An Efficient Ultrasound-assisted Method for the Synthesis of 1,4-Disubstituted Triazoles

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An efficient method for the synthesis of 1,4-disubstituted triazoles has been developed with the help of ultrasound irradiation in water at room temperature. Under the optimized conditions, a novel series of 1,4-disubstituted 1,2,3-triazoles was synthesized in high yields.

Key words: Huisgen Cycloaddition, $Cu(OAc)_2$/Cu Wire, Ultrasound, 1,4-Disubstituted Triazole

Introduction

The classical Huisgen 1,3-dipolar cycloaddition reaction of organic azides and alkynes, studied by Huisgen and co-workers in the 1960s [1], has recently regained attention, owing to the discovery that the rate of the cycloaddition can be accelerated greatly by Cu(I) catalysis [2, 3]. The active Cu(I) ion can be generated directly from Cu(I) salts or *in situ* from Cu(II) salts in the presence of a reducing agent (often sodium ascorbate or metallic copper). Usually Cu(I) salts are used in organic or aqueous solvents together with a base or a ligand [2 – 4]. Cu(II) salts in the presence of sodium ascorbate have been successfully applied to the 1,3-dipolar cycloaddition, except in special circumstances, when the reactants are reduced by sodium ascorbate *in situ* [5]. It was reported that metallic copper can replace sodium ascorbate as a reducing agent to generate Cu(I) ions by the comproportionation of Cu(0) and Cu(II). The reduction of the reactants can often be avoided by using metallic copper as a less reductive agent. Compared to catalyst systems composed of Cu(I) salts and Cu(II) salts/sodium ascorbate, reactions catalyzed by a Cu(II) salt/Cu catalyst system usually need relatively long reaction times at room temperature [6 – 9].

Ultrasound-assisted organic synthesis, as a synthetic approach, is a powerful technique that is used to accelerate organic reactions. The notable features of the ultrasound approach are enhanced reaction rates, formation of pure products in high yields, and easier manipulation [10, 11]. However, only a few 1,3-dipolar cycloadditions promoted by ultrasound irradiation have been reported. Reddy described a three-component reaction catalyzed by CuI with the help of ultrasound irradiation, by which the corresponding 1,2,3-triazoles were obtained in a one-pot reaction using substituted benzyl chlorides, sodium azide and alkyne as reactants. The disadvantage of the one-pot method is that the influence of ultrasound on the essential step of 1,3-dipolar cycloadditions can not be explored directly [12]. Cravotto chose only metallic copper as a catalyst for the investigation of the 1,3-dipolar cycloaddition in 1,4-dioxane/water with the help of ultrasound irradiation, however, a relatively high temperature was needed [13, 14]. It is known that organic reactions in water are of great interest especially in relation to today's environmental concerns. However, the 1,3-dipolar cycloaddition in water was necessarily carried out in the presence of a ligand or a base, otherwise a long reaction time would be necessary [15 – 19]. In the work described in this paper, an efficient method for 1,3-dipolar cycloadditions under relatively mild and environmentally friendly conditions is established, involving $Cu(OAc)_2$/metallic copper as a catalyst system and water as reaction medium with the help of ultrasound irradiation in the absence of the related ligand or a base.

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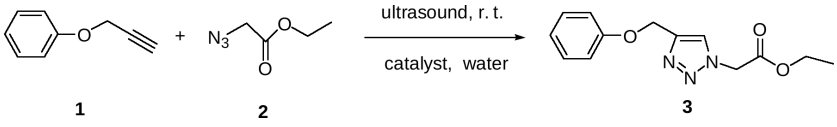


Scheme 1. Model reaction of cycloaddition under ultrasound at room temperature.

Table 1. Screening of catalysts for the synthesis of triazoles (Scheme 1) in water at room temperature under ultrasound irradiation.

Entry	Catalyst system	Time (min)	Yield (%)[a]
1	$CuSO_4$/Cu wire	120	88
2	$CuCl_2$/Cu wire	120	62
3	$CuBr_2$/Cu wire	120	52
4	Cu $(NO_3)_2$/Cu wire	120	52
5	$Cu(ClO_4)_2$/Cu wire	120	20
6	$Cu(OAc)_2$/Cu wire	20	92
7	$Cu(OAc)_2 \cdot H_2O$	120	70
8	Cu wire	120	trace
9	$Cu(OAc)_2$/Cu wire[b]	1200	80

[a] Isolated yield; [b] without ultrasound irradiation.

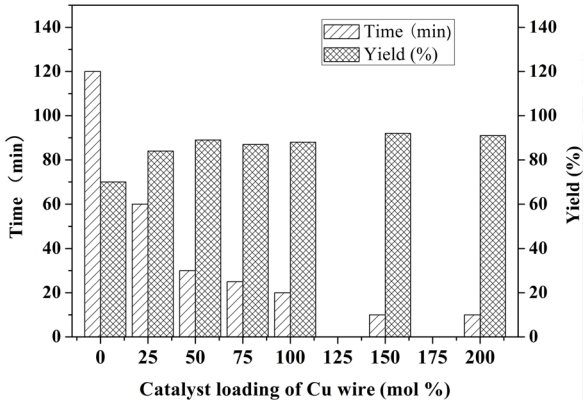


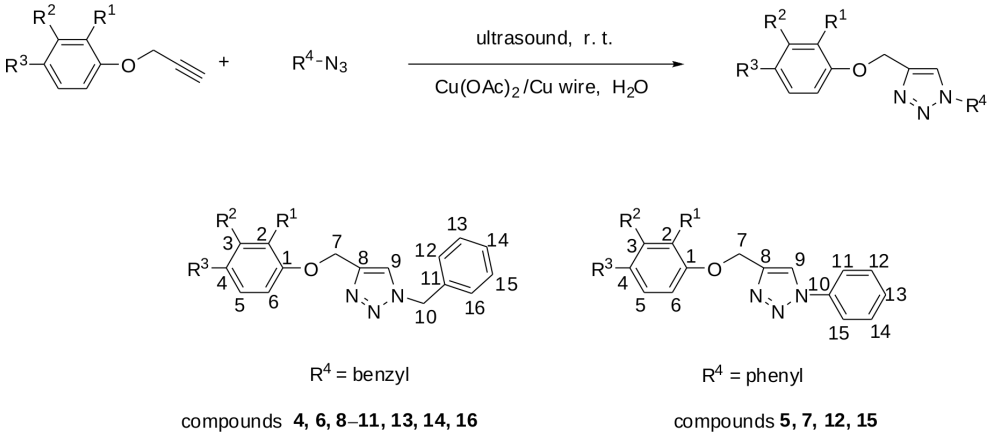
Fig. 1. Reaction time *versus* catalyst loading of copper wire by fixing the loading (5 mol-%) of $Cu(OAc)_2$ for the model reaction.

Results and Discussion

Initially, different cupric salts (5 mol-%) together with copper wire (100 mol-%) shown in Table 1 were screened for their catalytic efficiency in the 1,3-dipolar cycloaddition. Propargyl phenyl ether (**1**) [20] and ethyl 2-azidoacetate (**2**) [21] were used as representative substrates in this screening (Scheme 1). All the reactions were carried out in water under continuous sonication for 120 min. Among the tested catalysts the best catalytic efficiency was observed for $Cu(OAc)_2$/Cu wire. Most notably, the 1,3-dipolar cycloaddition reaction catalyzed by $Cu(OAc)_2$/Cu wire was completed within 20 min in 92 % yield (Table 1). In comparision to $Cu(OAc)_2$/Cu wire, lower catalytic efficiencies were observed for other cupric salt/Cu wire catalysts, among which $Cu(ClO_4)_2$/Cu wire showed the lowest (20 % yield) and $CuSO_4$/Cu wire the highest (88 % yield). It is worth to mention that nearly no catalytic effect was observed for Cu wire within 120 min, wheras a relatively high efficiency was observed for $Cu(OAc)_2 \cdot H_2O$ (70 % yield within 120 min). The catalytic efficiency of the cupric salt/Cu wire increases in the order $Cu(ClO_4)_2$/Cu wire, $Cu(NO_3)_2$/Cu wire, $CuBr_2$/Cu wire, $CuCl_2$/Cu wire, $CuSO_4$/Cu wire and $Cu(OAc)_2$/Cu wire.

In order to investigate the influence of the amounts of copper wire in the $Cu(OAc)_2$/Cu wire catalyst system, the cycloaddition reactions were performed with gradually varied amounts of copper wire, from 5 mol-% to 200 mol-% with a fixed amount of $Cu(OAc)_2$ (5 mol-%). The higher the concentration of Cu(I) generated from the comproportionation of $Cu(OAc)_2$/Cu wire *in situ*, the faster was the rate of the reaction [22]. As can be seen from Fig. 1, the reaction time decreased with increasing amounts of copper wire until the amount of copper wire was raised to 150 mol-%, indicating that at least 150 mol-% copper wire was needed to provide a sufficient surface area exposed to $Cu(OAc)_2$ for accelerating the comproportionation. The cycloaddition can be complete within 10 min with a concentration of 150 mol-% copper wire. $Cu(OAc)_2$ (5 mol-%)/Cu wire (150 mol-%) was finally chosen as an appropriate composition of a catalyst for the 1,3-dipolar cycloaddition.

In order to investigate the influence of ultrasound on the 1,3-dipolar cycloaddition, the following experiment was designed. The cycloaddition catalyzed by $Cu(OAc)_2$/Cu wire was carried out in water at room temperature in the absence or presence of ultrasound irradiation. According to TLC monitoring, 20 h were required to complete the cycloaddition reaction in the absence of ultrasound irradiation in 80 % yield, but only 10 min in the presence of ultrasound irradiation in 92 % yield, showing that the ultrasound irradiation greatly accelerates the reaction and enhances the yield. In all, the optimized relative quantities of reactants, catalyst and solvent are: organic azide (1.0 mmol), terminal alkyne (1.0 mmol),



Scheme 2. Synthesis of compounds **4** – **16**.

Table 2. Synthesis of 1,4-disubstituted 1,2,3-triazoles.

Compound	R^1	R^2	R^3	R^4	Time (min)	Yield (%)
4	OMe	H	H	benzyl	30	99
5	OMe	H	H	phenyl	30	96
6	H	OMe	H	benzyl	30	97
7	H	OMe	H	phenyl	30	95
8	H	H	OMe	benzyl	35	99
9	NO_2	H	H	benzyl	70	95
10	H	H	NO_2	benzyl	80	91
11	Cl	H	Cl	benzyl	80	99
12	Cl	H	Cl	phenyl	80	97
13	H	H	Cl	benzyl	40	92
14	H	Me	H	benzyl	45	90
15	H	Me	H	phenyl	45	92
16	Me	H	H	benzyl	40	90

$Cu(OAc)_2 \cdot H_2O$ (5 mol-%)/Cu wire (150 mol-%) and water (5 mL).

A series of 1,4-disubstituted 1,2,3-triazole derivatives were synthesized based on the optimized conditions (Scheme 2, Table 2). As shown in Table 2, reactions between substituted terminal alkynes and organic azides, including benzyl azide and phenyl azide, under the optimized conditions gave 1, 4-disubstituted 1,2,3-triazoles in good yields.

In summary, a highly efficient synthesis of 1,4-disubstituted 1,2,3-triazoles in water was developed by using $Cu(OAc)_2$/Cu wire as the catalyst with ultrasound irradiation.

Experimental Section

General

All the chemicals were obtained from Tianjin Kermel Chemical Reagent Co., Ltd. and used as received. Melting points were recorded on an electrothermal apparatus and are uncorrected. Sonication was performed in a Kunshan KQ-250B ultrasonic cleaner with a frequency of 40 kHz and a power of 150 W. IR spectra were recorded on a Shimadazu IR-408 spectrometer. ^{1}H and ^{13}C spectra were recorded on a Bruker 400 spectrometer operating at 400.13 and 100.61 MHz, respectively, with ^{13}C spectra being recorded proton-decoupled. ^{1}H and ^{13}C chemical shifts are quoted in parts per million downfield from TMS. ESI MS were recorded on a Bruker Esquire 3000 instrument. High-resolution mass spectra (HRMS) were performed on a Micromass Q-TOF MicroTM mass spectrometer with an ESI source (Waters, Manchester, UK). Substituted terminal alkynes were synthesized according to the literature [20, 23 – 26]. Benzyl azide [21] and phenyl azide [27] were also synthesized according to previous reports.

General procedure for the synthesis of triazoles

A mixture of organic azide (1.0 mmol), terminal alkyne (1.0 mmol), $Cu(OAc)_2 \cdot H_2O$/Cu wire (10 mol-%) in water (5 mL) was sonicated for the time indicated in Table 2 in a laboratory ultrasonic cleaning bath at r. t. After completion of the reaction as indicated by TLC, the reaction mixture was diluted with saturated aq. NH_4Cl (20 mL) and extracted with CH_2Cl_2 (3 × 15 mL). The combined organic layers were washed with brine (10 mL) and dried over anhydrous Na_2SO_4 and filtered. The solvent of the filtrate was removed *in vacuo* to give the pure product.

*1-Benzyl-4-[(2-methoxyphenoxy)methyl]-1,2,3-triazole (**4**)*

M. p. 112 – 114 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3131, 3034, 2968, 2930, 2878, 1388, 2834, 1590, 1503, 1453, 1251, 1216, 1122, 1028. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.57 (s, 1H, 9-H), 7.39 – 7.36 (m, 3H, 13, 14, 15-H), 7.27 (dd, J = 2.0, 7.2 Hz, 2H, 12, 16-H), 7.06 – 7.04 (dd, J = 2.0, 8.0 Hz, 1H, 6-H), 6.98 – 6.94 (td, J = 2.0, 8.0 Hz, 1H, 4-H), 6.91 – 6.88 (m, 2H, 3, 5-H), 5.53 (s, 2H, 10-H), 5.28 (s, 2H, 7-H), 3.85 (s, 3H, -O*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 149.6, 147.6, 144.5, 134.6, 129.0, 128.7, 128.1, 123.1,

121.9, 120.8, 114.4, 111.8, 63.1, 55.7, 54.0. – MS (ESI): *m/z* (%) = 296 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 296.1404 (calcd. 296.1399 for $C_{17}H_{18}N_3O_2$, $[M+H]^+$).

*4-[(2-Methoxyphenoxy)methyl]-1-phenyl-1,2,3-triazole (**5**)*

M. p. 130 – 132 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3150, 3084, 2955, 2922, 2876, 2835, 1385, 1592, 1503, 1465, 1250, 1218, 1126, 1024. – ^1H NMR (400 MHz, $CDCl_3$): δ = 8.10 (s, 1H, 9-H), 7.74 – 7.72 (dd, *J* = 1.2, 7.6 Hz, 2H, 11, 15-H), 7.53 (t, *J* = 7.6 Hz, 2H, 12, 14-H), 7.45 (t, *J* = 7.6 Hz, 1H, 13-H), 7.12 – 7.10 (dd, *J* = 1.6, 8.0 Hz, 1H, 3-H), 6.99 – 6.96 (dd, *J* = 1.6, 8.0 Hz, 1H, 5-H), 6.94 – 6.92 (m, 2H, 4, 6-H), 5.39 (s, 2H, 7-H), 3.90 (s, 3H, -O*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 149.5, 147.5, 145.1, 137.0 , 129.8, 128.8, 122.0, 121.1, 120.9, 120.6, 114.2, 111.2, 63.1, 55.9. – MS (ESI): *m/z* (%) = 282 (100) $[M+H]^+$. – HRMS((+)-ESI): *m/z* = 282.1243 (calcd. 282.1238 for $C_{16}H_{16}N_3O_2$, $[M+H]^+$).

*1-Benzyl-4-[(3-methoxyphenoxy)methyl]-1,2,3-triazole (**6**)*

M. p. 84 – 86 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3138, 3093, 2933, 2875, 1384, 1596, 1495, 1462, 1231, 1193, 1121, 1053, 1024, 1012. – ^1H NMR (400 MHz, $CDCl_3$): δ = 7.54 (s, 1H, 9-H), 7.40 – 7.38 (m, 3H, 13, 14, 15-H), 7.30 – 7.28 (dd, *J* = 2.4, 7.2 Hz, 2H, 12, 16-H), 7.19 (t, *J* = 8.4 Hz, 1H, 5-H), 6.59 – 6.53 (m, 3H, 2, 4, 6-H), 5.55 (s, 2H, 10-H), 5.18 (s, 2H, 7-H), 3.78 (s, 3H, -O*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 160.8, 159.5, 44.5, 134.5, 130.0, 129.1, 128.8, 128.1, 122.8, 107.0, 106.8, 101.2, 62.0, 55.3, 54.2. – MS (ESI): *m/z* (%) = 296 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 296.1397 (calcd. 296.1399 for $C_{17}H_{18}N_3O_2$, $[M+H]^+$).

*4-[(3-Methoxyphenoxy)methyl]-1-phenyl-1,2,3-triazole (**7**)*

M. p. 104 – 106 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3141, 2910, 1594, 1510, 1461, 1370, 1230, 1109, 1041. – ^1H NMR (400 MHz, $CDCl_3$): δ = 8.07 (s, 1H, 9-H), 7.77 – 7.74 (dd, *J* = 1.6, 7.2 Hz, 2H, 11, 15-H), 7.54 (t, *J* = 7.2 Hz, 2H, 12, 14-H), 7.46 (dd, *J* = 1.6, 7.2 Hz, 1H, 13-H), 7.23 (t, *J* = 8.0 Hz, 1H, 5-H), 6.65 (dd, *J* = 2.4, 8.0 Hz, 1H, 6-H), 6.61 (t, *J* = 2.4 Hz, 1H, 2-H), 6.57 (dd, *J* = 2.4, 8.0 Hz, 1H, 4-H), 5.30 (s, 2H, 7-H), 3.81 (s, 3H, -O*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 160.9, 159.5, 144.8, 136.9, 130.1, 129.8, 128.9, 121.1, 120.5, 107.0, 106.8, 101.3, 61.9, 55.3. – MS (ESI): *m/z* (%) = 282 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 282.1243 (calcd. 282.1238 for $C_{16}H_{16}N_3O_2$, $[M+H]^+$).

*1-Benzyl-4-[(4-methoxyphenoxy)methyl]-1,2,3-triazole (**8**)*

M. p. 86 – 88 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3124, 3082, 2948, 2928, 2831, 1510, 1454, 1233, 1119, 1048. – ^1H NMR (400 MHz, $CDCl_3$): δ = 7.52 (s, 1H, 9-H), 7.40 – 7.37 (m, 3H, 13, 14, 15-H), 7.29 – 7.26 (dd, *J* = 2.8, 7.2 Hz, 2H, 12, 16-H), 6.91 (d, *J* = 9.2 Hz, 2H, 2, 6-H), 6.83 (d, *J* = 9.2 Hz, 2H, 3, 5-H), 5.54 (s, 2H, 10-H), 5.15 (s, 2H, 7-H), 3.77 (s, 3H, -O*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.2, 152.3, 144.7, 134.6, 129.1, 128.7, 128.1, 122.8, 115.9, 114.6, 62.7, 55.6, 54.1. – MS (ESI): *m/z* (%) = 296 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 296.1397 (calcd. 296.1399 for $C_{17}H_{18}N_3O_2$, $[M+H]^+$).

*1-Benzyl-4-[(2-nitrophenoxy)methyl]-1,2,3-triazole (**9**)*

M. p. 107 – 108 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3151, 3088, 3056, 2928, 1616, 1585, 1456, 1529, 1340, 1274, 1161, 1045. – ^1H NMR (400 MHz, $CDCl_3$): δ = 7.85 (dd, *J*= 1.6, 8.1 Hz, 1H, 3-H), 7.67 (s, 1H, 9-H), 7.58 – 7.53 (td, *J* = 1.6, 7.6, 8.0 Hz, 1H, 5-H), 7.40 – 7.37 (m, 3H, 13, 14, 15-H), 7.30 – 7.27 (m, 3H, 6, 12, 16-H), 7.07 (td, *J* = 1.2, 7.6 Hz, 1H, 4-H), 5.55 (s, 2H, 10-H), 5.37 (s, 2H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.5, 143.6, 140.0, 134.5, 134.3, 129.1, 128.8, 128.0, 125.6, 123.3, 121.1, 115.4, 63.7, 54.2. – MS (ESI): *m/z* (%) = 311 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 311.1149 (calcd. 311.1144 for $C_{16}H_{15}N_4O_3$, $[M+H]^+$).

*1-Benzyl-4-[(4-nitrophenoxy)methyl]-1,2,3-triazole (**10**)*

M. p. 103 – 104 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3147, 3116, 1606, 1494, 1337, 1267, 1114, 1055. – ^1H NMR (400 MHz, $CDCl_3$): δ = 8.21 (d, *J* = 9.2 Hz, 2H, 3, 5-H), 7.57 (s, 1H, 9-H), 7.42 – 7.39 (m, 3H, 13, 14, 15-H), 7.31 – 7.27 (dd, *J* = 3.2, 7.6 Hz, 2H, 12, 16-H), 7.07 (d, *J* = 9.2 Hz, 2H, 2, 6-H), 5.57 (s, 2H, 10-H), 5.28 (s, 2H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.2, 143.0, 141.7, 134.4, 129.2, 128.9, 128.2, 125.9, 123.3, 114.8, 62.4, 54.3. – MS (ESI): *m/z* (%) = 311 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 311.1148 (calcd. 311.1144 for $C_{16}H_{15}N_4O_3$, $[M+H]^+$).

*1-Benzyl-4-[(2,4-dichlorophenoxy)methyl]-1,2,3-triazole (**11**)*

M. p. 88 – 90 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3142, 3036, 2928, 1586, 1485, 1468, 1289, 1249, 1103, 1066. – ^1H NMR (400 MHz, $CDCl_3$): δ = 7.59 (s, 1H, 9-H), 7.40 – 7.37 (m, 3H, 13, 14, 15-H), 7.36 (d, *J* = 2.8 Hz, 1H, 3-H), 7.30 (dd, *J* = 2.8, 6.8 Hz, 2H, 12, 16-H), 7.18 (dd, *J* = 2.4, 8.8 Hz, 1H, 5-H), 7.05 (d, *J* = 8.8 Hz, 1H, 6-H), 5.55 (s, 2H, 10-H), 5.26 (s, 2H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 152.5, 143.7, 134.5, 123.0, 129.1, 128.8, 128.1, 127.7, 126.4, 123.8, 123.1, 115.1, 63.4, 54.2. – MS (ESI): *m/z* (%) = 334 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 334.0511 (calcd. 334.0514 for $C_{16}H_{14}Cl_2N_3O$, $[M+H]^+$).

*4-[(2,4-Dichlorophenoxy)methyl]-1-phenyl-1,2,3-triazole (**12**)*

M. p. 117 – 119 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3156, 3096, 3034, 2921, 2874, 1739, 1291, 1596, 1506, 1491, 1451, 1248, 1105, 1059, 1043. – ^1H NMR (400 MHz,

$CDCl_3$): δ = 8.12 (s, 1H, 9-H), 7.76 (d, J = 8.0 Hz, 2H, 11, 15-H), 7.56 (t, J = 8.0 Hz, 2H, 12, 14-H), 7.47 (t, J = 7.6 Hz, 1H, 13-H), 7.40 (d, J = 2.4 Hz, 1H, 3-H), 7.22 (dd, J = 2.4, 8.8 Hz, 1H, 5-H), 7.11 (d, J = 8.8 Hz, 1H, 6-H), 5.38 (s, 2H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.5, 144.1, 136.8, 130.1, 129.8, 129.0, 127.7, 126.4, 123.8, 121.3, 120.5, 114.9, 63.3. – MS (ESI): *m/z* (%) = 320 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 320.0357 (calcd. 320.0362 for $C_{15}H_{12}Cl_2N_3O$, $[M+H]^+$).

*1-Benzyl-4-[(4-chlorophenoxy)methyl]-1,2,3-triazole (**13**)*

M. p. 99 – 100 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3141, 2928, 2875, 1594, 1492, 1457, 1241, 1126, 1055. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (s, 1H, 9-H), 7.40 – 7.38 (m, 3H, 13, 14, 15-H), 7.30 (dd, J = 2.8, 7.2 Hz, 2H, 12, 16-H), 7.24 (d, J = 7.2 Hz, 2H, 3, 5-H), 6.91 (d, J = 7.2 Hz, 2H, 2, 6-H), 5.55 (s, 2H, 10-H), 5.16 (s, 2H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 156.8, 144.1, 134.4, 129.4, 129.2, 128.9, 128.1, 126.1, 122.8, 116.1, 62.2, 54.2. – MS (ESI): *m/z* (%) = 300 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 300.0906 (calcd. 300.0904 for $C_{16}H_{15}ClN_3O$, $[M+H]^+$).

*1-Benzyl-4-(m-tolyloxymethyl)-1,2,3-triazole (**14**)*

M. p. 78 – 80 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3136, 3032, 2925, 2874, 1605, 1582, 1487, 1458, 1383, 1256, 1153, 1040. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (s, 1H, 9-H), 7.42 – 7.37 (m, 3H, 13, 14, 15-H), 7.29 (dd, J = 2.8, 8.0 Hz, 2H, 12, 16-H), 7.17 (t, J = 8.0 Hz, 1H, 5-H), 6.80 – 6.77 (m, 3H, 2, 4, 6-H), 5.55 (s, 2H, 10-H), 5.19 (s, 2H, 7-H), 2.33 (s, 3H, -*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.2, 144.8, 139.6, 134.6, 129.3, 129.2, 128.8, 128.1, 122.6, 122.1, 115.6, 111.6, 62.0, 54.2, 21.6. – MS (ESI): *m/z* (%) = 280 (100) [M+H]. – HRMS ((+)-ESI): *m/z* = 280.1454 (calcd. 280.1450 for $C_{17}H_{18}N_3O$, $[M+H]^+$).

*1-Phenyl-4-(m-tolyloxymethyl)-1,2,3-triazole (**15**)*

M. p. 87 – 89 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3141, 3062, 2926, 2870, 1378, 1599, 1585, 1503, 1461, 1259, 1157, 1046. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06 (s, 1H, 9-H), 7.75 (d, J = 8.0 Hz, 2H, 11, 15-H), 7.55 (t, J = 8.0 Hz, 2H, 12, 14-H), 7.46 (t, J = 7.2 Hz, 1H, 13-H), 7.21 (t, J = 7.6 Hz, 1H, 5-H), 6.88 – 6.80 (m, 3H, 2, 4, 6-H), 5.31 (s, 2H, 7-H), 2.36 (s, 3H, -*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.2, 145.1, 139.7, 137.0, 129.8, 129.4, 128.9, 122.2, 121.0, 120.5, 115.6, 111.6, 61.9, 21.6. – MS (ESI): *m/z* (%) = 266 (100) $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 266.1290 (calcd. 266.1293 for $C_{16}H_{17}N_3O$, $[M+H]^+$).

*1-Benzyl-4-(o-tolyloxymethyl)-1,2,3-triazole (**16**)*

M. p. 66 – 68 °C. – IR (KBr): ν_{max} (cm^{-1}) = 3145, 3031, 2928, 1602, 1591, 1496, 1466, 1381, 1246, 1126, 1056. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (s, 1H, 9-H), 7.40 – 7.37 (m, 3H, 13, 14, 15-H), 7.30 (dd, J = 2.4, 8.0 Hz, 2H, 12, 16-H), 7.16 (t, J = 7.6 Hz, 2H, 3, 5-H), 6.95 (d, J = 8.0 Hz, 1H, 6-H), 6.89 (t, J = 7.6 Hz, 1H, 4-H), 5.56 (s, 2H, 10-H), 5.22 (s, 2H, 7-H), 2.21 (s, 3H, -*Me*). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 156.4, 145.0, 134.7, 130.8, 129.1, 128.8, 128.0, 127.0, 126.9, 122.6, 121.0, 111.6, 62.3, 54.1, 16.4. – MS (ESI): *m/z* (%) = 280 $[M+H]^+$. – HRMS ((+)-ESI): *m/z* = 280.1452 (calcd. 280.1450 for $C_{17}H_{18}N_3O$, $[M+H]^+$).

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