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Palladium-Catalyzed Nitration of Arenes by 1,2,3-Triazole-Directed C–H Activation

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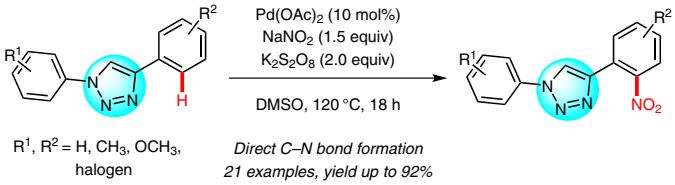

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Abstract An efficient palladium-catalyzed regioselective nitration of 1,4-disubstituted 1,2,3-triazoles has been described with good functional group compatibility, using $Pd(OAc)_2$ as the catalyst and $NaNO_2$ as the nitration source, leading to the synthesis of 1,2,3-triazoles containing nitro groups in good to excellent yields.

Key words palladium, C–H activation, 1,4-disubstituted 1,2,3-triazoles, nitration, regioselectivity

Transition-metal-catalyzed C–H bond functionalizations are effective, attractive, and ideal reactions, which enable the efficient construction of carbon–carbon or carbon–heteroatom bonds as a highly atom-economical and direct approach.[1] The second-row transition metals, such as Ru,[2] Rh,[3] and Pd,[4] have been considerably explored for this purpose. Typically, C–H bond activation requires the combination of transition metals and directing groups to facilitate regioselective C–H bond cleavage. Sulfoximine,[5] pyridine,[6] azo group,[7] and carboxylic acids[8] have been explored as effective directing groups (DGs) to assist selective C–H bond functionalization and employed in a variety of reactions.

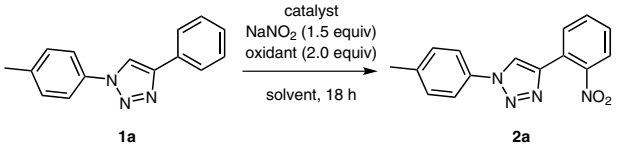
In the past decade, the area of transition-metal-catalyzed chelation-assisted inert C–H bond functionalization has witnessed great progress;[9] thus, it has become a remarkable strategy in the regioselective construction of a variety of carbon–carbon or carbon–heteroatom bonds with features of step-economics and green chemistry. With this concept, a series of synthetic methods for nitroarenes (constructing C–N bond) have been developed. For example, in 2010, Liu's group[10] developed the palladium-catalyzed *ortho*-specific nitration of aromatic C–H bonds by using N-heterocycles as directing groups, and $AgNO_2$ as nitro source. From then on, NO_2,[11] MNO_2,[12] and *t*-BuONO[13] were used as nitro source in the direct *ortho*-nitration of aromatic C–H bond. Additionally, a similar chelation-directed strategy was explored in several copper-,[14] and rhodium[15]-catalyzed *ortho*-nitrations of aryl sp^2 C–H bonds with various nitro sources, respectively, using N-heterocycles as directing groups.

1,2,3-Triazoles are known to play a very important role in organic chemistry as they are widely applied in various fields including synthetic organic chemistry,[16] biological science,[17] medicinal chemistry,[18] and materials science.[19] In recent years, Kuang's group[20] achieved the Pd-catalyzed direct C–H bond halogenation, arylation, alkoxylation, acylation, and acyloxylation of 2-monosubstituted 1,2,3-triazoles, using the triazole ring as the directing group. At the same time, transition-metal-catalyzed arylation of the C-4 or C-5 position of 1,4-disubstituted 1,2,3-triazoles were also demonstrated.[21] However, to the best of our knowledge, there is still no report on the transition-metal-catalyzed direct nitration of 1,2,3-triazoles. Herein, we report on the first examples of palladium-catalyzed regioselective nitration of arenes through 1,2,3-triazole-directed C–H activation.

An initial investigation of the reaction conditions, including catalyst (10% mol), oxidant, temperature, and solvent, was conducted under dioxygen atmosphere, using the nitration of 4-phenyl-1-(*p*-tolyl)-1*H*-1,2,3-triazole (**1a**) as a model (Table 1). First, several palladium catalysts were screened using $NaNO_2$ (1.5 equiv) as a nitro source and $K_2S_2O_8$ (2 equiv) as an oxidant in DMSO at 120 °C for 18 hours. It was found that $PdCl_2$, $Pd_2(dba)_3$, and $PdCl_2(PPh_3)$ showed low catalytic activity (Table 1, entries 1–3). However, $Pd(OAc)_2$ exhibited excellent efficiency to give the de-

sired product **2a** in 86% yield (entry 4). The reaction gave inferior results when the catalyst loading were decreased to 5 mol% (entry 5). Increasing or decreasing the reaction temperature did not favor the nitration (entries 6, 7). We then examined the influence of oxidant including $K_2S_2O_8$, AgOAc, $Cu(OAc)_2$, DDQ, and $PhI(OAc)_2$, among which $K_2S_2O_8$ was found to be the most suitable oxidant (entry 4, entries 8–11). However, control experiments (entry12) showed that the reaction failed to give the desired product only in the oxygen atmosphere without other oxidant. Finally, several solvents were surveyed for the reaction, and it was found that no target molecules were detected in DMF, MeOH (entries 13,14). Additionally, other solvents, including TFA, toluene, *p*-xylene, and DCE, showed low efficiency (entries 16–18). Thus, the optimized reaction conditions for the nitration of 4-phenyl-1-(*p*-tolyl)-1*H*-1,2,3-triazole (**1a**) was established as $Pd(OAc)_2$ (10% mol), $NaNO_2$ (1.5 equiv), and $K_2S_2O_8$ (2 equiv) in DMSO at 120 °C for 18 hours.

Table 1 Optimization of Reaction Conditions[a]



1a **2a**

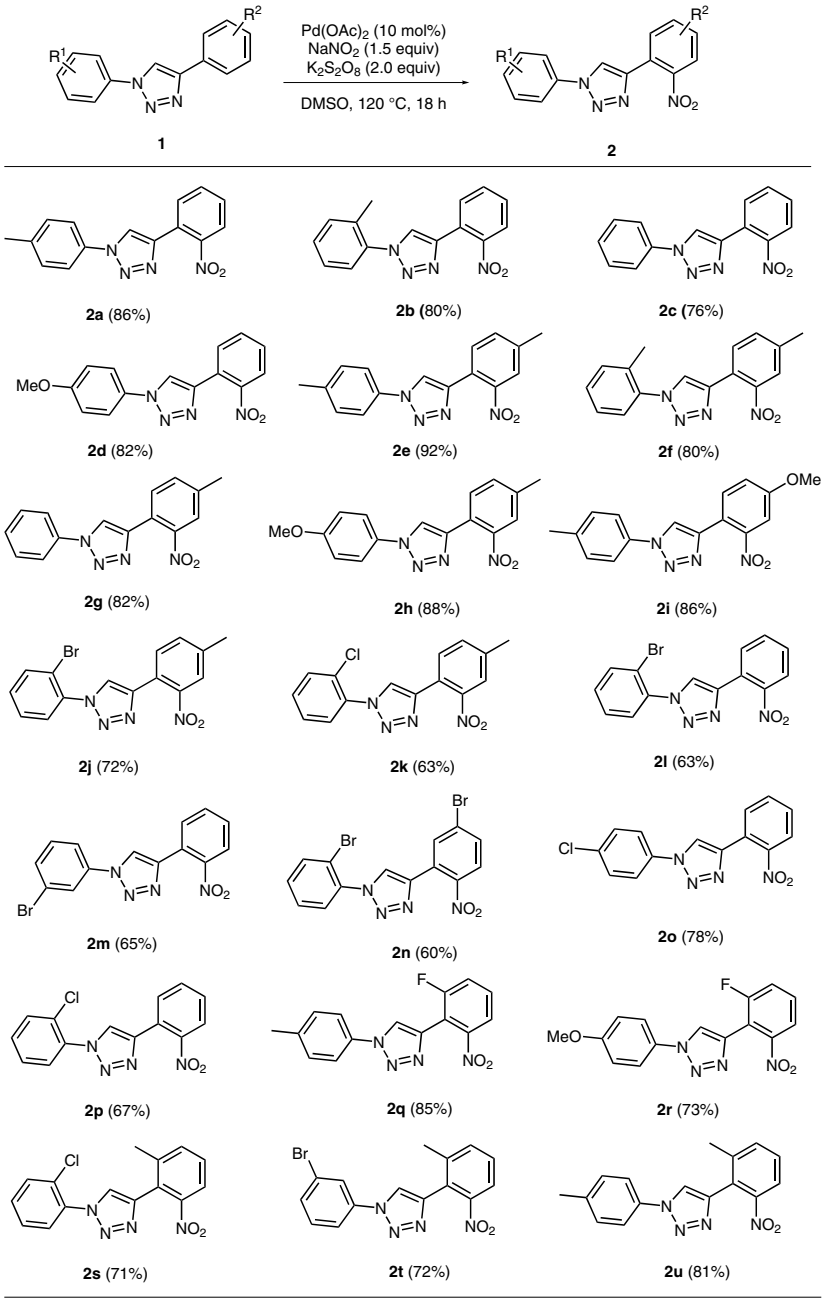
Entry	Catalyst	Oxidant	Temp (°C)	Solvent	Yield (%)[b]
1	$PdCl_2$	$K_2S_2O_8$	120	DMSO	35
2	$Pd_2(dba)_3$	$K_2S_2O_8$	120	DMSO	40
3	$PdCl_2(PPh_3)_2$	$K_2S_2O_8$	120	DMSO	22
4	$Pd(OAc)_2$	$K_2S_2O_8$	120	DMSO	86
5	$Pd(OAc)_2$	$K_2S_2O_8$	120	DMSO	72[c]
6	$Pd(OAc)_2$	$K_2S_2O_8$	110	DMSO	68
7	$Pd(OAc)_2$	$K_2S_2O_8$	130	DMSO	70
8	$Pd(OAc)_2$	AgOAc	120	DMSO	21
9	$Pd(OAc)_2$	$Cu(OAc)_2$	120	DMSO	45
10	$Pd(OAc)_2$	DDQ	120	DMSO	0
11	$Pd(OAc)_2$	$PhI(OAc)_2$	120	DMSO	trace
12	$Pd(OAc)_2$	O_2	120	DMSO	0
13	$Pd(OAc)_2$	$K_2S_2O_8$	120	DMF	0
14	$Pd(OAc)_2$	$K_2S_2O_8$	120	MeOH	0
15	$Pd(OAc)_2$	$K_2S_2O_8$	120	TFA	38
16	$Pd(OAc)_2$	$K_2S_2O_8$	120	toluene	21
17	$Pd(OAc)_2$	$K_2S_2O_8$	120	*p*-xylene	18
18	$Pd(OAc)_2$	$K_2S_2O_8$	120	DCE	23

[a] Reaction conditions (unless otherwise noted): compound **1a** (0.2 mmol), [Pd] (0.02 mmol), $NaNO_2$ (0.3 mmol), oxidant (0.4 mmol) in DMSO (1.5 mL) at 120 °C for 18 h.
[b] Yield of isolated product after column chromatography.
[c] $Pd(OAc)_2$ used: 5 mol%.

With the optimized reaction conditions in hand, we turned our attention to investigate the scope of the substrates. The results are summarized in Scheme 1. A series of arenes carrying either an electron-donating substituent such as methyl, methoxy (Scheme 1, 2a–i, u) or an electron-withdrawing group (F, Cl, Br) (**2j**–**r**) proceeded smoothly. Substrates bearing an electron-donating group at the *para*- or *ortho*-position of the arenes of 1,2,3-triazoles all gave the corresponding products in good to excellent yields (**2a**,**b**,**e**,**f** and **2j** vs **2l**). However, substrates possessing electron-withdrawing group (Br) at the arenes of C-1 and/or C-4 position of 1,2,3-triazoles could deliver the desired products only in somewhat lower yields (**2l**–**n**); the reason may be that halogen (Br) may cause some side reactions. Additionally, substrates substituted with Br group at the 2-position of C-1 aryl of 1,2,3-triazoles resulted in lower yield compared with that at the 3-position (**2l** vs **2m**). The reactions of arenes carrying a group at the *para*-position could furnish nitroarenes in higher yields than the *ortho*-substituted ones (**2a** vs **2b**, **2e** vs **2f**, **2m** vs **2n**, and **2o** vs **2p**), which may be owing to the steric hindrance of the latter. The molecules with Br at the 2-position of C-1 aryl of 1,2,3-triazoles resulted in lower yield than that with a Cl group (**2m** vs **2o**); the reason may be that bromine is more active and causes more side reactions. Notably, substrates possessing an electron-withdrawing group (F) or an electron-donating (methyl) at the *ortho*- position of C-4 arenes of 1,2,3-triazoles could also deliver the desired products in good yields (**2q**–**u**).

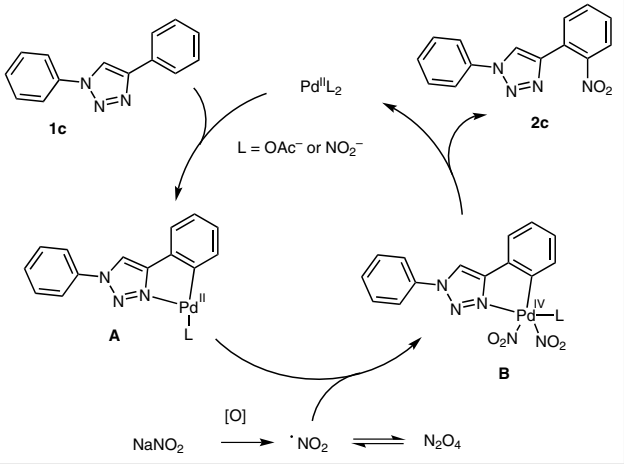
On the basis of the above experiments and previous reports,[12a] a plausible mechanism for the palladium-catalyzed nitration of 1,4-diphenyl-1*H*-1,2,3-triazole (**1c**) is proposed in Scheme 2. First, selective coordination of electron-richer N(3)[22] in 1,2,3-triazole **1c** to Pd(II) species followed by *ortho* C–H activation forms the five-membered palladacycle **A**. Then, addition of NO_2 radicals (the radical may be generated from $NaNO_2$ through an oxidation process) to the metal center generates Pd^{IV} species **B**.[12a] Reductive elimination from the Pd^{IV} center gives the target product **2c** and regenerates the Pd^{II} catalyst.

In addition, some applications of the synthesized products were investigated. One of the most important process is to transform the obtained nitroarenes to aromatic amine molecules, which are versatile intermediates and precursors in the preparation of dyes, pharmaceuticals, pigments, agrochemicals, and polymers.[23] According to reported methods,[24] some experiments were carried out to reduce the nitroarenes by adding Fe, Zn, and $NaBH_4$, respectively, to the system as a reductant through a one-pot manipulation when the nitration process was finished. However, the product mixture was complex, as observed by TLC, and further study is ongoing in our lab.



Scheme 1 Palladium-catalyzed nitration of 1,4-disubstituted 1,2,3-triazoles. *Reaction conditions*: compound **1** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), $NaNO_2$ (0.3 mmol), $K_2S_2O_8$(0.4 mmol) in DMSO (1.5 mL) at 120 °C for 18 h. Yield of isolated product after column chromatography.

In summary, we have described the palladium-catalyzed nitration of arenes through 1,2,3-triazole-directed C–H activation. The reaction allowed the nitration of a series of 1,4-disubstituted 1,2,3-triazoles with either electron-donating or electron-withdrawing groups directly and efficiently. The present protocol showed high regio- and chemoselectivity with good functional group tolerance, which may provide an appealing approach for the synthesis of valuable 1,2,3-triazoles derivatives with nitro group.



Scheme 2 Proposed mechanism

^{1}H and ^{13}C NMR spectra were recorded using Bruker AM-400 and Bruker AM-300 spectrometers in $CDCl_3$ with TMS as an internal standard. Mass spectra were obtained on a VG Auto Spec 3000 or a Finnigan MAT 90 instrument. IR spectra were obtained with KBr plates using a PerkinElmer Spectrum 1600 Series spectrometer. Melting points were obtained using a Büchi melting point apparatus and are uncorrected. Commercially obtained reagents were used without further purification. All reactions were monitored by TLC with HuanghaiGF 254 silica gel coated plates. Column chromatography was carried out using 300–400 mesh silica gel at medium pressure.

Palladium-Catalyzed C–H Nitration of 1,4-Disubstituted 1,2,3-Triazoles; Typical Procedure

1,4-Disubstituted 1,2,3-triazole **1** (0.2 mmol), $Pd(OAc)_2$ (4.5 mg, 0.02 mmol), $NaNO_2$ (21 mg, 0.3 mmol), $K_2S_2O_8$ (108 mg, 0.4 mmol), and DMSO (1.5 mL) were sequentially added to a 10 mL tube. Then the tube was sealed and stirred at 120 °C for18 h. Upon completion, H_2O (15 mL) was added to the mixture and extracted with EtOAc (3 × 15 mL). The combined organic layers were washed with brine (3 × 5 mL), dried (Na_2SO_4), and concentrated under reduced pressure to afford the crude product. Purification by column chromatography on silica gel afforded the desired product **2**.

4-(2-Nitrophenyl)-1-(*p*-tolyl)-1*H*-1,2,3-triazole (2a)

White solid; yield: 48 mg (86%); mp 128–130 °C.

IR (KBr): 3427, 2961, 1527, 1383, 1263, 1103, 1038, 753 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.20 (s, 1 H), 8.12 (d, *J* = 7.8 Hz, 1 H), 7.85 (d, *J* = 8.1 Hz, 1 H), 7.73–7.62 (m, 3 H), 7.53 (t, *J* = 7.8 Hz, 1 H), 7.34 (d, *J* = 7.9 Hz, 2 H), 2.44 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.2, 142.4, 139.2, 134.3, 132.5, 131.1, 130.2, 129.0, 124.4, 124.0, 121.0, 120.5, 21.1.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{13}N_4O_2$: 281.1033; found: 281.1036.

4-(2-Nitrophenyl)-1-(*o*-tolyl)-1*H*-1,2,3-triazole (2b)

Light yellow solid; yield: 45 mg (80%); mp 60–62 °C.

IR (KBr): 3440, 3147, 3080, 2961, 1923, 2860, 1616, 1527, 1459, 1303, 1261, 1099, 1035, 803, 765, 708 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.18 (d, *J* = 7.8 Hz, 1 H), 8.02 (s, 1 H), 7.87 (d, *J* = 8.1 Hz, 1 H), 7.72 (t, *J* = 7.6 Hz, 1 H), 7.54 (t, *J* = 7.7 Hz, 1 H), 7.47–7.35 (m, 4 H), 2.28 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.2, 141.7, 136.0, 133.7, 132.6, 131.5, 131.1, 130.1, 129.0, 126.9, 125.9, 124.6, 124.4, 124.1, 17.8.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{13}N_4O_2$: 281.1033; found: 281.1035.

4-(2-Nitrophenyl)-1-phenyl-1*H*-1,2,3-triazole (2c)[16f]

Yellow solid; yield: 40 mg (76%); mp 82–83 °C.

IR (KBr): 3435, 2961, 2826, 2359, 2068, 1604, 1462, 1381, 1262, 1097, 1036, 807, 674, 613, 552, 462 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.25 (s, 1 H), 8.13 (d, *J* = 7.7 Hz, 1 H), 7.87 (d, *J* = 8.0 Hz, 1 H), 7.79 (d, *J* = 7.7 Hz, 2 H), 7.71 (t, *J* = 7.6 Hz, 1 H), 7.55 (q, *J* = 7.4 Hz, 3 H), 7.48 (t, *J* = 7.4 Hz, 1 H).

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{14}H_{11}N_4O_2$: 267.0877; found: 267.0879.

1-(4-Methoxyphenyl)-4-(2-nitrophenyl)-1*H*-1,2,3-triazole (2d)

Yellow solid; yield: 49 mg (82%); mp 123–125 °C.

IR (KBr): 3441, 3021, 1599, 1518, 1358, 1303, 1171, 1097, 1036, 806, 749, 706 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.27–8.02 (m, 2 H), 7.85 (d, *J* = 8.1 Hz, 1 H), 7.69 (dd, *J* = 12.3, 8.2 Hz, 3 H), 7.53 (t, *J* = 7.7 Hz, 1 H), 7.05 (d, *J* = 8.5 Hz, 2 H), 3.88 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.9, 148.1, 142.4, 132.5, 131.0, 130.0, 129.0, 124.4, 124.0, 122.3, 121.1, 114.7, 55.6.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{13}N_4O_3$: 297.0982; found: 297.0985

4-(4-Methyl-2-nitrophenyl)-1-(*p*-tolyl)-1*H*-1,2,3-triazole (2e)

Light yellow solid; yield: 54 mg (92%); mp 138–140 °C.

IR (KBr): 3137, 2918, 1617, 1523, 1361, 1232, 1109, 1034, 918, 808, 758 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.17 (s, 1 H), 8.00 (d, *J* = 8.0 Hz, 1 H), 7.65 (d, *J* = 8.6 Hz, 3 H), 7.50 (d, *J* = 8.0 Hz, 1 H), 7.34 (d, *J* = 7.9 Hz, 2 H), 2.46 (d, *J* = 18.3 Hz, 6 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.0, 142.5, 139.8, 139.1, 134.4, 133.3, 130.9, 130.2, 124.3, 121.6, 120.8, 120.5, 21.1, 20.9.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{16}H_{15}N_4O_2$: 295.1190; found: 295.1193.

4-(4-Methyl-2-nitrophenyl)-1-(*o*-tolyl)-1*H*-1,2,3-triazole (2f)

White solid; yield: 47 mg (80%); mp 105–107 °C.

IR (KBr): 3427, 3147, 2961, 2923, 1610, 1523, 1380, 1262, 1099, 1034, 807, 708, 672 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.05 (d, *J* = 8.0 Hz, 1 H), 7.98 (s, 1 H), 7.67 (s, 1 H), 7.52 (d, *J* = 7.8 Hz, 1 H), 7.49 – 7.30 (m, 4 H), 2.49 (s, 3 H), 2.27 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.0, 141.8, 139.8, 138.1, 136.1, 133.7, 133.4, 131.5, 130.9, 130.0, 126.8, 126.0, 124.4, 121.6, 20.9, 17.8.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{16}H_{15}N_4O_2$: 295.1190; found: 295.1195.

4-(4-Methyl-2-nitrophenyl)-1-phenyl-1*H*-1,2,3-triazole (2g)

Yellow solid; yield: 46 mg (82%); mp 138–140 °C.

IR (KBr): 3446, 2963, 1615, 1517, 1384, 1346, 1262, 1095, 1030, 763 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.24 (s, 1 H), 8.02 (d, *J* = 8.0 Hz, 1 H), 7.69 (s, 2 H), 7.68–7.30 (m, 5 H), 2.50 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.1, 141.9, 139.9, 134.5, 133.4, 131.0, 130.8, 128.7, 127.7, 124.8, 124.4, 121.5, 20.9.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{15}H_{13}N_4O_2$: 281.1033; found: 281.1030.

1-(4-Methoxyphenyl)-4-(4-methyl-2-nitrophenyl)-1*H*-1,2,3-triazole (2h)

Light yellow solid; yield: 55 mg (88%); mp 165–167 °C.

IR (KBr): 3438, 2961, 1606, 1521, 1374, 1255, 1032, 700 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.12 (s, 1 H), 8.00 (d, *J* = 8.0 Hz, 1 H), 7.67 (d, *J* = 8.9 Hz, 3 H), 7.50 (d, *J* = 8.0 Hz, 1 H), 7.04 (d, *J* = 8.8 Hz, 2 H), 3.88 (s, 3 H), 2.48 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.9, 148.0, 142.5, 139.8, 133.3, 130.9, 130.1, 124.3, 122.3, 121.6, 121.0, 114.7, 55.6, 20.9.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{16}H_{15}N_4O_3$: 311.1139; found: 311.1137.

4-(4-Methoxy-2-nitrophenyl)-1-(*p*-tolyl)-1*H*-1,2,3-triazole (2i)

Yellow solid; yield: 53 mg (86%); mp 164–166 °C.

IR (KBr): 3426, 2961, 1621, 1421, 1274, 1155, 1076, 932, 723, 656, 601 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.14 (s, 1 H), 8.01 (d, *J* = 8.7 Hz, 1 H), 7.65 (d, *J* = 8.1 Hz, 2 H), 7.38–7.32 (m, 3 H), 7.23 (d, *J* = 8.7 Hz, 1 H), 3.92 (s, 3 H), 2.44 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.7, 148.8, 139.1, 134.5, 132.3, 130.2, 120.5, 118.9, 116.8, 109.1, 55.9, 21.1.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{16}H_{15}N_4O_3$: 311.1139; found: 311.1141.

1-(2-Bromophenyl)-4-(4-methyl-2-nitrophenyl)-1*H*-1,2,3-triazole (2j)

Light yellow solid; yield: 52 mg (72%); mp 138–139 °C.

IR (KBr): 3434, 2962, 1609, 1517, 1345, 1262, 1220, 1098, 1029, 806, 754 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.20 (s, 1 H), 8.03 (d, *J* = 7.9 Hz, 1 H), 7.79 (d, *J* = 8.0 Hz, 1 H), 7.69 (s, 1 H), 7.63 (d, *J* = 7.8 Hz, 1 H), 7.52 (d, *J* = 5.9 Hz, 2 H), 7.43 (t, *J* = 7.7 Hz, 1 H), 2.50 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.0, 141.8, 139.9, 136.2, 133.9, 133.4, 131.3, 131.1, 128.5, 128.1, 124.9, 124.4, 121.5, 118.6, 21.0.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{15}H_{12}BrN_4O_2$: 359.0138; found: 359.0140.

1-(2-Chlorophenyl)-4-(4-methyl-2-nitrophenyl)-1*H*-1,2,3-triazole (2k)

Light yellow solid; yield: 40 mg (63%); mp 143–145 °C.

IR (KBr): 3417, 3149, 2965, 1380, 1261, 1095, 1036, 868, 806, 682 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.22 (s, 1 H), 8.00 (d, *J* = 8.0 Hz, 1 H), 7.78 (d, *J* = 8.0 Hz, 2 H), 7.67 (s, 1 H), 7.58–7.49 (m, 3 H), 2.49 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.0, 142.7, 139.9, 136.7, 133.3, 130.9, 130.7, 129.7, 129.4, 128.9, 124.4, 121.5, 120.8, 120.6, 20.9.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{15}H_{12}ClN_4O_2$: 315.0643; found: 315.0645.

1-(2-Bromophenyl)-4-(2-nitrophenyl)-1*H*-1,2,3-triazole (2l)

Yellow solid; yield: 43 mg (63%); mp 88–90 °C.

IR (KBr): 3435, 2926, 2827, 2359, 2068, 1604, 1462, 1382, 1261, 1098, 806, 673, 557, 462 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.23 (s, 1 H), 8.16 (d, *J* = 7.8 Hz, 1 H), 7.88 (d, *J* = 8.1 Hz, 1 H), 7.79 (d, *J* = 8.0 Hz, 1 H), 7.73 (t, *J* = 7.6 Hz, 1 H), 7.63 (d, *J* = 7.9 Hz, 1 H), 7.54 (dd, *J* = 16.6, 8.2 Hz, 2 H), 7.44 (t, *J* = 7.7 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.2, 141.7, 136.1, 133.9, 132.6, 131.4, 131.2, 129.1, 128.5, 128.1, 125.1, 124.2, 124.1, 118.5.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{14}H_{10}BrN_4O_2$: 344.9982; found: 344.9986.

1-(3-Bromophenyl)-4-(2-nitrophenyl)-1*H*-1,2,3-triazole (2m)

White solid; yield: 45 mg (65%); mp 120–122 °C.

IR (KBr): 3427, 3141, 1590, 1526, 1463, 1373, 1232, 1097, 787, 746 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.25 (s, 1 H), 8.10 (d, *J* = 7.8 Hz, 1 H), 7.99 (s, 1 H), 7.88 (d, *J* = 8.1 Hz, 1 H), 7.72 (dd, *J* = 15.5, 7.9 Hz, 2 H), 7.66–7.48 (m, 2 H), 7.43 (t, *J* = 8.0 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.1, 142.9, 137.5, 132.6, 132.0, 131.0, 131.1, 129.3, 124.2, 124.0, 123.7, 123.3, 120.9, 119.1.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{14}H_{10}BrN_4O_2$: 344.9982; found: 344.9985.

4-(5-Bromo-2-nitrophenyl)-1-(2-bromophenyl)-1*H*-1,2,3-triazole (2n)

Light yellow solid; yield: 51 mg (60%); mp 132–134 °C.

IR (KBr): 3436, 2926, 2830, 2359, 2068, 1837, 1605, 1513, 1461, 1382, 1262, 1095, 1031, 811, 754, 671, 558, 463 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.37 (s, 1 H), 8.27 (s, 1 H), 7.82–7.77 (m, 2 H), 7.67 (d, *J* = 8.7 Hz, 1 H), 7.62 (s, 1 H), 7.54 (t, *J* = 7.6 Hz, 1 H), 7.45 (t, *J* = 7.5 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 146.7, 140.5, 136.0, 134.1, 134.0, 132.1, 131.5, 128.6, 128.1, 127.4, 126.1, 125.7, 125.7, 118.6.

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{14}H_9Br_2N_4O_2$: 422.9087; found: 422.9089.

1-(4-Chlorophenyl)-4-(2-nitrophenyl)-1*H*-1,2,3-triazole (2o)[16f]

Light yellow solid; yield: 46 mg (78%); mp 107–109 °C.

IR (KBr): 3435, 2925, 2841, 2359, 1604, 1514, 1463, 1383, 1347, 1222, 1103, 1070, 1027, 856, 749, 702, 660, 516, 458 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.27 (s, 1 H), 8.15 (d, *J* = 7.7 Hz, 1 H), 7.88 (d, *J* = 8.0 Hz, 1 H), 7.77–7.66 (m, 2 H), 7.61 (d, *J* = 3.4 Hz, 1 H), 7.59–7.34 (m, 3 H).

HRMS (ESI): *m*/*z* [M + H^+] calcd for $C_{14}H_{110}ClN_4O_2$: 301.0487; found: 301.0484.

1-(2-Chlorophenyl)-4-(2-nitrophenyl)-1*H*-1,2,3-triazole (2p)

Light yellow solid; yield: 40 mg (67%); mp 115–117 °C.

IR (KBr): 3435, 2926, 2724, 2359, 2068, 1837, 1603, 1384, 1263, 1097, 1036, 810, 674, 558, 468 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.23 (s, 1 H), 8.10 (d, *J* = 7.8 Hz, 1 H), 7.87 (d, *J* = 8.1 Hz, 1 H), 7.72 (dd, *J* = 17.3, 8.1 Hz, 3 H), 7.55 (t, *J* = 9.7 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.1, 142.8, 135.1, 134.8, 132.6, 131.1, 129.9, 129.3, 128.9, 126.2, 124.1, 124.0, 121.8, 120.9.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{14}H_{10}ClN_4O_2$: 301.0487; found: 301.0489.

4-(2-Fluoro-6-nitrophenyl)-1-(*p*-tolyl)-1*H*-1,2,3-triazole (2q)

Light yellow solid; yield: 50 mg (85%); mp 158–160 °C.

IR (KBr): 3431, 3260, 2860, 1632, 1572, 1357, 1301, 1272, 1196, 1032, 728, 706 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.26 (s, 1 H), 7.68 (d, *J* = 8.1 Hz, 3 H), 7.53 (dd, *J* = 13.6, 8.0 Hz, 1 H), 7.44 (t, *J* = 8.8 Hz, 1 H), 7.34 (t, *J* = 8.8 Hz, 2 H), 2.44 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 139.2, 134.3, 130.3, 130.1, 130.0, 122.1, 122.0, 120.5, 120.1, 120.0, 119.6, 119.4, 21.1.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{12}FN_4O_2$: 299.0939; found: 299.0936.

4-(2-Fluoro-6-nitrophenyl)-1-(4-methoxyphenyl)-1*H*-1,2,3-triazole (2r)

Light yellow solid; yield: 46 mg (73%); mp 155–157 °C.

IR (KBr): 3421, 3160, 2962, 1603, 1527, 1375, 1304, 1172, 1096, 1033, 738, 703 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.21 (s, 1 H), 7.69 (dd, *J* = 14.5, 8.5 Hz, 3 H), 7.53 (dd, *J* = 13.8, 7.6 Hz, 1 H), 7.44 (t, *J* = 8.8 Hz, 1 H), 7.06 (d, *J* = 8.4 Hz, 2 H), 3.89 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 160.0, 149.9, 136.3, 130.1, 130.0, 122.3, 122.2, 120.1, 120.0, 119.6, 119.4, 114.8, 55.6.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{12}FN_4O_3$: 315.0888; found: 315.0886.

1-(2-Chlorophenyl)-4-(2-methyl-6-nitrophenyl)-1*H*-1,2,3-triazole (2s)

Light yellow solid; yield: 45 mg (71%); mp 140–142 °C.

IR (KBr): 3427, 3150, 2975, 1388, 1251, 1085, 1026, 865, 801, 662 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 (s, 1 H), 7.80–7.61 (m, 2 H), 7.56–7.48 (m, 2 H), 7.45–7.38 (m, 3 H), 2.29 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.8, 140.9, 140.8, 134.6, 134.2, 130.9, 130.7, 129.3, 128.6, 128.0, 127.8, 125.2, 123.8, 121.5, 20.7.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{12}ClN_4O_2$: 315.0643; found: 315.0645.

1-(3-Bromophenyl)-4-(2-methyl-6-nitrophenyl)-1*H*-1,2,3-triazole (2t)

Light yellow solid; yield: 52 mg (72%); mp 160–162 °C.

IR (KBr): 3416, 2951, 1611, 1431, 1254, 1145, 1026, 932, 726 636, 600 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.99 (s, 1 H), 7.93 (t, *J* = 1.8 Hz, 1 H), 7.68 (dd, *J* = 11.6, 4.7 Hz, 2 H), 7.50 (dd, *J* = 16.0, 7.8 Hz, 2 H), 7.38 (dt, *J* = 18.9, 8.0 Hz, 2 H), 2.26 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.7, 141.9, 140.7, 137.6, 134.2, 131.9, 131.1, 129.4, 123.5, 123.5, 123.3, 121.5, 121.0, 118.9, 20.7.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{15}H_{12}BrN_4O_2$: 359.0138; found: 359.0140.

4-(2-Methyl-6-nitrophenyl)-1-(*p*-tolyl)-1*H*-1,2,3-triazole (2u)

White solid; yield: 48 mg (81%); mp 104–106 °C.

IR (KBr): 3417, 3127, 2941, 2925, 1609, 1522, 1381, 1263, 1100, 1031, 802, 706, 662 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.94 (s, 1 H), 7.62 (dd, *J* = 18.1, 8.3 Hz, 3 H), 7.47 (d, *J* = 7.5 Hz, 1 H), 7.38 (t, *J* = 7.9 Hz, 1 H), 7.26 (d, *J* = 8.2 Hz, 2 H), 2.36 (s, 3 H), 2.27 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.8, 141.5, 140.8, 139.0, 134.4, 134.1, 130.2, 129.2, 123.9, 121.3, 121.1, 120.4, 21.0, 20.7.

HRMS (ESI): *m*/*z* [M + H$^+$] calcd for $C_{16}H_{15}N_4O_2$: 295.1190; found: 295.1195.

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Supporting Information

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