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Graphical Abstract

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One-Pot Synthesis of [1,2,4]Triazolo[1,5-*a*]pyridines from Azines and Benzylidenemalononitriles via Copper-Catalyzed Tandem Cyclization

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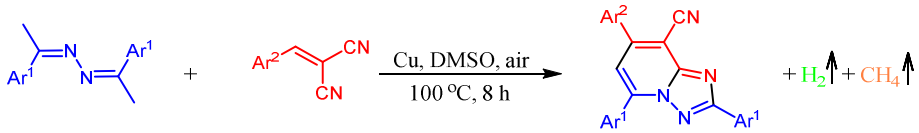
[a]*Department of Chemistry, Innovative Drug Research Center, Shanghai University, Shanghai 200444, China*
[b]*Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Science, Shanghai 200032, China*



tandem reaction
C-C and sp^3 C-H scission
blue fuorescence

28 examples,
up yo 78% yield

Tetrahedron
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One-Pot Synthesis of [1,2,4]Triazolo[1,5-*a*]pyridines from Azines and Benzylidenemalononitriles *via* Copper-Catalyzed Tandem Cyclization

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[a]*Department of Chemistry, Innovative Drug Research Center, Shanghai University, Shanghai 200444, China*
[b]*Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Science, Shanghai 200032, China*

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ABSTRACT

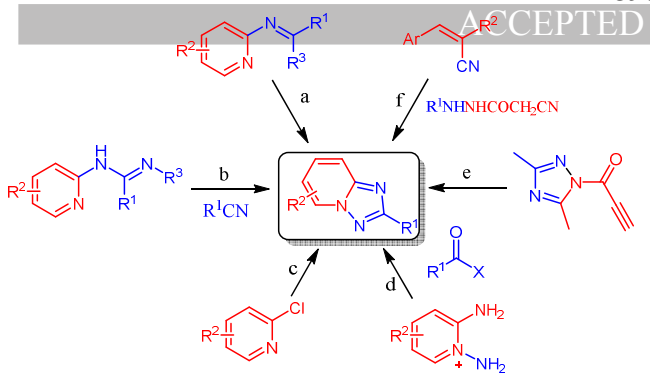
A simple and efficient copper-catalyzed tandem radical cyclization reaction has been discovered for the synthesis of triaryl [1,2,4]triazolo[1,5-*a*]pyridines from easily accessible azines and benzylidenmalononitriles. The new transformation involves multiple C-H/C-C bonds cleavage and C-C/C-N bonds formation, with extrusion of gaseous hydrogen and methane. A wide variety of substrates with different functional groups could be converted into the corresponding products in good yields. The fused heterocycles have strong blue fluorescence with large Strokes shifts and high quantum yields.

1. Introduction

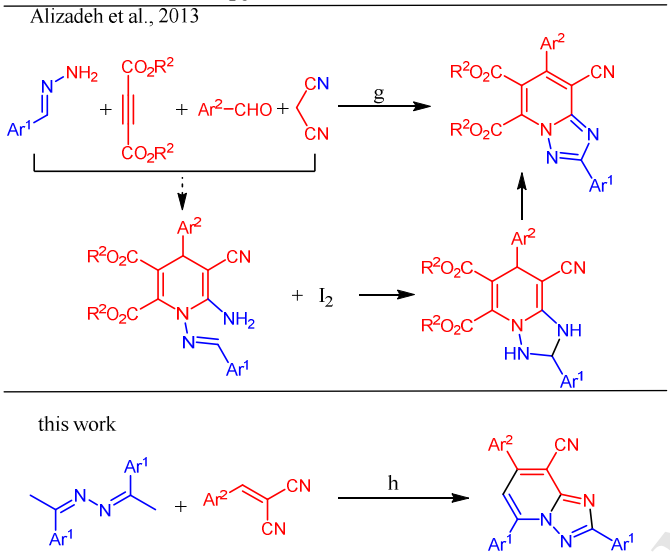
Triazolopyridines represent an important class of nitrogen-rich heterocyclic aromatic compounds. The 1,2,4-triazole unit can be found in numerous molecules with various biological activities, including kinase inhibitor[1], antibacterial[2], and antioxidative[3]. Their applications in material chemistry and other fields have been also explored.[4] During the past decades, a number of synthetic routes to construct [1,2,4]triazolo[1,5-*a*]pyridines had been revealed. Based on different available raw materials, the syntheses can be divided into three main strategies: 1) pyridines and their derivatives; 2) triazoles and their derivatives; 3) multiple components. Representative examples included oxidative cyclization of pyridylimidamides[5a-j] or guanidyl pyridines (**Scheme 1**, route a),[5k] tandem addition/cyclization of 2-aminopyridines with nitriles catalyzed by aluminium trichloride,[6a] copper catalysts[6b-d] (**Scheme 1**, route b), coupling reactions of 2-chloropyridines with thiadiazoles (**Scheme 1**, route c),[7] cyclization of aliphatic and aromatic acids or their derivatives with 1,2-diaminopyridium salts generated by reacting 2-amninopyridines with hydroxylamine-*O*-sulfonic acid (**Scheme 1**, route d),[8] pyrolysis/cyclization of triazole functionalized with an alkynyl group (**Scheme 1**, route e).[9] A majority of conventional protocols chose easily available aminopyridines and their derivatives as the initial synthetic point to establish the adjacent triazole nucleus by forming one or two new bonds. Direct approaches to simultaneously construct both pyridine and triazole moieties within one channel had been rarely reported due to the complexity and efficiency of forming multiple bonds.[10] For instance, condensation of arylmethylenemalononitriles with cyanoacetohydrazides led to a range of highly substituted triazolopyridines (**Scheme 1**, route f).[11] In 2013, Alizadeh and his co-workers studied on the one-pot synthesis of [1,2,4]triazolo[1,5-*a*]pyridines through the iodine-catalyzed multi-component reactions from four acyclic fragments, namely dimethyl acetylenedicaroxylate, benzylidenehydrazines, aryl aldehydes and malononitrile (**Scheme 2**, route g).[11e] Whereas only alkynes with strong electron deficient groups can be applied in this method, the new strategy could directly introduce multi-functionalities into triazolopyridines *via* a sequential 1,4-dihydropyridine construction and C–N bond formation in the presence of molecular iodine.

2. Results and discussion

Based on our previous experiences in radical synthesis of heterocycles,[12] herein we report on an efficient copper-catalyzed one-pot elaboration of multi-substituted [1,2,4]triazolo[1,5-*a*]pyridines from readily accessible azines and benzylidenemalononitriles (**Scheme 2**, route h).



Scheme 1 Typically traditional synthetic routes to [1,2,4]Triazolo[1,5-*a*]pyridines.



Scheme 2 One-pot synthesis of [1,2,4]Triazolo[1,5-*a*]pyridines.

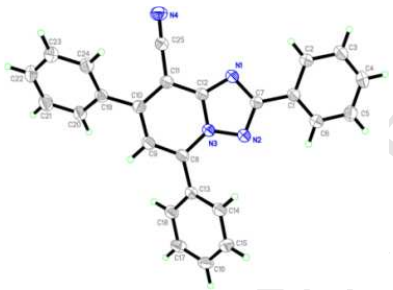
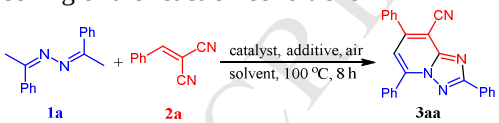


Fig. 1 X-ray Crystallographic Structure of 3aa.

We chose (1*E*, 2*E*)-1,2-bis(1-phenylethylidene)hydra-zine (**1a**, 0.5 mmol) and 2-benzylidenemalononitrile (**2a**, 1.0mmol) as starting materials in our initial reaction optimization (**Table 1**). Various azines and benzylidenmalononitriles can be easily obtained from arylketones with hydrazines, and arylaldehydes with malononitrile respectively (see in supporting information). In the presence of CuCl (0.1 mmol) using dry DMSO (10mL) as solvent under air atmosphere, 2,5,7-triphenyl-[1,2,4]-triazolo[1,5-*a*]pyridine-8-carbonitrile (**3aa**) was obtained in 66% isolated yield at 100 °C after 8 h (**Table 1**, entry 1). The structure of **3aa** was unambiguously confirmed by single crystal X-ray diffraction analysis (**Fig. 1**)[13]. Notably, the reaction hardly took place without the copper catalyst (**Table 1**, entry 2). While other copper catalysts were also applicable, copper powder was found to be the best for the reaction, affording **3aa** in 74% yield (**Table 1**, entries 3-5). Other common solvents such as NMP, toluene, DMF, 1,4-dioxane, acetic acid or pyridine could not achieve comparable results as DMSO (**Table 1**, entries 6-11). The reaction was not further improved by adding molecular sieves, but the yield was slightly decreased by other additives such as *m*-CPBA and 1,10-phenanthroline (**Table 1**, entries 12-14). Water and even mild base K_2CO_3 dramatically affected the reaction (**Table 1**, entries 15-16). Reducing catalyst loadings lowered the yield, but the increasement could not further improve the conversion (**Table 1**, entries 17-18). Oxygen was important to this catalytic system, by contrast, the desired product was obtained in only 22% yield under N_2 atmosphere (**Table 1**, entries 19-20). The optimal condition for this multi-component reaction was therefore established as fellows: **1a** (0.5 mmol), **2a** (1.0 mmol), Cu (0.1 mmol) in dry DMSO (10 mL) at 100 °C for 8 h under air (**Table 1**, entry 3).

Table 1

Screening of the reaction conditions[a]



1a 2a 3aa

Entry	Catalyst (mmol)	Additive	Solvent	Yield[b](%)
1	CuCl (0.1)	—	DMSO	66
2	—	—	DMSO	Trace
3	Cu (0.1)	—	DMSO	74
4	CuI (0.1)	—	DMSO	47
5	Cu_2O (0.1)	—	DMSO	66
6	Cu (0.1)	—	NMP	17
7	Cu (0.1)	—	Toluene	Trace
8	Cu (0.1)	—	DMF	50
9	Cu (0.1)	—	Dioxane	10
10	Cu (0.1)	—	HOAc	10
11	Cu (0.1)	—	Pyridine	Trace
12	Cu (0.1)	*m*-CPBA	DMSO	62
13	Cu (0.1)	4Å-MS	DMSO	73
14	Cu (0.1)	Phen	DMSO	53
15	Cu (0.1)	K_2CO_3	DMSO	Trace
16	Cu (0.1)	H_2O	DMSO	30
17	Cu (0.05)	—	DMSO	52
18	Cu (0.15)	—	DMSO	71
19[c]	Cu (0.1)	O_2	DMSO	61
20[d]	Cu (0.1)	N_2	DMSO	22

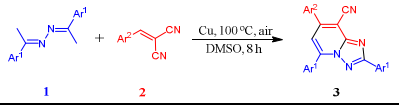
a) Reaction conditions: **1a** (0.5 mmol), **2a** (1.0 mmol), solvent (10 mL), 100 °C, 8 h, under air atmosphere. b) Isolated yields of **3aa** based on **1a**. c) Under oxygen atmosphere. d) Under nitrogen atmosphere.

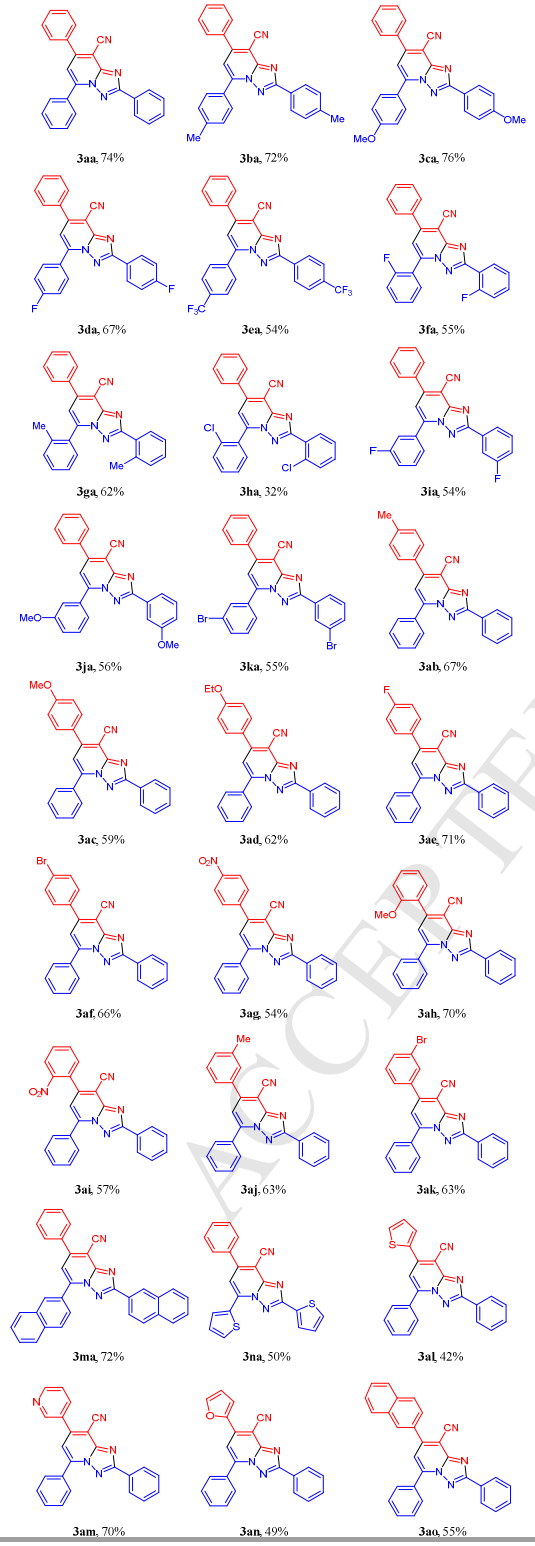
With the optimized reaction conditions in hand, we further investigated the applicability of this new catalytic reaction with a broad spectrum of substrates (**Table 2**). In general, azines bearing electron-donating groups on the *para* positions of the phenyl rings led to higher yields than those bearing electron-withdrawing groups (**Table 2**, **3aa-3ea**). Azines that contains nitro substituent would inhibit the reaction, however, benzylidenmalononitriles bearing strongly electron-withdrawing nitro group could still give the desired products in moderate yields (**3ag** and **3ai**). Lower yields were observed when *ortho*- and *meta*-substituted azines were used (**3fa-3ka**), probably due to steric effects. Furthermore, Naphthalyl and even heterocyclic substances were also tolerated in this reaction (**3ma-3ao**). It is worth noting that different halogenated triazolopyridines could be easily realized from this method, which are interesting intermediates and building blocks for synthesis of complicated heterocycles (**3da, 3fa**, **3ka**, **3ae**,

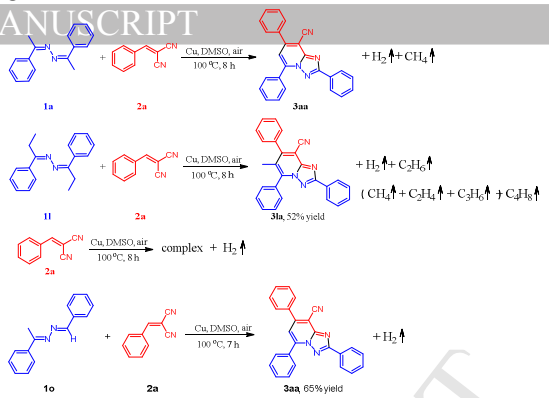
3af, and **3ak**). In addition, these products were strongly blue emissive under UV light (**Fig. 2**, †ESI). The facts that the resulting multiarylated triazolopyridines are characterized in high fluorescence quantum yield and stokes shift indicate that they have great potential as fluorescent probes in medical applications (**Fig. S7-S31**, †ESI).

Table 2

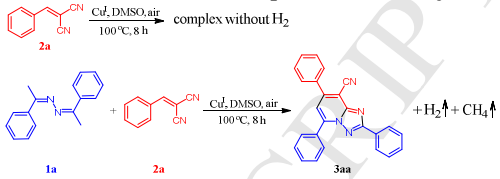
Synthesis of triarylated [1,2,4] triazolo[1,5-*a*]pyridines[a]



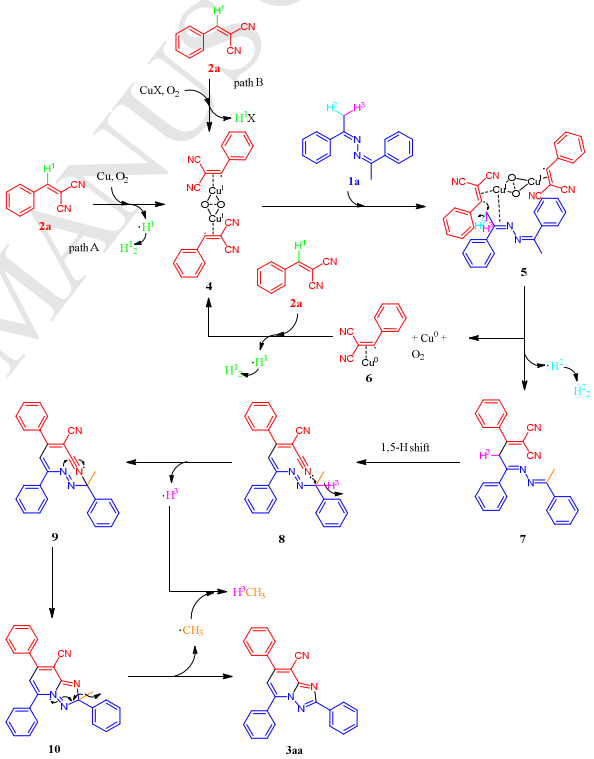




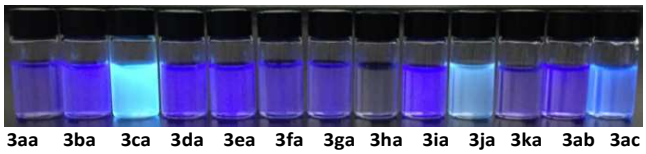
Scheme 3 Controlled experiments catalyzed by Cu^0.



Scheme 4 Controlled experiments catalyzed by Cu^I.



Scheme 5 Proposed Reaction Mechanism for The One-Step Synthesis of [1,2,4]Triazolo[1,5-*a*]pyridines Catalyzed by Copper



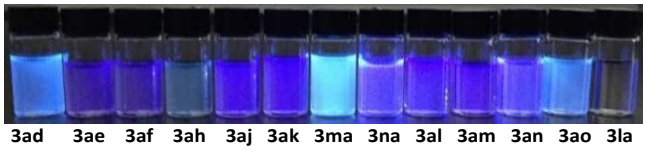


Fig. 2 Photographs of products (0.5×10^{-4} M) in MeCN upon illumination with a UV lamp (~365 nm).

A series of controlled experiments by the assistance of gas chromatography analysis were carried out to gain some insight into the mechanism (**Scheme 3** and **4**). When TEMPO was added into the reaction system, no desired products were observed. This result indicated the reaction probably involved a free radical process. Furthermore, gaseous hydrogen and methane were detected by GC from the reaction mixture (**Scheme 3** and **Scheme S3-S8** , †ESI).[14] Both Cu^0 species and Cu^I species were detected from reactions that catalyzed by Cu or CuCl by using X-ray photoelectron spectroscopy (**XPS**, **Fig. S3-S6,** †ESI).[15] When ethyl-substituted azine **1l** was applied to the reaction system, which was derived from propiophenone and hydrazine, the corresponding product **3la** was obtained in 52% yield (**Scheme 3**) and the structure was confirmed by single crystal **X-ray** diffraction analysis.[16] Hydrogen, methane, ethane, ethylene, propylene and isobutene were all detected by GC from this reaction (**Scheme 3**, †ESI), which implies the presence of ethyl radical during the whole process. The *in-situ* generated hydrogen and ethyl radicals could induce various free radical fragments and the corresponding coupling products.[17] When asymmetrical substrate **1o** was employed to the reaction with **2a**, the product **3aa** was obtained in 65% yield (**Scheme 3**). It was surprised to find that H_2 was detected only from the reaction of Cu^0 and **2a**. On the contrary, GC could not observe any hydrogen from the reaction of CuCl with **2a** (**Scheme 4**, †ESI).

As depicted in **Scheme 5**, we propose a radical mechanism for this one-pot process based on the above findings from the controlled experiments. Initially, an active Cu^I–oxygen olefin-chelate complex **4** was formed from Cu^0 and benzylidenemalononitrile in the presence of oxygen by releasing hydrogen.[18] However, hydride was produced instead of hydrogen in the reaction using Cu^I catalysts. Azine **1a** is then attacked by **4**, generating the intermediate **7** through the activation of $C(sp^3)$-H bond forming a new C-C bond.[19] Meanwhile, Cu^I is transformed into Cu^0 which then reacts with **2a** to regenerate complex **4**.[20] A 1,5-H shift process occurs to give intermediate **8,**[21] which undergoes a tandem addition/cyclization reaction affording **10**, from which two new C–N bonds are formed. The final product is generated from **10** by extruding a methyl radical forming methane in the end.[22]

3. Conclusion

In conclusion, we have developed a novel copper-catalyzed tandem radical cyclization of azines with benzylidenemalononitriles, wherein one new C–C bond and two new C–N bonds are constructed within one step. The highly practical one-pot process provides a simple and efficient route to multi-functionalized [1,2,4]triazolo[1,5-*a*]pyridines from easily accessible raw materials. GC analysis confirmed the by-products of gaseous hydrogen and methane from the reaction. An appropriate mechanism was proposed based on the controlled experiments and analytical results. The resulting triarylated triazolopyridines have great potential as fluorescent probes in medical applications due to their strong blue fluorescence with large Strokes shifts and high quantum yields. Further evaluation of this one-pot method for the synthesis of even more complicated heterocycles as well as the investigation of their applications in medical chemistry and material science is ongoing. Further exploration of the detailed reaction development and application researsh is currently in progress.

4. Experimental section

4.1 General

All reactions were performed in oven-dried glassware. Solvents were distilled prior to use. Analytical thin layer chromatography (TLC) was performed on pre-coated silica gel 60 F254 plates. Visualization on TLC was achieved by the use of UV light (254 nm, 365 nm). Chromatographic separations were performed using Biotage Flash Isolera Prime RP-LC. IR spectra were recorded on a Nicolet AVATAR 370 spectrometer. All ^1H, ^{19}F and ^{13}C NMR were recorded in $CDCl_3$ or DMSO-d_6 or CD_2Cl_2 at 25 ºC on a Bruker AM500 spectrometers. 1H NMR chemical shifts were determined relative to the signal of the residual protonated solvent. ^{13}C NMR chemical shifts were determined relative to internal TMS at δ 0.0. Data for ^1H, ^{13}C and ^{19}F NMR are recorded as follows: chemical shift (δ, ppm), multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet, q = quartet, br = broad). High-resolution mass data were recorded on a high–resolution mass spectrometer in the MALDL mode. The absolute configurations of **3aa** and **3la** were assigned by the X-ray analysis. UV spectra were recorded on a UV-2501PC spectrometer. Fluorescence spectra were recorded on a Shimadzu RF-5310 spectrometer. X-ray photoelectron spectra were obtained by using Thermo Scientific Escalab 250Xi X-ray photoelectron spectrometer. Gas qualitative appraisals were performed on Ke Chuang GC9800(N)TH gas chromatograph and Agilent HP6890 gas chromatograph.

4.2 General procedure for Synthsis of [1,2,4]Triazolo[1,5-*a*]pyridines.To a dry 25 mL round-bottom flask was added azine (0.5 mmol), propanedinitrile (1.0 mmol), Cu (0.1 mmol), dry dimethylsulfoxide (10 mL) respectively. The reaction was stirred at 100 ºC for 8 h. The solvent was removed under reduced pressure, and the residue was subject to column chromatograph (petroleum ether/dichloromethane) to give the pure product.

4.2.1 *2,5,7-triphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3aa**): white solid, 74% yield (0.1376 g), m.p. 201.6-202.3 ºC; ^1H NMR (500 MHz, $CDCl_3$) δ 8.41 – 8.34 (m, 2H), 8.16 – 8.10 (m, 2H), 7.79 – 7.73 (m, 2H), 7.65 – 7.60 (m, 3H), 7.60 – 7.53 (m, 3H), 7.52 – 7.45 (m, 3H), 7.27 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.61, 152.48, 149.18, 143.80, 135.85, 131.34, 130.96, 130.68, 130.29, 129.97, 129.51, 129.21, 128.80, 128.68, 128.64, 127.88, 114.74, 114.64, 96.61; UV-vis (CH_3CN) λ_{max} /nm 264, 334; FT-IR ν/cm^{-1} (KBr): 3053, 2218, 1607, 1526, 1493, 1441, 1385, 1322, 1290, 1224, 767, 730, 692; MALDI-FTICR MS m/z Calcd for $C_{25}H_{16}N_4$ M 372.1375, Found 372.1374.

4.2.2 *7-phenyl-2,5-di-p-tolyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ba**): white solid, 72% yield (0.1440 g), m.p. 224.7-225.1ºC; ^1H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, *J* = 8.2 Hz, 2H), 8.04 (d, *J* = 8.2 Hz, 2H), 7.77 – 7.73 (m, 2H), 7.61 – 7.52 (m, 3H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.29 (d, *J* = 8.0 Hz, 2H), 7.23 (s, 1H), 2.50 (s, 3H), 2.43 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.62, 152.50, 149.00, 143.84, 141.92, 140.87, 136.00, 130.18, 129.48, 129.44, 129.35, 129.16, 128.67, 128.13, 127.81, 127.24, 114.82, 114.19, 96.01, 21.64, 21.60; UV-vis (CH_3CN) λ_{max} /nm 268, 339; FT-IR ν/cm^{-1} (KBr): 3024, 2908, 2858, 2216, 1607, 1498, 1445, 1377, 1282, 1176, 1114, 822, 754, 694; MALDI-

FTICR MS m/z Calcd for $C_{27}H_{20}N_4$ $[M+H]^+$ 401.1761, Found 401.1767.

4.2.3 *2,5-bis(4-methoxyphenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ca**): white solid, 76% yield (0.1642 g), m.p. 221.9-222.1 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.27 (d, *J* = 8.6 Hz, 2H), 8.12 (d, *J* = 8.7 Hz, 2H), 7.73 (d, *J* = 6.6 Hz, 2H), 7.62 – 7.49(m, 3H), 7.16 (s, 1H), 7.07 (d, *J* = 8.7 Hz, 2H), 6.96 (d, *J* = 8.6 Hz, 2H), 3.91 (s, 3H), 3.85 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.21, 161.93, 161.58, 152.56, 148.81, 143.32, 136.05, 131.20, 130.08, 129.34, 129.09, 128.64, 123.11, 122.59, 114.95, 114.11, 113.94, 113.50, 95.17, 55.53, 55.33; UV-vis (CH_3CN) λ_{max} /nm 274, 350; FT-IR ν/cm^{-1} (KBr): 3050, 3004, 2220, 1606, 1501, 1450, 1295, 1250, 1171, 1117, 1014, 834, 763, 699 ; MALDI-FTICR MS m/z Calcd for $C_{27}H_{20}N_4O_2$ M 432.1586, Found 432.1589.

4.2.4 *2,5-bis(4-fluorophenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3da**): white solid, 67% yield (0.1367 g), m.p. 243.4-243.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.36 (dd, *J* = 8.5, 5.5 Hz, 2H), 8.14 (dd, *J* = 8.7, 5.3 Hz, 2H), 7.80 – 7.71 (m, 2H), 7.65 – 7.54 (m, 3H), 7.31 (t, *J* = 8.5 Hz, 2H), 7.25 (s, 1H), 7.18 (t, *J* = 8.7 Hz, 2H); ^{19}F NMR (470 MHz, DMSO-d_6) δ -108.49, -109.74; ^{13}C NMR (125 MHz, DMSO-d_6) δ164.15 (d, J_{FC} = -240.7 Hz), 164.12 (d, J_{FC} = -250.1 Hz), 163.61, 152.56, 149.68, 142.85, 135.95, 133.01 (d, J_{FC}= 8.9 Hz), 130.79, 130.06 (d, J_{FC}= 8.9 Hz), 129.49, 129.48, 127.50 (d, J_{FC} = 3.3 Hz), 126.68 (d, J_{FC} = 2.7 Hz), 116.62 (d, J_{FC} = 21.9 Hz), 116.16 (d, J_{FC} = 22.0 Hz), 115.78, 115.41, 96.02; UV-vis (CH_3CN) λ_{max} /nm 264, 335; FT-IR ν/cm^{-1} (KBr): 3075, 2227, 1606, 1501, 1450, 1232, 1158, 840, 760, 695; MALDI-FTICR MS m/z Calcd for $C_{25}H_{14}F_2N_4$ $[M+H]^+$ 409.1259, Found 409.1259.

4.2.5 *7-phenyl-2,5-bis(4-(trifluoromethyl)phenyl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ea**): white solid, 54% yield (0.1372 g), m.p. 230.6-231.0°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 (d, *J* = 8.1 Hz, 2H), 8.24 (d, *J* = 8.2 Hz, 2H), 7.90 (d, *J* = 8.2 Hz, 2H), 7.80 – 7.72 (m, 4H), 7.64 – 7.56 (m, 3H), 7.35 (s, 1H); ^{19}F NMR (470 MHz, DMSO-d_6) δ -62.80, -62.99; ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.38, 151.36, 148.57, 141.24, 134.28, 133.04 (d, J_{FC} = 1.3 Hz), 132.10 (q, J_{FC}= 33.0 Hz), 132.04 (d, J_{FC} = 1.2 Hz), 131.44 (q, J_{FC} = 32.5 Hz), 129.63, 128.93, 128.90, 128.33, 127.61, 127.10, 124.83 (q, J_{FC} = 3.8 Hz), 124.63 (q, J_{FC} = 3.7 Hz), 122.90 (q, J_{FC} = -272.4 Hz), 122.56 (q, J_{FC} = -272.6 Hz), 114.64, 113.13, 96.82; UV-vis (CH_3CN) λ_{max} /nm 263, 331; FT-IR ν/cm^{-1} (KBr): 3460, 2224, 1617, 1533, 1446, 1326, 1247, 1171, 1114, 1063, 1010, 846, 773, 700; MALDI-FTICR MS m/z Calcd for $C_{27}H_{14}F_6N_4$ M 508.1123, Found 508.1125.

4.2.6 *2,5-bis(2-fluorophenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3fa**): white solid, 55% yield (0.1122 g), m.p. 226.6-227.0 °C;^{1}H NMR (500 MHz, $CDCl_3$) δ 8.32 (td, *J* = 7.6, 1.7 Hz, 1H), 7.98 (td, *J* = 7.6, 1.7 Hz, 1H), 7.80 – 7.74 (m, 2H), 7.64 – 7.54 (m, 4H), 7.49 – 7.43 (m, 1H), 7.39 (td, *J* = 7.7, 1.1 Hz, 1H), 7.35 (d, *J* = 1.4 Hz, 1H), 7.34 – 7.30 (m, 1H), 7.28 (td, *J* = 7.7, 1.1 Hz, 1H), 7.23 – 7.17 (m, 1H); ^{19}F NMR (470 MHz, DMSO-d_6) δ -110.59, -110.71; ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.25 (d, J_{FC} = 5.0 Hz), 160.94 (d, J_{FC} = 257.0 Hz), 160.05 (d, J_{FC} = 253.4 Hz), 151.44, 149.11, 138.58 (d, J_{FC} = 1.2 Hz), 135.57, 133.15 (d, J_{FC} = 8.7 Hz), 132.11 (d, J_{FC} = 8.4 Hz), 131.46 (d, J_{FC} = 14.6 Hz), 131.45 (d, J_{FC} = 13.9 Hz), 130.43, 129.25, 128.76, 124.36 (d, J_{FC} = 21.0 Hz), 124.33 (d, J_{FC} = 21.1 Hz), 118.94 (d, J_{FC} = 13.2 Hz), 118.21 (d, J_{FC} = 11.2 Hz), 116.81 (d, J_{FC} = 3.9 Hz), 116.63 (d, J_{FC} = 21.4 Hz), 116.58 (d, J_{FC} = 21.6 Hz), 114.34, 97.59; UV-vis (CH_3CN) λ_{max} /nm 258, 327; FT-IR ν/cm^{-1} (KBr): 3070, 2224, 1614, 1579, 1530, 1598, 4181, 1316, 1227, 751, 698; MALDI-FTICR MS m/z Calcd for $C_{25}H_{14}F_2N_4$ M 408.1187, Found 408.1176.

4.2.7 *7-phenyl-2,5-di-o-tolyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ga**): white solid, 62% yield (0.1240 g), m.p. 182.7-183.1°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ8.19 – 8.15 (m, 1H), 7.80 – 7.76(m, 2H), 7.61 – 7.55 (m, 3H), 7.52 – 7.46 (m, 2H), 7.42 (d, *J* = 7.7 Hz, 1H), 7.40 – 7.35 (m, 1H), 7.33 (m, 1H), 7.29 (m, 2H), 7.15 (s, 1H), 2.64 (s, 3H), 2.29 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.80, 151.06, 148.93, 144.70, 138.20, 137.54, 135.76, 131.31, 131.23, 130.72, 130.68, 130.61, 130.31, 129.96, 129.76, 129.21, 129.17, 128.77, 126.04, 125.84, 115.70, 114.57, 96.94, 21.94, 20.11; UV-vis (CH_3CN) λ_{max} /nm 260, 325; FT-IR ν/cm^{-1} (KBr); 3060, 2958, 2856, 2221, 1616, 1532, 1596, 1451, 1309, 1286, 768, 732, 699; MALDI-FTICR MS m/z Calcd for $C_{27}H_{20}N_4$ M 400.1688, Found 400.1679.

4.2.8 *2,5-bis(2-chlorophenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ha**): white solid, 32% yield (0.0706 g), m.p. 166.5-167.0 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, *J* = 6.6 Hz, 1H), 7.79 (d, *J* = 6.3 Hz, 2H), 7.69 (d, *J* = 7.2 Hz, 1H), 7.65 – 7.55 (m, 4H), 7.54 (t, *J* = 7.7 Hz, 1H), 7.49 (m, 2H), 7.38 (m, 2H), 7.31 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.33, 151.07, 149.08, 141.40, 135.52, 133.81, 133.68, 132.49, 132.07, 131.48, 131.05, 130.72, 130.48, 130.42, 130.12, 129.27, 128.80, 127.05, 126.73, 116.90, 114.23, 97.96; UV-vis (CH_3CN) λ_{max} /nm 257, 321; FT-IR ν/cm^{-1} (KBr): 3060, 2226, 1608, 1524, 1425, 1316, 1042, 746, 695; MALDI-FTICR MS m/z Calcd for $C_{25}H_{14}C_{l2}N_4$ M 440.0596, Found 440.0585.

4.2.9 *2,5-bis(3-fluorophenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ia**): white solid, 54% yield (0.1102 g), m.p. 232.6-232.7 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.19 – 8.13 (m, 1H), 8.05 (ddd, *J* = 9.7, 2.5, 1.5 Hz, 1H), 7.93 – 7.85 (m, 2H), 7.79 – 7.73 (m, 2H), 7.64 – 7.54 (m, 4H), 7.47 (m, 1H), 7.34 (tdd, *J* = 8.4, 2.5, 0.8 Hz, 1H), 7.31 (s, 1H), 7.22 – 7.15 (m, 1H); ^{19}F NMR (470 MHz, DMSO-d_6) δ -112.11, -113.23; ^{13}C NMR (125 MHz, CD_2Cl_2) δ 164.37 (d, J_{FC} = 3.1 Hz), 163.05 (d, J_{FC} = 245.3 Hz), 162.54 (d, J_{FC} = 246.7 Hz), 152.47, 149.55, 142.39 (d, J_{FC} = 2.6 Hz), 135.69, 132.69 (d, J_{FC} = 8.5 Hz), 132.18 (d, J_{FC}= 8.5 Hz), 130.61 (d, J_{FC} = 8.3 Hz), 130.52 (d, J_{FC} = 8.2 Hz), 130.46, 129.19, 128.71, 125.37 (d, J_{FC} = 3.1 Hz), 123.49 (d, J_{FC} = 3.0 Hz), 118.31 (d, J_{FC} = 21.1 Hz), 117.60 (d, J_{FC} = 21.2 Hz), 116.63 (d, J_{FC} = 24.2 Hz), 115.48, 114.45 (d, J_{FC} = 23.5 Hz), 114.38, 97.30; UV-vis (CH_3CN) λ_{max} /nm 264, 332; FT-IR ν/cm^{-1} (KBr); 3062, 2226, 1613, 1583, 1527, 1468, 1431, 1377, 1318, 1240, 1205, 865, 791, 756, 689; MALDI-FTICR MS m/z Calcd for $C_{25}H_{14}F_2N_4$ M 408.1187, Found 408.1177.

4.2.10 *2,5-bis(3-methoxyphenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ja**): white solid, 56% yield (0.1210 g), m.p. 185.1-185.2 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 – 7.94 (m, 1H), 7.91 (dd, *J* = 2.5, 1.4 Hz, 1H), 7.79 – 7.74 (m, 2H), 7.74 – 7.70 (m, 1H), 7.67 – 7.62 (m, 1H), 7.62 – 7.54 (m, 3H), 7.51 (t, *J* = 8.0 Hz, 1H), 7.39 (t, *J* = 7.9 Hz, 1H), 7.28 (s, 1H), 7.15 (m, 1H), 7.03 (m, 1H), 3.92 (s, 3H), 3.92 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.46, 159.85, 159.64, 152.45, 149.16, 143.59, 135.83, 132.06, 131.28, 130.31, 129.89, 129.74, 129.22, 128.69, 121.80, 120.34, 117.17, 117.12, 114.97, 114.81, 114.63, 112.48, 96.65, 55.57, 55.49; UV-vis (CH_3CN) λ_{max} /nm 263, 338; FT-IR ν/cm^{-1} (KBr): 3050, 3004, 2936, 2840, 2220, 1610, 1501, 1450, 1384, 1495, 1250, 1171, 1117, 1024, 834, 763, 699; MALDI-FTICR MS m/z Calcd for $C_{27}H_{20}N_4O_2$ M 432.1586, Found 432.1577.

4.2.11 *2,5-bis(3-bromophenyl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ka**): white solid, 55% yield (0.1458 g), m.p. 257.5-257.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.51 (t, J = 1.7 Hz, 1H), 8.32 – 8.28 (m, 1H), 8.19 (t, *J* = 1.8 Hz, 1H), 8.08 (ddd, *J* = 7.9, 1.7, 1.0 Hz, 1H), 7.79 – 7.74 (m, 3H), 7.64 – 7.57 (m, 4H), 7.52 (t, *J* = 8.0 Hz, 1H), 7.38 (t, *J* = 7.9 Hz, 1H), 7.29 (s, 1H); ^{13}C NMR (125 MHz, CD_2Cl_2) δ 164.12, 152.44, 149.61, 142.24, 135.66, 134.26, 133.69, 132.72, 132.22, 132.04, 130.48, 130.45, 130.39, 129.20, 128.71, 128.25, 126.35, 122.80, 122.64, 115.54, 114.36, 97.39; UV-vis (CH_3CN) λ_{max} /nm 265, 333; FT-IR ν/cm^{-1} (KBr): 3069, 2229, 1617, 1559, 1520, 1460, 1323, 1290, 762, 689, 597, 513; MALDI-FTICR MS m/z Calcd for $C_{25}H_{14}Br_2N_4$ M 527.9585, Found 527.9569.

4.2.12 *2,5-diphenyl-7-(p-tolyl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (*3***ab**): white solid, 67% yield (0.1293 g), m.p. 217.0-217.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 – 8.32 (m, 2H), 8.11 (dt, *J* = 8.1, 3.4 Hz, 2H), 7.66 (d, *J* = 8.1 Hz, 2H), 7.63 – 7.57 (m, 3H), 7.51 – 7.44 (m, 3H), 7.38 (d, *J* = 7.9 Hz, 2H), 7.25 (s, 1H), 2.46 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.47, 152.53, 149.21, 143.66, 140.71, 132.94, 131.26, 131.01, 130.61, 130.01, 129.90, 129.49, 128.76, 128.61, 128.58, 127.85, 114.82, 114.70, 96.27, 21.42; UV-vis (CH_3CN) λ_{max} /nm 267, 335; FT-IR ν/cm^{-1} (KBr):3067, 3032, 2225, 1611, 1527, 1440, 1286, 1228, 1027, 831, 767, 723, 686; MALDI-FTICR MS m/z Calcd for $C_{26}H_{18}N_4$ M 386.1531, Found 386.1536.

4.2.13 *7-(4-methoxyphenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ac**): colourless solid, 59% yield (0.1186 g), m.p. 251.0-251.3 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.37 (dt, *J* = 8.9, 2.8 Hz, 2H), 8.15 – 8.08 (m, 2H), 7.77 – 7.71 (m, 2H), 7.65 – 7.58 (m, 3H), 7.52 – 7.46 (m, 3H), 7.25 (s, 1H), 7.12 – 7.07 (m, 2H), 3.91 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 165.50, 161.38, 152.66, 148.90, 143.65, 131.28, 131.09, 130.64, 130.24, 130.07, 129.52, 128.80, 128.65, 128.05, 127.89, 115.04, 114.71, 114.64, 95.87, 55.55; UV-vis (CH_3CN) λ_{max} /nm 262, 340; FT-IR ν/cm^{-1} (KBr):3069, 2988, 2933, 2841, 2224, 1604, 1523, 1487, 1434, 1380, 1291, 1249, 1176, 1116, 1016, 837, 771, 724, 703, 686; MALDI-FTICR MS m/z Calcd for $C_{26}H_{18}N_4O$ $[M+H]^+$ 403.1553, Found 403.1554.

4.2.14 *7-(4-ethoxyphenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ad**): white solid, 62% yield (0.1290 g), m.p. 226.1-226.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 – 8.33 (m, 2H), 8.14 – 8.08 (m, 2H), 7.75 – 7.70 (m, 2H), 7.64 – 7.59 (m, 3H), 7.51 – 7.45 (m, 3H), 7.24 (s, 1H), 7.09 – 7.04 (m, 2H), 4.13 (q, *J* = 7.0 Hz, 2H), 1.47 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.41, 160.76, 152.63, 148.89, 143.57, 131.23, 131.06, 130.58, 130.19, 130.05, 129.49, 128.75, 128.61, 127.84, 127.78, 115.12, 115.05, 114.63, 95.70, 63.78, 14.75; UV-vis (CH_3CN) λ_{max} /nm 262, 341; FT-IR ν/cm^{-1} (KBr): 3071, 3034, 2980, 2925, 2881, 2228, 1604, 1522, 1484, 1435, 1833, 1294, 1247, 1171, 1037, 841, 772, 724, 703, 687; MALDI-FTICR MS m/z Calcd for $C_{27}H_{20}N_4O$ M 416.1634, Found 416.1631.

4.2.15 *7-(4-fluorophenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ae**): white solid, 71% yield (0.1385 g), m.p. 237.2-237.8°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.41 – 8.33 (m, 2H), 8.12 (dd, *J* = 6.5, 3.2 Hz, 2H), 7.80 – 7.71 (m, 2H), 7.68 – 7.58 (m, 3H), 7.53 – 7.46 (m, 3H), 7.29 (d, *J* = 8.5 Hz, 2H), 7.23 (s, 1H); ^{19}F NMR (470 MHz, DMSO-d_6) δ -109.71; ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.72, 163.94 (d, J_{FC} = -251.8 Hz), 152.40, 148.04, 143.94, 131.91 (d, J_{FC} = 3.4 Hz), 131.44, 130.85, 130.76 (d, J_{FC} = 8.6 Hz), 130.75, 129.89, 129.51, 128.84, 128.67, 127.89, 116.45 (d, J_{FC} = 22.0 Hz), 114.56, 114.52, 96.56; UV-vis (CH_3CN) λ_{max} /nm 265, 335; FT-IR ν/cm^{-1} (KBr): 3068, 2224, 1606, 1520, 1443, 1380, 1300, 1231, 1160, 1111, 841, 765, 723, 688; MALDI-FTICR MS m/z Calcd for $C_{25}H_{15}FN_4$ M 390.1283, Found 390.1285.

4.2.16 *7-(4-bromophenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3af**): white solid, 66% yield (0.1488 g), m.p. 236.1-236.2 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 – 8.33 (m, 2H), 8.15 – 8.08 (m, 2H), 7.76 – 7.69 (m, 2H), 7.67 – 7.60 (m, 5H), 7.53 – 7.46 (m, 3H), 7.22 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.72, 152.33, 147.79, 144.02, 134.65, 132.46, 131.46, 130.77, 130.75, 130.19, 129.82, 129.49, 128.82, 128.64, 127.86, 125.02, 114.42, 114.26, 96.47; UV-vis (CH_3CN) λ_{max} /nm 268, 336; FT-IR ν/cm^{-1} (KBr): 3078, 2223, 1612, 1527, 1484, 1438, 1388, 1289, 1224, 1065, 830, 766, 721, 688; MALDI-FTICR MS m/z Calcd for $C_{25}H_{15}BrN_4$ M 450.0480, Found 450.0486.

4.2.17 *7-(4-nitrophenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ag**): yellow solid, 54% yield (0.1126 g), m.p. 296.8-297.1°C; ^{1}H NMR (500 MHz, CD_2Cl_2) δ 8.45 (d, *J* = 8.6 Hz, 2H), 8.40 – 8.33 (m, 2H), 8.18 – 8.11 (m, 2H), 7.96 (d, *J* = 8.6 Hz, 2H), 7.66 (d, *J* = 5.4 Hz, 3H), 7.59 – 7.49 (m, 3H), 7.30 (s, 1H); ^{13}C NMR (125 MHz, CD_2Cl_2) δ 165.84, 152.25, 148.81, 146.65, 144.49, 142.03, 131.62, 130.94, 130.70, 129.99, 129.84, 129.56, 128.86, 128.81, 127.75, 124.26, 114.31, 114.06, 97.10; UV-vis (CH_3CN) λ_{max} /nm 262, 339; FT-IR ν/cm^{-1} (KBr): 3062, 2227, 1605, 1523, 1440, 1343, 1303, 1209, 1109, 858, 748, 699; MALDI-FTICR MS m/z Calcd for $C_{25}H_{15}N_5O_2$ $[M+H]^+$ 418.1299, Found 418.1300.

4.2.18 *7-(2-methoxyphenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ah**): white solid, 70% yield (0.1407 g), m.p. 201.4-201.5 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (dd, *J* = 6.5, 3.0 Hz, 2H), 8.12 (dd, *J* = 6.6, 2.9 Hz, 2H), 7.64 – 7.58 (m, 3H), 7.55 – 7.50 (m, 1H), 7.49 (dd, *J* = 4.8, 1.6 Hz, 3H), 7.45 (dd, *J* = 7.5, 1.6 Hz, 1H), 7.25 (s, 1H), 7.17 – 7.07 (m, 2H), 3.91 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.31, 156.41, 152.20, 146.76, 143.21, 131.73, 131.16, 131.12, 130.60, 130.56, 130.13, 129.53, 128.72, 128.62, 127.87, 124.90, 121.08, 116.04, 114.52, 111.68, 99.06, 55.62; UV-vis (CH_3CN) λ_{max} /nm 262, 336; FT-IR ν/cm^{-1} (KBr): 3041, 2921, 2845, 2228, 1613, 1524, 1445, 1296, 1255, 1018, 747, 686; MALDI-FTICR MS m/z Calcd for $C_{26}H_{18}N_4O$ $[M+H]^+$ 403.1553, Found 403.1548.

4.2.19 *7-(2-nitrophenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (***3ai***): yellow solid, 57% yield (0.1188 g), m.p. 200.0-200.2°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.41 – 8.35 (m, 2H), 8.31 (dd, *J* = 8.3, 1.1 Hz, 1H), 8.13 – 8.06 (m, 2H), 7.85 (td, *J* = 7.6, 1.3 Hz, 1H), 7.79 – 7.73 (m, 1H), 7.64 – 7.62 (m, 1H), 7.61 (m, 2H), 7.60 – 7.57 (m, 1H), 7.53 – 7.47 (m, 3H), 7.06 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.84, 151.70, 147.49, 146.60, 144.01, 134.03, 131.75, 131.55, 131.38, 131.10, 130.83, 130.58, 129.82, 129.62, 128.81, 128.70, 127.94, 125.61, 113.73, 113.51, 98.02; UV-vis (CH_3CN) λ_{max} /nm 255, 332; FT-IR ν/cm^{-1} (KBr): 3054, 2224, 1613, 1522, 1440, 1341, 1297, 1198, 1025, 754, 707, 691; MALDI-FTICR MS m/z Calcd for $C_{25}H_{15}N_5O_2$ $[M+H]^+$ 418.1299, Found 418.1292.

4.2.20 *2,5-diphenyl-7-(m-tolyl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3aj**): light yellow solid, 63% yield (0.1216 g), m.p. 202.6-202.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.40 – 8.35 (m, 2H), 8.16 – 8.10 (m, 2H), 7.65 – 7.60 (m, 3H), 7.57 (d, *J* = 8.2 Hz, 1H), 7.55 (s, 1H), 7.51 – 7.44 (m, 4H), 7.37 (d, *J* = 7.6 Hz, 1H), 7.27 (s, 1H), 2.49 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.56, 152.49, 149.37, 143.69, 139.07, 135.83, 131.30, 131.04, 131.00, 130.65, 130.01, 129.51, 129.21, 129.10, 128.79,

128.63, 127.88, 125.83, 114.78, 114.65, 96.56, 21.50; UV-vis (CH_3CN) λ_{max} /nm 265, 334; FT-IR ν/cm^{-1} (KBr): 3065, 2916, 2849, 2216, 1607, 1523, 1492, 1438, 1332, 1293, 1258, 1027, 789, 764, 722, 691; MALDI-FTICR MS m/z Calcd for $C_{26}H_{18}N_4$ $[M+H]^+$ 387.1604, Found 387.1604.

4.2.21 *7-(3-bromophenyl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ak**): white solid, 63% yield (0.1421 g), m.p. 205.7-205.8 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.40 – 8.34 (m, 2H), 8.13 (dd, *J* = 6.5, 3.2 Hz, 2H), 7.84 (t, *J* = 1.8 Hz, 1H), 7.75 – 7.71 (m, 1H), 7.70 (ddd, *J* = 8.0, 1.8, 0.9 Hz, 1H), 7.66 – 7.60 (m, 3H), 7.52 – 7.48 (m, 3H), 7.47 (t, *J* = 8.0 Hz, 1H), 7.23 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.83, 152.30, 147.35, 144.11, 137.78, 133.27, 131.52, 131.45, 130.80, 130.75, 130.71, 129.83, 129.53, 128.86, 128.68, 127.92, 127.44, 123.23, 114.34, 114.22, 96.83; UV-vis (CH_3CN) λ_{max} /nm 264, 335; FT-IR ν/cm^{-1} (KBr): 3046, 2219, 1609, 1571, 1524, 1442, 1371, 1331, 1291, 1072, 791, 758, 686; MALDI-FTICR MS m/z Calcd for $C_{25}H_{15}BrN_4$ $[M+H]^+$ 451.0553, Found 451.0553.

4.2.22 *6-methyl-2,5,7-triphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3la**): white solid, 52% yield (0.1004 g), m.p. 290.5-290.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.29 – 8.21 (m, 2H), 7.67 – 7.50 (m, 8H), 7.46 – 7.39 (m, 5H), 2.03 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.94, 151.74, 149.81, 142.53, 135.92, 131.02, 130.38, 130.17, 130.12, 129.79, 129.47, 129.05, 128.80, 128.50, 128.48, 127.79, 120.98, 114.12, 99.71, 17.58; UV-vis (CH_3CN) λ_{max} /nm 257, 326; FT-IR ν/cm^{-1} (KBr): 3056, 2963, 2852, 2223, 1607, 1519, 1481, 1439, 1327, 1261, 1011, 756, 745, 696; MALDI-FTICR MS m/z Calcd for $C_{26}H_{14}N_4$ M 386.1531, Found 386.1535.

4.2.23 *2,5-di(naphthalen-2-yl)-7-phenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ma**): yellowish-green solid, 72% yield (0.1699 g), m.p. 271.2-271.3 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.96 (s, 1H), 8.70 (s, 1H), 8.44 (d, *J* = 8.7 Hz, 1H), 8.21 (d, *J* = 8.6 Hz, 1H), 8.10 (d, *J* = 8.7 Hz, 1H), 8.07 – 7.97 (m, 3H), 7.95 (d, *J* = 8.6 Hz, 1H), 7.88 (d, *J* = 5.4 Hz, 1H), 7.82 (d, *J* = 6.7 Hz, 2H), 7.71 – 7.57 (m, 5H), 7.57 – 7.49 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.79, 152.70, 149.32, 143.95, 135.94, 134.61, 134.47, 133.26, 132.92, 130.36, 130.27, 129.28, 129.04, 128.99, 128.76, 128.55, 128.40, 128.36, 128.19, 128.15, 127.91, 127.84, 127.33, 127.17, 127.13, 126.51, 125.74, 124.74, 115.09, 114.76, 96.61; UV-vis (CH_3CN) λ_{max} /nm 250, 346; FT-IR ν/cm^{-1} (KBr): 3047, 2227, 1612, 1518, 1431, 1347, 1278, 1133, 855, 815, 760, 698; MALDI-FTICR MS m/z Calcd for $C_{33}H_{20}N_4$ $[M+H]^+$ 473.1766, Found 473.1758.

4.2.24 *7-phenyl-2,5-di(thiophen-2-yl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3na**): yellowish-green solid, 50% yield (0.0960 g), m.p. 236.2-236.3°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.42 (d, *J* = 3.7 Hz, 1H), 8.07 (d, *J* = 3.3 Hz, 1H), 7.80 – 7.70 (m, 3H), 7.59 (m, 3H), 7.53 (d, *J* = 4.2 Hz, 2H), 7.34 – 7.29 (m, 1H), 7.23 – 7.17 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.49, 152.30, 149.08, 137.26, 135.93, 132.68, 132.57, 132.00, 131.81, 130.29, 129.44, 129.24, 129.09, 128.69, 128.28, 128.13, 114.64, 111.51, 94.71; UV-vis (CH_3CN) λ_{max} /nm 283, 367; FT-IR ν/cm^{-1} (KBr): 3086, 2213, 1604, 1557, 1519, 1468, 1397, 1304, 1211, 1091, 1048, 845, 764, 698; MALDI-FTICR MS m/z Calcd for $C_{21}H_{12}N_4S_2$ $[M+H]^+$ 385.0582, Found 385.0574.

4.2.25 *2,5-diphenyl-7-(thiophen-2-yl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3al**): yellowish-green solid, 42% yield (0.0794 g), m.p. 233.8-233.9 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.35 (dd, *J* = 6.5, 2.8 Hz, 2H), 8.11 (dd, *J* = 6.5, 2.8 Hz, 2H), 8.04 (d, *J* = 3.7 Hz, 1H), 7.68 – 7.56 (m, 4H), 7.51 – 7.44 (m, 3H), 7.34 (s, 1H), 7.27 (d, *J* = 5.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.62, 152.70, 143.76, 140.83, 137.26, 131.41, 130.80, 130.69, 129.99, 129.92, 129.89, 129.54, 129.01, 128.83, 128.64, 127.85, 115.12, 113.70, 93.89; UV-vis (CH_3CN) λ_{max} /nm 273, 351; FT-IR ν/cm^{-1} (KBr): 3100, 3057, 2217, 1611, 1529, 1419, 1297, 1242, 1065, 843, 764, 704; MALDI-FTICR MS m/z Calcd for $C_{23}H_{14}N_4S$ $[M+H]^+$ 379.1017, Found 379.1012.

4.2.26 *2,5-diphenyl-7-(pyridin-3-yl)-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3am**): white solid, 70% yield (0.1304 g), m.p. 247.5-247.6 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.96 (s, 1H), 8.81 (d, *J* = 3.9 Hz, 1H), 8.36 (dd, *J* = 6.5, 2.9 Hz, 2H), 8.18 – 8.07 (m, 3H), 7.63 (d, *J* = 3.5 Hz, 3H), 7.54 (dd, *J* = 7.7, 4.9 Hz, 1H), 7.51 – 7.44 (m, 3H), 7.25 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.92, 152.31, 151.20, 149.07, 145.52, 144.40, 136.16, 131.99, 131.64, 130.89, 130.66, 129.75, 129.55, 128.92, 128.72, 127.94, 123.78, 114.17, 114.12, 97.13; UV-vis (CH_3CN) λ_{max} /nm 262, 336; FT-IR ν/cm^{-1} (KBr): 3042, 2225, 1611, 1524, 1492, 1442, 1332, 1292, 1200, 1024, 761, 717, 683; MALDI-FTICR MS m/z Calcd for $C_{24}H_{15}N_5$ $[M+H]^+$ 374.1406, Found 374.1400.

4.2.27 *7-(furan-2-yl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3an**): yellowish-green solid, 49% yield (0.0887 g), m.p. 259.2-259.5 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.34 (dd, *J* = 6.5, 2.9 Hz, 2H), 8.13 (dd, *J* = 6.4, 2.9 Hz, 2H), 7.75 – 7.65 (m, 2H), 7.64 (s, 1H), 7.63 – 7.54 (m, 3H), 7.50 – 7.44 (m, 3H), 6.69 (dd, *J* = 3.4, 1.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.53, 152.55, 148.00, 145.23, 144.00, 135.97, 131.31, 131.03, 130.64, 130.54, 129.93, 129.53, 128.78, 128.63, 127.84, 115.10, 114.67, 113.36, 110.12; UV-vis (CH_3CN) λ_{max} /nm 277, 354; FT-IR ν/cm^{-1} (KBr): 3053, 2218, 1615, 1533, 1479, 1442, 1293, 1212, 1027, 760, 719; MALDI-FTICR MS m/z Calcd for $C_{23}H_{14}N_4O$ $[M+H]^+$ 363.1246, Found 363.1241.

4.2.28 *7-(naphthalen-2-yl)-2,5-diphenyl-[1,2,4]triazolo[1,5-a]pyridine-8-carbonitrile* (**3ao**): white solid, 55% yield (0.1161 g), m.p. 283.7-283.9 °C;^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (dd, *J* = 5.9, 2.4 Hz, 2H), 8.25 (s, 1H), 8.19 – 8.12 (m, 2H), 8.04 (d, *J* = 8.5 Hz, 1H), 7.99 (d, *J* = 8.3 Hz, 1H), 7.94 (d, *J* = 7.1 Hz, 1H), 7.86 – 7.81 (m, 1H), 7.63 (dd, *J* = 4.0, 2.4 Hz, 3H), 7.62 – 7.57 (m, 2H), 7.53 – 7.47 (m, 3H), 7.38 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.70, 152.59, 149.19, 143.85, 133.80, 133.15, 133.09, 131.39, 131.03, 130.72, 130.02, 129.57, 129.20, 128.87, 128.85, 128.74, 128.69, 127.94, 127.87, 127.73, 127.13, 125.45, 114.95, 114.75, 96.82; UV-vis (CH_3CN) λ_{max} /nm 266, 339; FT-IR ν/cm^{-1} (KBr): 3054, 2226, 1608, 1525, 1434, 1293, 1207, 1024, 821, 762, 715, 694; MALDI-FTICR MS m/z Calcd for $C_{29}H_{18}N_4$ $[M+H]^+$ 423.1610, Found 423.1604.

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& These authors contributed equally to this work and should be considered co-first authors.

Supplementary Material

Supplementary data associated with this article can be found in the online version, at

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