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Catalyst-free 1,3-dipolar cycloaddition of 3-nitrochromen with sodium azide: a facile method for the synthesis of 4-aryl-1,4-dihydrochromeno-[4,3-*d*][1,2,3]triazole derivatives

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ABSTRACT

1,3-Dipolar cycloaddition of 3-nitrochromen with sodium azide under catalyst-free conditions afforded 4-aryl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazole derivatives at 80 °C in DMSO is described. The generality of this reaction was demonstrated by synthesizing an array of 4-aryl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazole derivatives. Clean reaction conditions, easy isolation, and good yields of the triazoles are the salient features of the methodology.

1. Introduction

Five-membered nitrogen heterocycles play an important role in biological systems. Among these, the 1,2,3-triazole heterocycles are reported to posses several biological activities, including anti-HIV,[1] anti-allergic,[2] anti-fungal,[3] anti-viral,[4] and anti-microbial.[5] 1,2,3-Triazoles are useful building blocks in chemistry, and can be tuned to exhibit important role in pharmacological applications due to its stability toward light, moisture, oxygen, and metabolism in the body.[6] In addition, these moieties find wide range of applications in industry as photosensitizers, dyes,[7] agrochemicals,[8] and commercially employed as anti-corrosive agents.[9] Owing to the importance of these compounds, Huisgen and co-workers reported the first synthesis of triazoles by the 1,3-dipolar cycloaddition of azide with various alkynes.[10] However, these cycloadditions were often slow even at elevated temperatures and produced a mixture of regioisomers. Further, Sharpless and his co-workers utilized the concept of click chemistry to achieve the regioselective synthesis of 1,4-disubstituted triazoles catalyzed by copper(I) with the cycloaddtions of terminal alkynes only.[11]

Recently, other reports emerged in the literature for the synthesis of these molecules include the copper(I) systems in the presence of a base,[12] in aqueous PEG[13] and the redox couple copper(II)/ascorbic acid[14] in organic or organo-aqueous systems. Heterogeneous catalysis conditions can also be used as illustrated by efficient use of copper salts in zeolites,[15] charcoal,[16] polymer-supported versions,[17] and nanoparticles.[18] In spite of the available methods, some other groups also studied the [3+2] cycloaddtion reactions of azides with electron poor olefins and subsequent elimination reactions.[19] The synthesis of 1,2,3-triazole by 1,3-dipolar cycloaddition of electron deficient olefins with sodium azide in DMSO was first reported by Zefirov and co-workers in 1971.[20] Later on, Zard and his co-workers revisited the reaction and studied the optimized conditions to synthesize the NH triazoles.[21] Proline catalyzed cascade synthesis of triazoles was achieved using nitroolefin, aldehyde, and sodium azide.[22] Similarly, the [3+2] cycloaddition of $TMSN_3$ with 3-nitrocoumarins under solvent free conditions catalyzed by TBAF was reported.[23] The scarce application of these electron deficient substrates is probably due to the poor reactivity of the reactant.

Apart from this, 3-nitro-2-phenyl-2*H*-chromen derivatives have gained considerable attention in recent years due to its biological and synthetic utility. Derivatives of nitrochromens served as phospholipase C inhibitors,[24] intermediates in the synthesis of aminochromans and spiro-[*N*-hydroxy]-lactams,[25] and 2-components in 1,3-dipolar cycloadditions of azomethine ylides.[26] Some of the nitrochromen derivatives have been found to display efficient optical second harmonic generation.[27] Considering the synthetic utility of 3-nitrochromens and in continuation of our research work on nitroolefins,[28] we have developed a newer route for the synthesis of 4-phenyl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazoles by [3+2] cycloaddition of 3-nitro-2-phenyl-2*H*-chromen with sodium azide, under catalyst-free conditions at 80 °C in DMSO (Scheme 1). Although, DMSO is an unconventional solvent, it can be employed as an activator, a Lewis base and also as catalyst for various organic transformations.[29]

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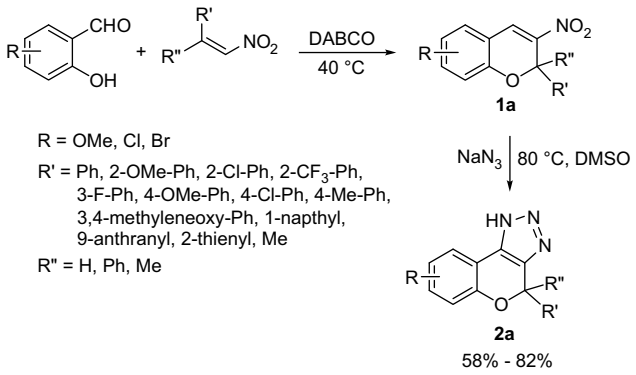


Scheme 1. Synthesis of 4-phenyl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazoles.

2. Results and discussion

The 3-nitro-2*H*-chromens utilized for this study were prepared by the treatment of β-nitroalkenes with various substituted 2-hydroxybenzaldehydes in the presence of DABCO under solvent free conditions reported earlier by our group.[30] Initially, we investigated the reaction between 3-nitrochromen and sodium azide at room temperature in DMSO. Unfortunately, we were not able to isolate any of the corresponding cycloaddition products after 24 h. At elevated temperature (40 °C), we were pleased to find the product 4-phenyl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazole **2a** in quantitative yield. Further, upon increasing the temperature to 80 °C, the reaction was almost completed in 25 min. With this encouraging result in hand, we carried out the optimization studies at 80 °C, varying the amounts of sodium azide.

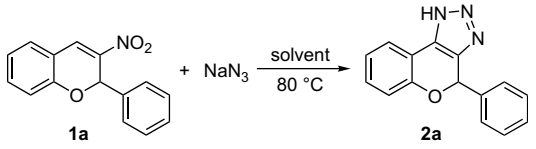
With 1 equiv of the sodium azide as the reactant afforded the product **2a** in 63% yield after 0.5 h. By means of 2 equiv of sodium azide, the reaction was completed to give the product in 90% yield in 25 min. Similarly, various solvents were screened to study their effects, including acetonitrile, 1,2-dichloroethane, water, *N*,*N*-dimethylformamide, dimethylsulfoxide, ethanol, and 1,4-dioxane. None of the solvent afforded the desired product, except the polar solvent such as water, *N*,*N*-dimethylformamide, and dimethylsulfoxide. According to Table 1, the best yield of the cycloaddition product was obtained with nitrochromen (1 equiv) and sodium azide (2 equiv) in DMSO at 80 °C. To further explore the scope and limitations of this methodology, we tested various 2-substituted-3-nitro-2*H*-chromen and its derivatives under optimized reaction conditions (Table 2).

As can be seen from Table 2, the product formation was controlled by both electronic and steric factors according to the nature of the substituent at 2-position of the nitrochromen. For example, 2-position of the nitrochromen containing the phenyl ring equipped with electron-withdrawing groups such as chloro, triflurometyl, and fluoro (entries 3, 4, 5, and 7) reacted efficiently to produce the corresponding cycloaddition products in good yields.

However, 3-nitrochromen containing the phenyl ring equipped with electron-donating groups methyl and methoxy (entries 2, 6, and 8) required relatively longer reaction time to give the triazolochromene derivatives in moderate yields. The 3-nitro-2*H*-chromen containing bulky substituents at 2-position such as naphthyl and anthranyl (entries 10 and 11) proceeded well under the present reaction conditions. Sterically hindered substrate such as 2,2-dimethyl-3-nitrochromen (entry 16) required prolonged reaction time. Whereas starting material was recovered in case of 2,2-diphenyl-3-nitrochromen (entry 17). The 3-nitrochromen containing different functionalities at 6 and 8 positions (entries 13, 14, and 15) reacted to give the corresponding products. It is important to note that the acid-sensitive moiety such as thienyl substituted 3-nitro-2*H*-chromen derivative (entry 12) survived under the present reaction conditions. Single crystal X-ray diffraction analysis for the adduct **2l** showed the position of the NH group of the triazole ring is oriented toward the benzene ring of the 3-nitrochromen. This may be due to the steric effect of the substituent present in the 2-position of the 3-nitrochromen. The X-ray crystal structure of the cycloaddition adduct (**2l**) is shown in Figure 1.

The most important feature of this method is bis-cycloaddition of 1,4-bis(3-nitro-2*H*-chromen-2-yl)benzene containing two nitrochromene moieties. Under the present reaction conditions, 1,4-bis(3-nitro-2*H*-chromen-2-yl)benzene was reacted with 4 equiv of sodium azide afforded the 1,4-bis(1,4-dihydrochromeno[4,3-*d*][1,2,3]triazol-4-yl)benzene (**3b**) shown below Scheme 2.

Table 1
Optimization of reaction conditions



Entry	Solvent	Yield[a,b] (%)
1	Acetonitrile	0
2	1,2-Dicholoroethane	0
3	Water	12
4	*N*,*N*-Dimethylformamide	38
5	Dimethylsulfoxide	63
6[c]	Dimethylsulfoxide	90
7	Ethanol	0
8	1,4-Dioxane	0

[a] Reactions were performed in 1 mmol scale.
[b] Yields were determined from crude ^{1}H NMR spectra using toluene as internal standard.
[c] Sodium azide (2 equiv) was used.

3. Conclusion

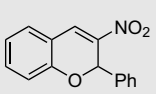
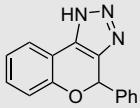
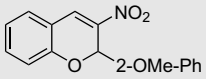
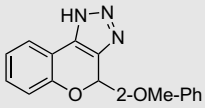
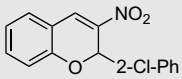
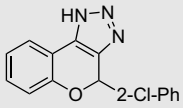
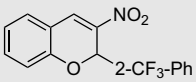
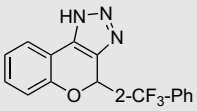
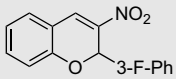
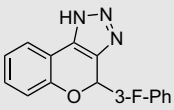
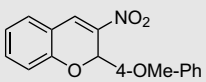
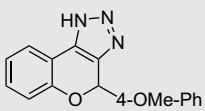
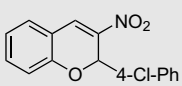
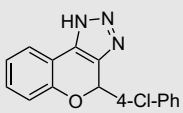
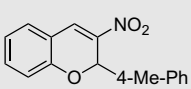
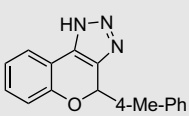
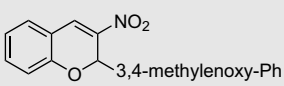
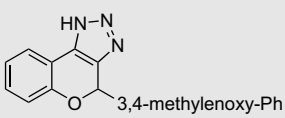
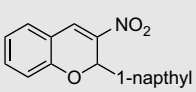
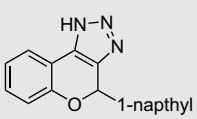
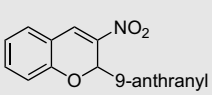
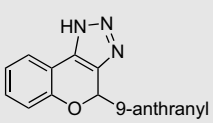
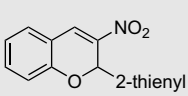
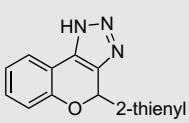
In conclusion, we have achieved a catalyst-free [3+2] cycloaddition of 3-nitro-2-phenyl-2*H*-chromen with sodium azide in DMSO at 80 °C. The procedure was compatible with structurally diverse 3-nitro-2-substituted chromen and its derivatives. Simple reaction conditions, catalyst-free and easy isolation of the compounds make this method an alternative to the existing methods.

4. Experimental

4.1. General

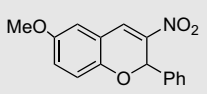
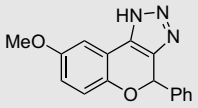
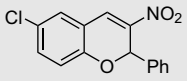
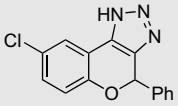
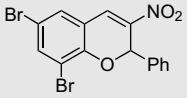
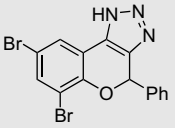
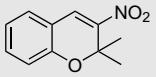
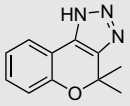
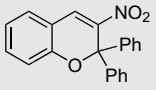
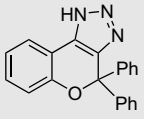
CAUTION: *Azides can be explosive compounds and should be handled with great care. During our study we encountered no problems.*[32] Solvents for extraction and chromatography were distilled before use. All the chemicals used were of commercial grade and used after distillation. Analytical thin layer chromatography was performed with E. Merck silica gel 60 F_{254} aluminum plates. All purifications were carried out by flash chromatography using 230–400 mesh silica gel. NaN_3 was purchased from the Acros Organics Co. Melting points were determined with a microscope hot-stage apparatus and uncorrected. ^{1}H and ^{13}C NMR were recorded with Varian Gemini-200 or Bruker Avance EX 400 FT NMR. Chemical shifts were reported in parts per million (δ) using TMS as internal standard, and coupling constants were expressed in hertz. MS or HRMS were measured using a JEOL JMS-D300 or JEOL JMS-HX 110 spectrometer. All the 3-nitrochromene derivatives were

Table 2
Reaction of various 3-nitrochromene derivatives with sodium azide in DMSO at 80 °C

Entry	3-Nitrochromen derivative	Product		Time (min)	Yield[a,b] (%)
1			**2a**	25	79
2			**2b**	70	60
3			**2c**	50	82
4			**2d**	60	60
5			**2e**	40	80
6			**2f**	75	62
7			**2g**	35	74
8			**2h**	45	63
9			**2i**	70	69
10			**2j**	60	64
11			**2k**	90	60
12			**2l**	25	77

(*continued on next page*)

Table 2 (*continued*)

Entry	3-Nitrochromen derivative	Product		Time (min)	Yield[a,b] (%)
13			**2m**	75	61
14			**2n**	45	78
15			**2o**	50	70
16			**2p**	180	58
17			**2q**	180[c]	Trace

[a] Isolated yields.
[b] Reactions were performed in 1 mmol scale.
[c] Reaction was prolonged for 24 h.

synthesized by following known procedures and spectral data was consistent with the literature reports.[30]

4.2. General procedure for the synthesis of 4-aryl-1,4-dihydrochromeno[4,3-*d*][1,2,3]triazole derivatives

To the solution of the 3-nitro-2-phenyl-2*H*-chromen (1 mmol) in DMSO (2 mL) was added sodium azide (2 mmol). The mixture was then heated at 80 °C until the starting material was totally consumed as indicated by TLC (25 min to 3 h). After cooling, water was added and the resulting precipitate was filtered, washed with excess of water, and dried to give the desired triazole, which was recrystallized. When no precipitate was observed, the triazole was isolated after extraction with ethylacetate. Further purification was done by column chromatography using ethylacetate/hexane as eluent.

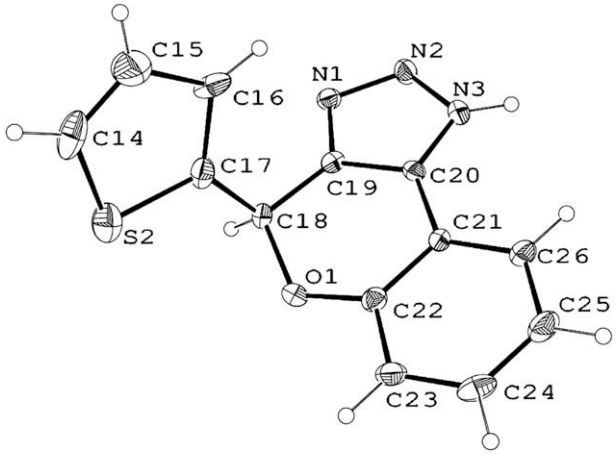


Figure 1. X-ray crystal structure of **2l** (ORTEP view).[31]

4.2.1. 4-Phenyl-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2a**)

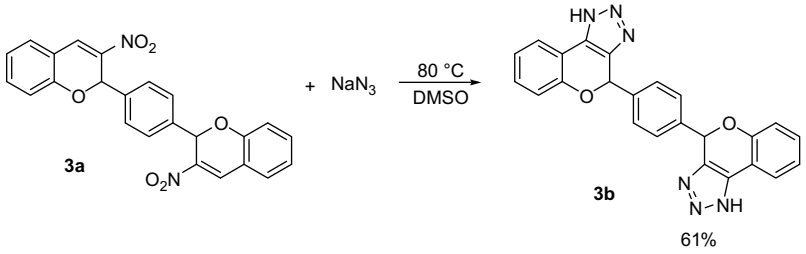
Colorless solid (79% yield). Mp 151–153 °C. ^{1}H NMR ($CDCl_3$) δ 7.76 (d, J=7.2 Hz, 1H), 7.45 (d, J=6.2 Hz, 2H), 7.37–7.29 (m, 4H), 7.05–7.02 (t, J=7.0 Hz, 2H), 6.58 (s, 1H). ^{13}C NMR ($CDCl_3$) δ 153.5, 141.7, 138.9, 138.2, 130.5, 128.9, 128.8, 127.2, 1233, 122.4, 117.8, 116.0, 76.3. MS (EI) m/z (%) 249 (M^+, 100), 219 (60), 171 (50), 164 (40), 116 (10). HRMS calcd for $C_{15}H_{11}N_3O$ (M^+) 249.0897, found 249.0896.

4.2.2. 4-(2-Methoxyphenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2b**)

Colorless solid (60% yield). ^{1}H NMR ($CDCl_3$) δ 12.68 (s, 1H), 7.80 (d, J=7.3 Hz, 1H), 7.33–7.22 (m, 3H), 7.06–7.00 (m, 3H), 6.96–6.89 (m, 2H), 3.85 (s, 3H). ^{13}C NMR ($CDCl_3$) δ 156.8, 153.9, 141.3, 138.5, 130.4, 130.3, 128.5, 127.0, 123.2, 122.2, 120.9, 117.6, 115.7, 111.3, 71.1, 55.8. MS (EI) m/z (%) 280 (M^+, 18), 278 (100), 263 (80), 247 (15), 220 (15), 220 (15), 189 (10), 172 (10), 152 (5), 89 (10). HRMS calcd for $C_{16}H_{13}N_3O_2$ (M^+) 279.1002, found 279.1003.

4.2.3. 4-(2-Chlorophenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2c**)

Colorless solid (82% yield). Mp 158–160 °C. ^{1}H NMR ($CDCl_3$) δ 12.47 (s, 1H), 7.81 (d, J=7.5 Hz, 1H), 7.47 (d, J=7.5 Hz, 1H), 7.39 (d, J=7.5 Hz, 1H), 7.31–7.22 (m, 3H), 7.10–7.01 (m, 3H). ^{13}C NMR ($CDCl_3$) δ 153.1, 141.6, 140.1, 136.4, 133.1, 131.2, 130.6, 130.5, 130.2, 128.0, 123.1, 122.8, 117.7, 116.1, 73.9. MS (EI) m/z (%) 283 (M^+, 20), 282



Scheme 2. Synthesis of 1,4-bis(1,4-dihydrochromeno[4,3-*d*][1,2,3]triazol-4-yl)benzene.

(100), 281 (25), 247 (40), 189 (15), 172 (100), 165 (10), 163 (10), 95 (5), 89 (10). HRMS calcd for $C_{15}H_{10}ClN_3O$ (M^+) 283.0507, found 283.0514.

*4.2.4. 4-(2-(Trifluoromethyl)phenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2d**)*

Colorless solid (60% yield): Mp 136–138 °C. ^{1}H NMR ($CDCl_3$) δ 12.95 (s, 1H), 7.83 (d, J=8.0 Hz, 1H), 7.74 (d, J=7.8 Hz, 1H), 7.58–7.50 (m, 2H), 7.47 (t, J=7.5 Hz, 1H), 7.32 (m, 1H), 7.11 (t, J=8.1 Hz, 1H), 7.04 (d, J=8.1 Hz, 1H), 6.92 (s, 1H). ^{13}C NMR ($CDCl_3$) δ 153.7, 142.1, 139.2, 137.0, 132.6, 130.9, 130.0, 129.2, 128.7 (q, J_{C-F}=31.0 Hz), 126.2 (q, J_{C-F}=6.0 Hz), 124.3 (q, J_{C-F}=272.0 Hz.), 123.5, 122.9, 117.9, 116.7, 72.5 (q, J_{C-F}=3.0 Hz). MS (EI) m/z (%) 317 (M^+, 70), 172 (100), 116 (10), 89 (5). HRMS calcd for $C_{16}H_{10}F_3N_3O$ (M^+) 317.0770, found 317.0773.

*4.2.5. 4-(3-Fluorophenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2e**)*

Colorless solid (80% yield). Mp 143–145 °C. ^{1}H NMR ($CDCl_3$) δ 12.40 (s, 1H), 7.79 (d, J=7.6 Hz, 1H), 7.36–7.24 (m, 3H), 7.19 (d, J=9.5 Hz, 1H), 7.10–6.97 (m, 3H), 6.60 (s, 1H). ^{13}C NMR ($CDCl_3$) δ 164.2 (d, J_{C-F}=246.0 Hz), 153.2, 141.6, 141.0 (d, J_{C-F}=6.0 Hz), 138.5, 130.7, 130.4 (d, J_{C-F}=3.0 Hz), 123.3, 122.6, 122.5 (d, J_{C-F}=3.0 Hz), 117.8, 115.9 (d, J_{C-F}=21.0 Hz), 115.4, 114.2 (d, J_{C-F}=23.0 Hz), 75.2. MS (EI) m/z (%) 268 (M+1, 15), 267 (M^+, 100), 237 (25), 212 (10), 190 (10), 183 (20), 172 (50), 116 (5), 89 (5). HRMS calcd for $C_{15}H_{10}FN_3O$ (M^+) 267.0802, found 267.0804.

*4.2.6. 4-(4-Methoxyphenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2f**)*

Colorless solid (62% yield). Mp 131–133 °C. ^{1}H NMR ($CDCl_3$) δ 12.41 (s, 1H), 7.78 (d, J=7.2 Hz, 1H), 7.36 (d, J=8.6 Hz, 2H), 7.25 (m, 1H), 7.05 (m, 2H), 6.90 (d, J=8.7 Hz, 2H), 6.53 (s, 1H), 3.81 (s, 3H). ^{13}C NMR ($CDCl_3$) δ 160.2, 153.6, 142.1, 138.7, 130.7, 130.6, 128.9, 123.4, 122.5, 117.9, 115.7, 114.3, 76.0, 55.4. MS (EI) m/z (%) 279 (M^+, 100), 250 (15), 248 (60), 220 (10), 190 (10), 172 (15), 152 (5), 89 (5). HRMS calcd for $C_{16}H_{13}N_3O_2$ (M^+) 279.1002, found 279.1004.

*4.2.7. 4-(4-Chlorophenyl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2g**)*

Colorless solid (74% yield). Mp183–185 °C. ^{1}H NMR ($CDCl_3$) δ 12.54 (s, 1H), 7.78 (d, J=7.2 Hz, 1H), 7.40–7.25 (m, 5H), 7.09–7.04 (m, 2H), 6.58 (s, 1H). ^{13}C NMR ($CDCl_3$) δ 152.5, 140.8, 137.9, 137.3, 133.3, 130.1, 128.8, 128.6, 122.7, 122.4, 117.5, 116.1, 74.6. MS (EI) m/z (%) 283 (M^+, 100), 253 (20), 247 (80), 219 (20), 172 (40), 95 (10). HRMS calcd for $C_{15}H_{10}ClN_3O$ (M^+) 283.0507, found 283.0507.

*4.2.8. 4-p-Tolyl-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2h**)*

Colorless solid (63% yield). Mp 163–165 °C. ^{1}H NMR ($CDCl_3$) δ 12.95 (s, 1H), 7.78 (d, J=7.3 Hz, 1H), 7.33 (d, J=8.0 Hz, 2H), 7.28–7.25 (m, 1H), 7.16 (d, J=8.0 Hz, 2H), 7.06–7.02 (t, J=8.0 Hz, 2H), 6.55 (s, 1H), 2.32 (s, 3H). ^{13}C NMR ($CDCl_3$) δ 153.5, 142.2, 138.8, 138.7, 135.7, 130.6, 129.6, 127.3, 123.4, 122.4, 117.9, 115.7, 76.2, 21.4. MS (EI) m/z (%) 264 (M+1, 15), 263 (M^+ 100), 248 (80), 234 (20), 220 (20), 189 (10), 172 (20), 165 (10), 130 (15), 114 (10), 8 (10). HRMS calcd for $C_{16}H_{13}N_3O$ (M^+) 263.1053, found 263.1052.

*4.2.9. 4-(Benzo[d][1,3]dioxol-4-yl)-1,4-dihydrochromeno [4,3-d][1,2,3]triazole (**2i**)*

Colorless solid (69% yield). Mp 148–150 °C. ^{1}H NMR ($CDCl_3$) δ 12.2 (s, 1H), 7.78 (m, 1H), 7.29 (m, 1H), 7.29–7.27 (m, 1H), 7.08–7.02 (m, 2H), 6.92 (m, 2H), 6.80 (d, J=8.5 Hz, 1H), 5.94 (s, 2H). ^{13}C NMR ($CDCl_3$) δ 153.4, 148.2, 148.0, 141.9, 138.6, 132.3, 130.6, 123.2, 122.4, 121.3, 117.7, 115.5, 108.3, 107.8, 101.3, 76.1. MS (EI) m/z (%) 293 (M^+, 100), 263 (25), 206 (15), 151 (10), 117 (5), 89 (5), 63 (5). HRMS calcd for $C_{16}H_{11}N_3O_3$ (M^+) 293.0798, found 293.0795.

*4.2.10. 4-(Naphthalen-1-yl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2j**)*

Colorless solid (64% yield). Mp 206–208 °C. ^{1}H NMR ($CDCl_3$) δ 14.40 (s, 1H), 8.30 (d, J=8.2 Hz, 1H), 7.89–7.80 (m, 3H), 7.58–7.49 (m, 2H), 7.40–7.32 (m, 3H), 7.22–7.14 (m, 1H), 7.06 (t, J=7.5 Hz, 1H), 6.95 (d, J=8.1 Hz, 1H). ^{13}C NMR ($CDCl_3$) δ 153.1, 140.6, 134.5, 134.0, 131.1, 129.8, 129.7, 128.6, 128.4, 126.4, 126.2, 125.8, 125.0, 124.2, 122.4, 122.1, 117.5, 116.3, 74.5. MS (EI) m/z (%) 299 (M^+, 100), 270 (55), 241 (10), 172 (15), 127 (10). HRMS calcd for $C_{19}H_{13}N_3O$ (M^+) 299.1053, found 299.1061.

*4.2.11. 4-(Anthracen-9-yl)-1,4-dihydrochromeno [4,3-d][1,2,3]triazole (**2k**)*

Colorless solid (60% yield). Mp 215–217 °C. ^{1}H NMR ($CDCl_3$) δ 12.04 (s, 1H), 8.53 (s, 1H), 8.21 (d, J=8.6 Hz, 2H), 8.02 (d, J=8.4 Hz, 2H), 7.94 (s, 1H), 7.87 (d, J=9.5 Hz, 1H), 7.51–7.30 (m, 5H), 7.16 (t, J=7.5 Hz, 1H), 7.05 (d, J=8.1 Hz, 1H). ^{13}C NMR ($CDCl_3$) δ 154.5, 139.4, 134.2, 131.8, 130.7, 130.3, 129.5, 127.3, 126.9, 126.5, 124.9, 124.1, 123.6, 122.7, 118.0, 116.2, 72.2. MS (EI) m/z (%) 349 (M^+, 100), 319 (50), 304 (20), 264 (10), 178 (20). HRMS calcd for $C_{23}H_{15}N_3O$ (M^+) 349.1210, found 349.1215.

*4.2.12. 4-(Thiophen-2-yl)-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2l**)*

Colorless solid (77% yield). Mp 144–146 °C. ^{1}H NMR ($CDCl_3$) δ 12.5 (s, 1H), 7.79 (m, 1H), 7.31 (m, 1H), 7.27 (m, 1H), 7.08–7.03 (m, 3H), 6.96 (m, 1H), 6.84 (s, 1H). ^{13}C NMR (MHz, $CDCl_3$) δ 152.9, 141.8, 138.9, 130.9, 130.7, 127.2, 127.1, 126.9, 123.4, 122.8, 118.3, 115.8, 71.8. MS (EI) m/z (%) 255 (M^+, 100), 225 (30), 200 (10), 171 (15), 154 (5), 127 (5). HRMS calcd for $C_{13}H_9N_3OS$ (M^+) 255.0461, found 255.0468.

*4.2.13. 8-Methoxy-4-phenyl-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2m**)*

Colorless solid (61% yield). Mp 191–193 °C. ^{1}H NMR ($CDCl_3$) δ 7.35–7.31 (m, 5H), 7.19 (d, J=2.9 Hz, 1H), 6.96 (d, J=7.6 Hz, 1H), 6.81 (d, J=3.0 Hz, 1H), 6.61 (s, 1H), 3.76 (s, 3H). ^{13}C NMR (DMSO-d_6) δ 154.6, 146.6, 141.1, 139.3, 130.4, 128.7, 128.1, 127.2, 118.6, 116.8, 116.0, 107.2, 75.4, 55.7. MS (EI) m/z (%) 279 (M^+, 100), 250 (15), 224

(5), 202 (30), 151 (5), 77 (3). HRMS calcd for $C_{16}H_{13}N_3O_2$ (M^+) 279.1002, found 279.1006.

4.2.14. 8-Chloro-4-phenyl-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2n**)

Colorless solid (78% yield). Mp 184–186 °C. ^{1}H NMR ($CDCl_3$) δ 12.08 (s, 1H), 7.76 (d, J=2.3 Hz, 1H), 7.24–7.35 (m, 5H), 7.28–7.20 (m, 1H), 7.00 (d, J=8.8 Hz, 1H), 6.58 (s, 1H). ^{13}C NMR (DMSO-d_6) δ 152.5, 135.9, 132.6, 130.7, 130.1, 129.9, 129.6, 127.5, 122.6, 122.3, 117.1, 115.6, 73.4. MS (EI) m/z (%) 283 (M^+, 100), 254 (70), 227 (30), 205 (30), 189 (30), 164 (10), 77 (10). HRMS calcd for $C_{15}H_{10}ClN_3O$ (M^+) 283.0507, found 283.0511.

4.2.15. 6,8-Dibromo-4-phenyl-1,4-dihydrochromeno[4,3-d][1,2,3]triazole (**2o**)

Colorless solid (70% yield). Mp 203–205 °C. ^{1}H NMR ($CDCl_3$, DMSO-d_6) δ 7.84 (d, J=2.1 Hz, 1H), 7.60 (d, J=2.2 Hz, 1H), 7.44 (d, J=7.0 Hz, 2H), 7.37–7.29 (m, 3H), 6.76 (s, 1H). ^{13}C NMR (DMSO-d_6) δ 147.4, 137.0, 133.4, 127.5, 127.4, 127.3, 126.2, 125.4, 125.3, 123.2, 122.8, 111.1, 75.5. MS (EI) m/z (%) 407 (M+2, 100), 378 (30), 351 (20), 296 (10), 190 (30), 162 (30), 95 (10), 77 (10). HRMS calcd for $C_{15}H_9Br_2N_3O$ (M^+) 404.9107, found 404.9120, and for HRMS of $C_{15}H_9Br^{81}BrN_3O$ (M^+) 406.9086, found 404.9084; HRMS calcd for $C_{15}H_9Br^{81}BrN_3O$ (M^+) 408.9066, found 408.9075.

4.2.16. 4,4-Dimethyl-1,4-dihydrochromeno[4,3-d]-[1,2,3]triazole (**2p**)

Colorless solid (58% yield). Mp 173–175 °C. ^{1}H NMR ($CDCl_3$) δ 12.74 (s, 1H), 7.78 (d, J=7.5 Hz, 1H,), 7.29–7.24 (m, 1H), 7.06–6.99 (m, 2H), 1.71 (s, 6H). ^{13}C NMR ($CDCl_3$) δ 153.2, 147.3, 130.5, 123.3, 122.1, 118.2, 115.7, 114.8, 76.9, 27.8. MS (EI) m/z (%) 201 (M^+, 30), 186 (100), 131 (5), 103 (10), 77 (5). HRMS calcd for $C_{11}H_{11}N_3O$ (M^+) 201.0897, found 201.0900.

4.2.17. 1,4-Bis(1,4-dihydrochromeno[4,3-d][1,2,3]triazol-4-yl)benzene (**3b**)

Colorless solid (61% yield). Mp 203–205 °C. ^{1}H NMR (DMSO-d_6) δ 7.67 (d, J=6.9 Hz, 2H), 7.39 (s, 4H), 7.28 (t, J=7.6 Hz, 2H), 7.04 (m, 4H), 6.76 (s, 2H). ^{13}C NMR (DMSO-d_6) δ 152.9, 141.3, 139.8, 137.6, 130.5, 127.7, 123.0, 122.7, 117.8, 116.5, 75.4. MS (EI) m/z (%) 419 (M^+, 100), 362 (15), 249 (20), 247 (100), 219 (10), 171 (40), 164 (15), 115 (5). HRMS calcd for $C_{24}H_{16}N_6O_2$ (M^+) 420.1340, found 420.1338.

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31. CCDC number of compound **2l** is 720916. These data can be obtained free of charge from Cambridge Crystallographic Data Center via www.ccdc.cam.ac.uk/datarequest/cif.
32. For a discussion on the hazards associated with azides, see: *Prudent Practice for Handling Hazardous Chemicals in Laboratories*; National Academic: Washington, DC; 1983, pp 87–88 for human toxicity, see: *The Merck, Index*, 12th ed.; Merck: Rahway, NJ, 1996, pp 4818 and 8726.