = 7.9 Hz, 2 H), 2.49 (s, 3 H), 4.46–4.41 (m, 2 H), 2.29 (s, 3 H).

**13C NMR (101 MHz, CDCl3):** δ = 8.25–8.00 (m, 2 H), 7.48 (d, J = 8.9 Hz, 2 H), 7.43–7.40 (m, 1 H), 7.12 (d, J = 7.9 Hz, 2 H), 4.59–4.54 (m, 2 H), 4.46–4.41 (m, 2 H), 2.29 (s, 3 H).

**2,3-Dihydrobenzo[b][1,4]dioxine-6-diazonium 4-Methylbenzenesulfonate (4i)**

Light brown solid; yield: 4.23 g (91%).

**1H NMR (400 MHz, CDCl3):** δ = 8.05 (d, J = 8.7 Hz, 2 H), 4.01 (s, 3 H), 2.50 (s, 3 H).

**13C NMR (101 MHz, CDCl3):** δ = 152.9, 132.9, 132.0, 131.4, 130.9, 129.5, 120.1, 52.6, 21.9.

**HRMS-ESI:** calcd for C14H13FN4O4Na [M + Na]: 305.0814; found: 305.0814.

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HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0858; found: 303.0857.

Prepared from 2-diazo-1-(pyridin-3-yl)ethan-1-one (5f) and benzenediazonium tosylate (4a).

Pale yellow solid; yield: 65 mg (70%); mp 122.7–123.9 °C (dec).

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₃Na [M + Na]: 333.0958; found: 333.0961.

(3,4-Dimethoxyphenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3j)

Prepared from 2-diazo-1-(3,4-dimethoxyphenyl)ethan-1-one (5a) and benzenediazonium tosylate (4a).

Pale orange solid; yield: 48 mg (64%); mp 74.6–77.6 °C.


Beige solid; yield: 53 mg (62%); mp 106.0–107.5 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0858.

(4-Methoxyphenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3k)

Prepared from 2-diazo-1-(4-methoxyphenyl)ethan-1-one (4a) and benzenediazonium tosylate (4a).

Yellow solid; yield: 49 mg (57%); mp 104.3–105.8 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

Beige solid; yield: 48 mg (64%); mp 74.6–77.6 °C.


(4-Chlorophenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3l)

Prepared from 1-(4-chlorophenyl)-2-diazoethan-1-one (5e) and benzenediazonium tosylate (4a).

Yellow solid; yield: 60 mg (71%); mp 86.9–87.8 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

Beige solid; yield: 48 mg (64%); mp 74.6–77.6 °C.


(2-Chlorophenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3m)

Prepared from 1-(2-chlorophenyl)-2-diazoethan-1-one (5d) and benzenediazonium tosylate (4a).

Light yellow solid; yield: 49 mg (57%); mp 104.3–105.8 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

Beige solid; yield: 60 mg (71%); mp 86.9–87.8 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

Yellow solid; yield: 49 mg (57%); mp 104.3–105.8 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

(2-Chlorophenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3o)

Prepared from 2-diazo-1-(2-chlorophenyl)ethan-1-one (5a) and 4-(trifluoromethyl)benzenediazonium tosylate (4g).

Pale beige solid; yield: 81 mg (81%); mp 130.9–133.3 °C (dec).


Beige solid; yield: 53 mg (62%); mp 106.0–107.5 °C.

HRMS-ESI: m/z calcld for C₁₅H₁₄N₄O₂Na [M + Na]: 303.0852; found: 303.0853.

Beige solid; yield: 48 mg (64%); mp 74.6–77.6 °C.


(2-Chlorophenyl)(2-phenyl-2H-tetrazol-5-yl)methanone (3p)

Prepared from 2-diazo-1-(2-chlorophenyl)ethan-1-one (5a) and 4-(trifluoromethyl)benzenediazonium tosylate (4g).

Pale beige solid; yield: 81 mg (81%); mp 130.9–133.3 °C (dec).

(2-Phenyl-2H-tetrazol-5-yl)(thiophen-2-yl)methanone (3p)
Prepared from 2-diazo-1-(thiophen-2-yl)ethan-1-one (5j)18 and benzenediazonium tosylate (4a).
Beige solid; yield: 54 mg (70%); mp 109.5–110.8 °C.
1H NMR (400 MHz, CDCl3): δ = 8.68 (dd, J = 3.9, 1.1 Hz, 1 H), 8.32–8.24 (m, 2 H), 7.89 (dd, J = 4.9, 1.2 Hz, 1 H), 7.68–7.56 (m, 3 H), 7.30 (dd, J = 5.0, 3.9 Hz, 1 H).
13C NMR (101 MHz, CDCl3): δ = 173.7, 162.1, 141.8, 137.1, 136.7, 136.4, 130.7, 129.9, 128.8, 120.4.

Naphthalen-1-yl(2-(4-(trifluoromethyl)phenyl)-2H-tetrazol-5-yl)methanone (3u)
Prepared from 2-diazo-1-(naphthalen-1-yl)ethan-1-one (5o)18 and (trifluoromethyl)benzenediazonium tosylate (4g).
Beige solid; yield: 91 mg (82%); mp 148.4–148.6 °C (dec).
1H NMR (400 MHz, CDCl3): δ = 8.75 (d, J = 8.5 Hz, 1 H), 8.41–8.28 (d, J = 8.5 Hz, 2 H), 8.28–8.12 (m, 1 H), 7.90 (d, J = 8.5 Hz, 2 H), 7.70 (dd, J = 8.5, 6.8, 1.5 Hz, 1 H), 7.66–7.59 (m, 2 H).
13C NMR (101 MHz, CDCl3): δ = 184.3, 163.9, 139.8, 134.7, 133.7, 132.7, 132.5 (q, J = 33.2 Hz), 132.4, 131.0, 128.8, 128.7, 127.2 (q, J = 3.7 Hz), 126.9, 125.4, 124.7, 124.3, 123.3 (q, J = 272.6 Hz), 126.0. 

Morpholinol(2-(4-(trifluoromethoxy)phenyl)-2H-tetrazol-5-yl)methanone (3k)
Prepared from 2-diazo-1-(morpholin-1-yl)ethan-1-one (5k)21 and benzenediazonium tosylate (4a).
Yellowish amorphous solid; yield: 44 mg (44%).
1H NMR (400 MHz, CDCl3): δ = 8.33–8.22 (m, 2 H), 7.46 (d, J = 8.7 Hz, 2 H), 3.96–3.89 (m, 4 H), 3.83–3.76 (m, 2 H).
13C NMR (101 MHz, CDCl3): δ = 160.1, 157.2, 150.3 (q, J = 1.8 Hz), 134.5, 122.2, 121.8, 120.3 (q, J = 255.2 Hz), 66.9, 66.7, 47.6, 43.1.
HRMS-ESI: m/z calcd for C13H12F3N5O3Na [M + Na]: 366.0784; found: 366.0804.

Morpholinol(2-(4-(trifluoromethoxy)phenyl)-2H-tetrazol-5-carboxamide (3s)
Prepared from 2-diazo-1-morpholinooethan-1-one (5l)22 and 4-(trifluoromethoxy)benzenediazonium tosylate (4h).
Pale yellow, amorphous solid; yield: 20 mg (18%).
1H NMR (400 MHz, CDCl3): δ = 8.17–8.06 (m, 2 H), 7.63–7.51 (m, 2 H), 3.63 (dq, J = 21.1, 7.1 Hz, 4 H), 2.21–2.10 (m, 3 H), 2.03–1.92 (m, 6 H), 1.89–1.75 (m, 6 H), 1.32 (td, J = 7.1, 2.0 Hz, 6 H).
13C NMR (101 MHz, CDCl3): δ = 160.5, 158.6, 153.9, 134.1, 126.3, 119.8, 43.4, 43.0, 40.9, 36.6, 36.5, 28.8, 14.6, 12.7.
HRMS-ESI: m/z calcd for C22H19F3N4O2 [M + Na]: 402.2264; found: 402.2272.

2-(4-(Adamant-1-yl)phenyl)-N,N-diethyl-2H-tetrazole-5-carboxamide (3t)
Prepared from 2-diazo-N,N-diethylacetamide (5m)23 and 4-((3RS,5R,7R)-adamant-1-yl)benzenediazonium tosylate (4k).
Pale yellow, amorphous solid; yield: 20 mg (18%).
1H NMR (400 MHz, CDCl3): δ = 8.17–8.06 (m, 2 H), 7.63–7.51 (m, 2 H), 3.63 (dq, J = 21.1, 7.1 Hz, 4 H), 2.21–2.10 (m, 3 H), 2.03–1.92 (m, 6 H), 1.89–1.75 (m, 6 H), 1.32 (td, J = 7.1, 2.0 Hz, 6 H).
13C NMR (101 MHz, CDCl3): δ = 160.5, 158.6, 153.9, 134.1, 126.3, 119.8, 43.4, 43.0, 40.9, 36.6, 36.5, 28.8, 14.6, 12.7.

(4-Bromophenyl)(2-(4-(trifluoromethoxy)phenyl)-2H-tetrazol-5-yl)methanone (3i)
Prepared from 1-(4-bromophenyl)-2-diazoethan-1-one (5n)18 and 4-(trifluoromethoxy)benzenediazonium tosylate (4h).
Pale yellow solid; yield: 95 mg (77%); mp 113.6–116.3 °C.
1H NMR (400 MHz, CDCl3): δ = 8.38–8.29 (m, 4 H), 7.80–7.71 (m, 2 H), 7.56–7.45 (m, 2 H).
13C NMR (101 MHz, CDCl3): δ = 181.0, 162.4, 150.5 (q, J = 1.9 Hz), 134.5, 134.1, 132.2, 130.2, 122.2 (q, J = 1.2 Hz), 122.0, 120.3 (q, J = 259.0 Hz).
HRMS-ESI: m/z calcd for C21H16BrF3N4O [M + Na]: 434.9675; found: 434.9692.
1H NMR (400 MHz, CDCl3): δ = 8.22–8.11 (m, 2 H), 7.64–7.50 (m, 3 H), 3.97–3.86 (m, 4 H), 3.83 (dd, J = 5.9, 4.0 Hz, 2 H), 3.78 (dd, J = 5.6, 4.0 Hz, 2 H).

13C NMR (101 MHz, CDCl3): δ = 159.8, 157.4, 136.4, 130.4, 129.8, 120.2, 66.9, 66.7, 47.5, 43.0.


**N,N-Diethyl-2-phenyl-2H-tetrazole-5-carboxamide (3y)**

Prepared from 2-diao-N,N-diethylacetamide (5m)\(^{23}\) and benzene-diazonium tosylate (4a).

Yellow oil; yield: 22 mg (30%).

1H NMR (400 MHz, CDCl3): δ = 8.23–8.16 (m, 2 H), 7.65–7.51 (m, 3 H), 3.65 (q, J = 7.1 Hz, 2 H), 3.60 (q, J = 7.1 Hz, 2 H), 1.33 (t, J = 7.1 Hz, 6 H).

13C NMR (101 MHz, CDCl3): δ = 160.6, 158.5, 136.5, 130.2, 129.8, 120.1, 43.4, 40.9, 14.6, 12.7.

HRMS-ESI: m/z calcd for C12H15N5ONa [M + Na]: 268.1169; found: 268.1182.

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