无金属参与的连续的 Ugi 三组分/炔烃-叠氮环加成反应一锅合成 [1,2,3]三唑并[1,5-*a*]喹喔啉

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摘要 报道了无金属参与的连续的催化型 Ugi 三组分/炔烃-叠氮环加成反应一锅合成[1,2,3]三唑并[1,5-*a*]喹喔啉。该反应使用邻叠氮基芳胺、炔醛以及异腈为原料,在磷酸催化下发生催化型 Ugi 三组分反应,随后在甲苯中加热发生环加成反应以 55%~85%的收率得到[1,2,3]三唑并[1,5-*a*]喹喔啉。

关键词 一锅; 无金属; [1,2,3]三唑并[1,5-*a*]喹喔啉; Ugi 三组分; 炔烃-叠氮环加成

One-Pot Metal-Free Synthesis of [1,2,3]triazolo[1,5-*a*]-quinoxalines by Sequential Ugi-3CR/Alkyne-Azide Cycloaddition Reaction

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Abstract A new one-pot metal-free preparation of [1,2,3]triazolo[1,5-*a*]quinoxalines by a Ugi-3CR/alkyne-azide cycloaddition sequence has been developed. The reaction of 2-azidobenzenamines, propiolic aldehydes and isocyanides produced [1,2,3]triazolo[1,5-*a*]quinoxalines in 55%~85% yields via sequential Ugi-3CR/alkyne-azide cycloaddition reaction in the presence of H₃PO₄ and heating in toluene respectively.

Keywords one-pot; metal-free; [1,2,3]triazolo[1,5-*a*]quinoxaline; Ugi-3CR; alkyne-azide cycloaddition

1 Introduction

1,2,3-Triazole skeleton is of considerable interest, and exhibits diverse pharmacological properties, such as anti-cancer, antituberculosis and antibacterial activities, therefore, it shows widespread applications in medicinal chemistry.^[1] Among the 1,2,3-triazole family, for example, the scaffold of [1,2,3]triazolo[1,5-*a*]quinoxaline has a good affinity towards the benzodiazepine and adenosine receptors.^[2] Consequently, considerable research efforts have been focused on the development for the synthesis of

[1,2,3]triazolo[1,5-*a*]quinoxalines. The traditional method for the preparation of this tricyclic system starts from 1-fluoro-2-nitrobenzene by multiple steps followed by Pictet-Spengler reaction (Scheme 1, a).^[3] Gong's group^[4] developed a copper(I)-catalyzed cascade reaction to 4-(trifluoromethyl)[1,2,3]triazolo[1,5-*a*]quinoxalines from *N*-(*o*-haloaryl)alkynyldimine and sodium azide (Scheme 1, b). Recently, Zhu's group^[5] prepared the 1,2,3-triazolo[1,5-*a*]quinoxaline scaffold starting from 1-azido-2-isocyanoarenes and terminal acetylenes using Cu(OAc)₂ as catalyst (Scheme 1, c). Though Cu(I) catalyzed reactions offer

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Received May 13, 2020; revised July 27, 2020; published online September 8, 2020.

Project supported by the Fund for Shanxi "1331 Project" Key Innovative Research Team (No. TD201718), the Key Research and Development Projects of Shanxi Province (No. 201803D31054), the Science Foundation for Youths of Shanxi Province (No. 201901D211422) and the Scientific and Technological Innovation Programs of Higher Education Institutions in Shanxi Province (No. 2019L0775).

山西省"1331工程"重点创新团队建设计划(No. TD201718)、山西省重点研发计划(No. 201803D31054)、山西省应用基础研究计划面上青年(No. 201901D211422)和山西省高等学校科技创新(No. 2019L0775)资助项目。

efficient approaches to 1,2,3-triazolo[1,5-*a*]quinoxalines, the employment of transition-metal catalysts would cause the metal contamination of products.^[6] Therefore, a new, convenient, and metal-free synthetic methodology to [1,2,3]triazolo[1,5-*a*]quinoxalines is still desirable.

(a) Traditional synthetic method

(b) Gong's work

(c) Zhu's work

(d) This work

Scheme 1 Approaches to [1,2,3]triazolo[1,5-*a*]quinoxalines

Isocyanide-based multicomponent reactions (IMCRs) are regarded as the green chemistry by minimizing the number of synthetic steps, energy consumption and waste production. Consequently, they provide access to more natural products, structurally diverse and complex heterocyclic scaffolds.^[7] Among the IMCRs, the Ugi reaction is considered as one of the best-known IMCRs due to its high versatility, exceptional efficiency, high atom economy and unexplored chemical space. The Ugi 4CR generates an α -acylamino-carboxamide adduct based on the concomitant reaction of amine, aldehyde, acid and isocyanide.^[8] The catalytic three-component Ugi reaction (Ugi-3CR) affords an α -amino amide by using aldehyde, primary amine and isocyanide in the presence of the catalyst such as acid, bromodimethyl-sulfonium bromide or ZnO-NPS and so on.^[9] In addition, some new progress of Ugi reaction like 1,4-addition Ugi reaction^[10] and chiral phosphoric acid catalyzed asymmetric Ugi reaction^[11] have further promoted

the development of Ugi reaction. However, the most of Ugi products construct linear peptide adducts rather than heterocyclic rings, the so-called post-Ugi modifications have been emerged as powerful approaches to access heterocyclic compounds. For example, Ugi/Diels-Alder,^[12] Ugi/Buchwald-Hartwig,^[13] Ugi/Heck,^[14] Ugi/aldol^[15] and Ugi/intramolecular alkyne-azide cycloaddition (IAAC)^[16] have been reported. In our previous work, the sequential Ugi/aza-Wittig,^[17] Ugi/Wittig^[18] have prepared multisubstituted quinoxalin-2(1*H*)-ones, indoles and benzimidazoles.

The IAAC reaction has been extensively applied to the synthesis of heterocycles which contain 1,2,3-triazole skeleton under mild reaction conditions.^[19] The combination of Ugi with IAAC has been proven to be a practical method for the synthesis of a series of 1,2,3-containing heterocycles, such as dihydrotriazolo[1,5-*a*]pyrazinones, triazolobenzodiazepines, cyclicpeptoid, macro-cyclic peptidomimetic and triazolobenzodiazepine-fused diketopiperazine.^[16]

To the best of our knowledge, there is no previous report on the sequential catalytic Ugi-3CR/IAAC reaction for synthesis of heterocycles. And we recently have decided to further explore a metal-free synthetic method towards [1,2,3]triazolo[1,5-*a*]quinoxaline. Herein, we wish to report a new facile synthesis of [1,2,3]triazolo[1,5-*a*]quinoxalines by a metal-free sequential catalytic Ugi-3CR/IAAC reaction starting from 2-azidobenzenamines (Scheme 1, d).

2 Results and discussion

Initially, standard substrates of 2-azidobenzeneamine (**1a**), 3-phenylpropionaldehyde (**2a**) and *tert*-butyl-isocyanide (**3a**) were employed in the presence of H₃PO₄ (20 mol%) which was used as an acid catalyst to optimize the reaction conditions (Table 1). To our delight, the catalytic Ugi-3CR proceeded smoothly in methanol for 2 d at ambient temperature. Our research was initiated with an attempt one-pot, metal-free sequential Ugi-3CR/IAAC reaction to synthesize [1,2,3]triazolo[1,5-*a*]quinoxalines, so the corresponding Ugi-3CR product was directly used for the further reaction. Although prolonging the reaction time to 48 h at room temperature, no desired product **5a** was detected (Table 1, Entry 2). Considering a higher reaction temperature maybe give a slightly better yield, then heated the reaction mixture to reflux for another 1–2 h, unfortunately, no product was obtained (Table 1, Entry 3). Subsequently, the solvent was switched from methanol to toluene, *N,N*-dimethylformamide (DMF), dimethyl sulfoxide (DMSO) or 1,4-dioxane which has a higher boiling point and heated at 80 °C for 1–2 h (Table, Entries 4–7). Fortunately, the screening results showed that toluene was found to be the best choice, and the expected product **5a** was precipitated during the reaction in 70% yield (Table 1, Entry 4).

The species and amount of acid catalyst all had a remarkable effect on the Ugi-3CR reaction. A rather lower yield of **5a** is caused by the decrease of the amount of H₃PO₄ to 10% (Table 1, Entry 8, 45%). Other protonic acids

(Table 1, Entries 9~11) and organic acids (Table 1, Entries 12~16) all resulted in a decreased yield. No product was obtained when Lewis acids such as AlCl_3 , ZnCl_2 , FeCl_2 , MgSO_4 and FeCl_3 were used as the catalyst (Table 1, Entries 17~21).

Table 1 Optimization of the reaction conditions

Entry	Catalyst (mol%)	Solvent 2	Temp./°C	Yield ^a /%
1	—	MeOH	r.t.	0
2	H_3PO_4 (20)	MeOH	r.t.	0
3	H_3PO_4 (20)	MeOH	65	0
4	H_3PO_4 (20)	Toluene	80	70
5	H_3PO_4 (20)	DMF	80	68
6	H_3PO_4 (20)	DMSO	80	65
7	H_3PO_4 (20)	1,4-Dioxane	80	55
8	H_3PO_4 (10)	Toluene	80	45
9	H_2SO_4 (20)	Toluene	80	40
10	HCl (20)	Toluene	80	50
11	HNO_3 (20)	Toluene	80	55
12	TsOH (20)	Toluene	80	50
13	$\text{CF}_3\text{SO}_3\text{H}$ (20)	Toluene	80	67
14	CH_3COOH (20)	Toluene	80	56
15	PhCOOH (20)	Toluene	80	0
16		Toluene	80	0
17	AlCl_3 (20)	Toluene	80	0
18	ZnCl_2 (20)	Toluene	80	0
19	FeCl_2 (20)	Toluene	80	0
20	MgSO_4 (20)	Toluene	80	0
21	FeCl_3 (20)	Toluene	80	0

^a Isolated yield based on 2-azidobenzeneamines **1**.

Under these optimized reaction conditions (Table 1, Entry 4), various 2-azidobenzeneamines **1**, propiolic aldehydes **2** and isocyanides **3** were used for the one-pot, metal-free sequential catalytic Ugi-3CR/IAAC reaction. They were smoothly converted into the corresponding [1,2,3]-triazolo[1,5-*a*]-quinoxalines **5** and gave moderate to good yields with different substituents of the reactants (**5a**~**5o**, 55%~

85%, Table 2). Various 2-azidobenzeneamines, propiolic aldehydes and isocyanides could be used in the one-pot reaction. Whereas good yields of **5** were separated when the 2-azidobenzeneamines substituted by an electron-donating group or 3-(trimethyl-silyl)-propiolaldehyde were utilized (**5c**, 85%, Table 2). As the low reactive aromatic isocyanide was used, the Ugi-3CR took place very slowly and no product was obtained (Entry 16, Table 2). Affected by steric hindrance, no product was obtained when *o*-substituted 2-azidobenzeneamines were used (Entry 17~19, Table 2).

Table 2 Preparation of [1,2,3]triazolo[1,5-*a*]quinoxalines **5**

Entry	5	R ¹	R ²	R ³	Yield ^a /%
1	5a	H	Ph	<i>t</i> -Bu	70
2	5b	H	Ph	<i>c</i> -C ₆ H ₁₁	71
3	5c	4-CH ₃	Si(CH ₃) ₃	<i>t</i> -Bu	85
4	5d	4-Cl	Ph	<i>t</i> -Bu	65
5	5e	4-Cl	Ph	<i>c</i> -C ₆ H ₁₁	67
6	5f	4-Br	Ph	<i>t</i> -Bu	62
7	5g	4-Br	Ph	<i>c</i> -C ₆ H ₁₁	63
8	5h	H	Si(CH ₃) ₃	<i>t</i> -Bu	80
9	5i	H	Si(CH ₃) ₃	<i>c</i> -C ₆ H ₁₁	81
10	5j	4-Cl	Si(CH ₃) ₃	<i>t</i> -Bu	75
11	5k	4-Br	Si(CH ₃) ₃	<i>t</i> -Bu	70
12	5l	H	CH ₃ (CH ₂) ₄	<i>t</i> -Bu	68
13	5m	4-Cl	CH ₃ (CH ₂) ₄	<i>t</i> -Bu	60
14	5n	H	Ph	<i>n</i> -Bu	74
15	5o	H	Ph	Benzyl	55
16	5p	H	Ph	Ph	0
17	5q	3-Br	Ph	<i>t</i> -Bu	0
18	5r	3-CH ₃	Ph	<i>t</i> -Bu	0
19	5s	4,6-(CH ₃) ₂	Ph	<i>t</i> -Bu	0

^a Isolated yields based on 2-azidobenzeneamine **1**.

On the basis of the above observations and literature reports,^[9,18] a plausible mechanism is depicted in Scheme 2. The reaction of 2-azidobenzeneamine **1** and propiolic aldehyde **2** produced imine **6** with loss of water. Protonation of **6** gave the intermediate **7**, which favored the nucleophilic attack of isocyanide **3** to provide the intermediate **8**. Subsequently, water attacked intermediate **8** to give **9**, which underwent a further 1,3-hydrogen shift to generate the Ugi-3CR product **4**. The exact structure of compound **4a** was unambiguously assigned by NMR, HRMS and IR an-

alyse which further confirmed the rationality of the mechanism. Finally, **4** underwent an intramolecular [3+2] cycloaddition reaction to get the [1,2,3]triazolo[1,5-*a*]quinoxalines **5**.

Scheme 2 Plausible reaction mechanism

3 Conclusions

In conclusion, a new one-pot metal-free preparation of [1,2,3]triazolo[1,5-*a*]quinoxalines utilizing sequential Ugi-3CR/IAAC reaction was developed. The used 2-azidobenzamines, propiolic aldehydes and isocyanides can be varied broadly, producing the products with amplified molecular complexity. The method was adapted to the synthesis of various [1,2,3]triazolo[1,5-*a*]quinoxalines in one-pot fashion under metal-free condition which makes it useful in synthetic and medicinal chemistry.

4 Experimental section

Melting points were determined using an X-4 model apparatus and were uncorrected. Analytical thin-layer chromatography (TLC) was carried out on silica gel 60 F254 plates, which were visualized by exposure to ultraviolet light. HRMS (ESI) was performed on a Thermo Scientific LTQ Orbitrap XL. ¹H NMR spectra were recorded in CDCl₃ or DMSO-*d*₆ on a Varian Mercury 400 or 600 spectrometer and resonances were relative to TMS. ¹³C NMR spectra were recorded on a Varian Mercury 400/600 (100/150 MHz) with complete proton decoupling spectrophotometers (CDCl₃: δ 77.0, DMSO: δ 39.5).

A mixture of 2-azidobenzamines **1** (1 mmol), propiolic aldehydes **2** (1 mmol), and isocyanides **3** (1 mmol) in the presence of H₃PO₄ (20 mol%) were stirred in methanol (5 mL) at room temperature for 24~48 h, then the solvent was removed completely under reduced pressure. Toluene (5 mL) was added to the reaction system, and the reaction mixture was heated to 80 °C for 1~2 h to form [1,2,3]triazolo[1,5-*a*]quinoxalines **5** which precipitated during the reaction.

2-((2-Azidophenyl)amino)-*N*-(*tert*-butyl)-4-phenylbut-3-ynamide (**4a**): White solid (278 mg, 80% yield). m.p. 150~151 °C; ¹H NMR (CDCl₃, 600 MHz) δ: 7.44 (d, *J*=7.2 Hz, 2H, Ar-H), 7.35~7.30 (m, 3H, Ar-H), 7.09~7.04 (m, 2H, Ar-H), 6.87 (t, *J*=7.5 Hz, 1H, Ar-H), 6.72 (d, *J*=7.8 Hz, 1H, Ar-H), 6.52 (s, 1H, NH), 5.08 (s, 1H, NH), 4.63 (s, 1H, CH), 1.39 (s, 9H, 3CH₃); ¹³C NMR (CDCl₃, 150 MHz) δ: 166.3, 137.7, 131.8, 128.8, 128.3, 126.0, 125.6, 121.9, 119.4, 117.9, 112.7, 85.4, 84.7, 52.0, 51.6, 28.5; IR (KBr) ν: 2119, 2102, 1666 cm⁻¹; HRMS (ESI) calcd for C₂₀H₂₂N₅O [M+H]⁺ 348.1819, found 348.1823.

N-(*tert*-Butyl)-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5a**): White solid (243 mg, 70% yield). m.p. 200~201 °C; ¹H NMR (CDCl₃, 600 MHz) δ: 8.07 (d, *J*=7.8 Hz, 1H, Ar-H), 7.84 (d, *J*=7.2 Hz, 2H, Ar-H), 7.52 (t, *J*=7.5 Hz, 2H, Ar-H), 7.44 (t, *J*=7.2 Hz, 1H, Ar-H), 7.22~7.20 (m, 1H, Ar-H), 6.96 (t, *J*=8.1 Hz, 2H, Ar-H), 5.41 (s, 1H, CH), 5.29 (s, 1H, NH), 5.01 (s, 1H, NH), 1.03 (s, 9H, 3CH₃); ¹³C NMR (CDCl₃, 150 MHz) δ: 167.0, 143.3, 134.1, 129.4, 129.2, 129.0, 126.9, 123.6, 121.9, 120.2, 116.8, 116.1, 53.7, 52.0, 28.2; IR (KBr) ν: 1677 cm⁻¹; HRMS (ESI) calcd for C₂₀H₂₂N₅O [M+H]⁺ 348.1819, found 348.1822.

N-Cyclohexyl-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5b**): White solid (265 mg, 71% yield). m.p. 202~203 °C; ¹H NMR (CDCl₃, 600 MHz) δ: 8.00 (d, *J*=7.8 Hz, 1H, Ar-H), 7.83 (d, *J*=7.2 Hz, 2H, Ar-H), 7.50~7.41 (m, 3H, Ar-H), 7.21 (t, *J*=7.5 Hz, 1H, Ar-H), 6.96~6.95 (m, 2H, Ar-H), 5.63 (s, 1H, NH), 5.42 (s, 1H, CH), 5.16 (s, 1H, NH), 3.62~3.61 (m, 1H, NCH), 1.59~0.83 (m, 10H, 5CH₂); ¹³C NMR (DMSO, 100 MHz) δ: 167.5, 142.1, 135.6, 130.1, 128.9, 128.6, 128.2, 126.6, 125.0, 121.1, 117.8, 115.6, 115.0, 52.6, 47.7, 32.0, 25.1, 24.1; IR (KBr) ν: 1647 cm⁻¹; HRMS (ESI) calcd for C₂₂H₂₄N₅O [M+H]⁺ 374.1975, found 374.1977.

N-(*tert*-Butyl)-8-methyl-3-(trimethylsilyl)-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5c**): White solid (304 mg, 85% yield). m.p. 218~219 °C; ¹H NMR (CDCl₃, 600 MHz) δ: 7.83 (s, 1H, Ar-H), 7.00 (d, *J*=8.4 Hz, 1H, Ar-H), 6.86 (d, *J*=7.8 Hz, 1H, Ar-H), 5.54 (s, 1H, NH), 5.19 (s, 1H, NH), 5.04 (s, 1H, CH), 2.34 (s, 3H, CH₃), 1.20 (s, 9H, 3CH₃), 0.43 (s, 9H, 3CH₃); ¹³C NMR (DMSO, 100 MHz) δ: 168.3, 140.9, 134.3, 133.0, 128.7, 126.8, 121.4, 115.9, 114.9, 52.8, 50.4, 28.2, 20.2, -1.01; IR (KBr) ν: 1686 cm⁻¹; HRMS (ESI) calcd for C₁₈H₂₈N₅-OSi [M+H]⁺ 358.2058, found 358.2060.

N-(*tert*-Butyl)-8-chloro-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5d**): White solid

(248 mg, 65% yield). m.p. 243~244 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.02 (d, $J=2.0$ Hz, 1H, Ar-H), 7.80 (d, $J=7.2$ Hz, 2H, Ar-H), 7.53~7.42 (m, 3H, Ar-H), 7.16~7.13 (m, 1H, Ar-H), 6.87 (d, $J=8.4$ Hz, 1H, Ar-H), 5.41 (s, 1H, CH), 5.36 (s, 1H, NH), 5.17 (s, 1H, NH), 1.03 (s, 9H, 3CH₃); ^{13}C NMR (DMSO, 100 MHz) δ : 167.6, 142.2, 134.7, 129.9, 128.9, 128.3, 128.2, 126.7, 125.1, 121.3, 120.7, 116.2, 115.1, 53.0, 50.7, 28.1; IR (KBr) ν : 1687 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{20}\text{H}_{21}\text{ClN}_5\text{O}$ $[\text{M}+\text{H}]^+$ 382.1429, found 382.1433.

8-Chloro-*N*-cyclohexyl-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5e**): White solid (273 mg, 67% yield). m.p. 234~235 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 7.85~7.76 (m, 3H, Ar-H), 7.51~7.42 (m, 3H, Ar-H), 7.16~7.13 (m, 1H, Ar-H), 6.87 (d, $J=8.8$ Hz, 1H, Ar-H), 5.84 (d, $J=6.8$ Hz, 1H, NH), 5.40 (s, 1H, CH), 5.16 (s, 1H, NH), 3.68~3.59 (m, 1H, NCH), 1.66~0.87 (m, 10H, 5CH₂); ^{13}C NMR (DMSO, 100 MHz) δ : 167.2, 142.2, 134.6, 129.8, 128.9, 128.3, 126.6, 125.0, 121.5, 120.9, 116.4, 115.2, 52.5, 47.7, 32.0, 31.9, 25.1, 24.1, 24.0; IR (KBr) ν : 1647 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{22}\text{H}_{23}\text{ClN}_5\text{O}$ $[\text{M}+\text{H}]^+$ 408.1586, found 408.1589.

8-Bromo-*N*-(*tert*-butyl)-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5f**): White solid (264 mg, 62% yield). m.p. 252~253 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.16 (d, $J=2.4$ Hz, 1H, Ar-H), 7.80~7.78 (m, 2H, Ar-H), 7.53~7.42 (m, 3H, Ar-H), 7.29~7.27 (m, 1H, Ar-H), 6.82 (d, $J=8.8$ Hz, 1H, Ar-H), 5.42 (s, 1H, CH), 5.37 (s, 1H, NH), 5.21 (s, 1H, NH), 1.03 (s, 9H, 3CH₃); ^{13}C NMR (DMSO, 100 MHz) δ : 167.6, 142.2, 135.1, 131.0, 129.9, 128.9, 128.3, 126.7, 125.0, 121.6, 117.7, 116.6, 107.6, 52.9, 50.7, 28.1; IR (KBr) ν : 1687 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{20}\text{H}_{21}\text{BrN}_5\text{O}$ $[\text{M}+\text{H}]^+$ 426.0924, found 426.0928.

8-Bromo-*N*-cyclohexyl-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5g**): White solid (284 mg, 63% yield). m.p. 229~230 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.07 (s, 1H, Ar-H), 7.80 (d, $J=7.6$ Hz, 2H, Ar-H), 7.52~7.43 (m, 3H, Ar-H), 7.30~7.28 (m, 1H, Ar-H), 6.83 (d, $J=8.8$ Hz, 1H, Ar-H), 5.62 (d, $J=6.8$ Hz, 1H, NH), 5.41 (s, 1H, CH), 5.16 (s, 1H, NH), 3.62~3.60 (m, 1H, NCH), 1.63~0.83 (m, 10H, 5CH₂); ^{13}C NMR (DMSO, 100 MHz) δ : 167.2, 142.2, 135.0, 131.0, 129.8, 128.9, 128.3, 126.6, 124.9, 121.8, 117.8, 116.8, 107.9, 52.5, 47.7, 32.0, 31.9, 25.1, 24.1, 24.0; IR (KBr) ν : 1645 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{22}\text{H}_{23}\text{BrN}_5\text{O}$ $[\text{M}+\text{H}]^+$ 452.1080, found 452.1086.

N-(*tert*-Butyl)-3-(trimethylsilyl)-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5h**): White solid (275 mg, 80% yield). m.p. 222~223 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.03 (d, $J=7.6$ Hz, 1H, Ar-H), 7.18 (t, $J=7.6$ Hz, 1H, Ar-H), 6.95 (t, $J=8.2$ Hz, 2H, Ar-H), 5.42 (s, 1H, NH), 5.22 (s, 1H, NH), 5.07 (s, 1H, CH), 1.19 (s, 9H, 3CH₃), 0.43 (s, 9H, 3CH₃); ^{13}C NMR (CDCl_3 , 100 MHz) δ : 168.2, 141.0, 135.4, 134.0, 128.1, 121.3, 117.6, 115.6, 114.8, 52.8, 50.5, 28.2, -1.02; IR (KBr) ν : 1681 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{17}\text{H}_{26}\text{N}_5\text{OSi}$ $[\text{M}+\text{H}]^+$ 344.1901,

found 344.1906.

N-Cyclohexyl-3-(trimethylsilyl)-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5i**): White solid (299 mg, 81% yield). m.p. 215~216 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.02 (d, $J=7.6$ Hz, 1H, Ar-H), 7.18 (t, $J=7.8$ Hz, 1H, Ar-H), 6.95 (t, $J=8.0$ Hz, 2H, Ar-H), 5.50 (s, 1H, NH), 5.21 (s, 1H, NH), 5.15 (s, 1H, CH), 3.68~3.58 (m, 1H, NCH), 1.81~0.83 (m, 10H, 5CH₂), 0.43 (s, 9H, 3CH₃); ^{13}C NMR (DMSO, 100 MHz) δ : 167.8, 141.1, 135.3, 133.9, 128.1, 121.3, 117.8, 115.6, 114.9, 52.5, 47.8, 32.2, 32.1, 25.2, 24.3, -1.04; IR (KBr) ν : 1677 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{19}\text{H}_{28}\text{N}_5\text{OSi}$ $[\text{M}+\text{H}]^+$ 370.2058, found 370.2060.

N-(*tert*-Butyl)-8-chloro-3-(trimethylsilyl)-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5j**): White solid (283 mg, 75% yield). m.p. 255~256 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.03 (d, $J=2.0$ Hz, 1H, Ar-H), 7.16~7.13 (m, 1H, Ar-H), 6.88 (d, $J=8.4$ Hz, 1H, Ar-H), 5.39 (s, 1H, NH), 5.32 (s, 1H, NH), 5.06 (s, 1H, CH), 1.21 (s, 9H, 3CH₃), 0.43 (s, 9H, 3CH₃); ^{13}C NMR (CDCl_3 , 100 MHz) δ : 167.3, 143.2, 132.6, 132.5, 128.8, 125.2, 122.5, 117.2, 53.6, 52.3, 28.4, -0.96; IR (KBr) ν : 1685 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{17}\text{H}_{25}\text{ClN}_5\text{OSi}$ $[\text{M}+\text{H}]^+$ 378.1511, found 378.1517.

8-Bromo-*N*-(*tert*-butyl)-3-(trimethylsilyl)-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5k**): White solid (295 mg, 70% yield). m.p. 267~268 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.17 (d, $J=2.4$ Hz, 1H, Ar-H), 7.29~7.27 (m, 1H, Ar-H), 6.83 (d, $J=8.8$ Hz, 1H, Ar-H), 5.41 (s, 1H, NH), 5.33 (s, 1H, NH), 5.07 (s, 1H, CH), 1.21 (s, 9H, 3CH₃), 0.43 (s, 9H, 3CH₃); ^{13}C NMR (DMSO, 100 MHz) δ : 167.9, 141.2, 134.9, 134.0, 130.6, 122.2, 117.8, 116.7, 107.8, 52.7, 50.5, 28.2, -1.08; IR (KBr) ν : 1686 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{17}\text{H}_{25}\text{BrN}_5\text{OSi}$ $[\text{M}+\text{H}]^+$ 422.1006, found 422.1011.

N-(*tert*-Butyl)-3-pentyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5l**): White solid (232 mg, 68% yield). m.p. 157~158 °C; ^1H NMR (CDCl_3 , 400 MHz) δ : 8.00 (d, $J=7.8$ Hz, 1H, Ar-H), 7.19 (t, $J=7.2$ Hz, 1H, Ar-H), 6.97~6.92 (m, 2H, Ar-H), 5.91 (s, 1H, NH), 5.11 (s, 1H, CH), 5.02 (s, 1H, NH), 2.82~2.76 (m, 2H, CH₂), 1.81~1.76 (m, 2H, CH₂), 1.38~1.37 (m, 4H, 2CH₂), 1.27 (s, 9H, 3CH₃), 0.91 (t, $J=6.9$ Hz, 3H, CH₃); ^{13}C NMR (CDCl_3 , 100 MHz) δ : 167.6, 144.6, 133.5, 128.6, 123.6, 122.2, 120.5, 116.7, 115.7, 54.2, 52.0, 31.6, 28.9, 28.5, 24.9, 22.5, 14.0; IR (KBr) ν : 1688 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{19}\text{H}_{28}\text{N}_5\text{O}$ $[\text{M}+\text{H}]^+$ 342.2288, found 342.2290.

N-(*tert*-Butyl)-8-chloro-3-pentyl-4,5-dihydro-[1,2,3]triazolo[1,5-*a*]quinoxaline-4-carboxamide (**5m**): White solid (225 mg, 60% yield). m.p. 213~214 °C; ^1H NMR (DMSO-*d*₆, 400 MHz) δ : 7.95 (s, 1H, NH), 7.74 (d, $J=2.4$ Hz, 1H, Ar-H), 7.20 (s, 1H, NH), 7.15~7.12 (m, 1H, Ar-H), 6.87 (d, $J=8.4$ Hz, 1H, Ar-H), 5.30 (d, $J=2.0$ Hz, 1H, CH), 2.71~2.59 (m, 2H, CH₂), 1.61~1.60 (m, 2H, CH₂), 1.33~1.32 (m, 4H, 2CH₂), 1.23 (s, 9H, 3CH₃), 0.88 (t, $J=6.8$ Hz, 3H, CH₃); ^{13}C NMR (DMSO-*d*₆, 100 MHz) δ : 168.2, 142.7, 135.2, 127.7, 124.9, 121.3, 120.1, 115.8,

114.6, 51.8, 50.4, 31.0, 28.5, 28.2, 23.8, 21.9, 13.9; IR (KBr) ν : 1688 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{19}\text{H}_{27}\text{ClN}_5\text{O}$ $[\text{M}+\text{H}]^+$ 376.1899, found 376.1901.

N-Butyl-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-a]quinoxaline-4-carboxamide (**5n**): White solid (257 mg, 74% yield). m.p. 205~206 $^{\circ}\text{C}$; ^1H NMR (CDCl_3 , 600 MHz) δ : 7.78~7.74 (m, 3H, Ar-H), 7.46~7.39 (m, 3H, Ar-H), 7.19 (t, $J=7.8$ Hz, 1H, Ar-H), 6.94~6.88 (m, 2H, Ar-H), 6.30 (s, 1H, NH), 5.36 (s, 1H, CH), 5.32 (s, 1H, NH), 3.28~3.05 (m, 2H, CH_2), 1.31~1.26 (m, 2H, CH_2), 1.08~1.02 (m, 2H, CH_2), 0.74 (t, $J=7.5$ Hz, 3H, CH_3); ^{13}C NMR (CDCl_3 , 150 MHz) δ : 168.3, 143.8, 134.2, 129.5, 129.2, 129.0, 128.7, 126.6, 123.2, 122.2, 120.3, 116.9, 116.2, 53.2, 39.7, 31.0, 19.6, 13.6; IR (KBr) ν : 1654 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{20}\text{H}_{22}\text{N}_5\text{O}$ $[\text{M}+\text{H}]^+$ 348.1819, found 348.1821.

N-Benzyl-3-phenyl-4,5-dihydro-[1,2,3]triazolo[1,5-a]quinoxaline-4-carboxamide (**5o**): White solid (211 mg, 55% yield). m.p. 270~271 $^{\circ}\text{C}$; ^1H NMR (CDCl_3 , 600 MHz) δ : 7.62~7.56 (m, 3H, Ar-H), 7.39~7.34 (m, 3H, Ar-H), 7.23~7.15 (m, 4H, Ar-H), 6.96~6.89 (m, 4H, Ar-H), 6.82 (s, 1H, NH), 5.38 (s, 1H, CH), 5.18 (s, 1H, NH), 4.42~4.36 (m, 2H, CH_2); ^{13}C NMR (CDCl_3 , 150 MHz) δ : 168.5, 144.0, 137.1, 134.1, 129.2, 129.1, 128.7, 128.6, 127.4, 127.2, 126.7, 123.1, 122.4, 120.6, 117.1, 116.4, 53.3, 43.8; IR (KBr) ν : 1654 cm^{-1} ; HRMS (ESI) calcd for $\text{C}_{23}\text{H}_{20}\text{N}_5\text{O}$ $[\text{M}+\text{H}]^+$ 382.1662, found 382.1665.

Supporting Information ^1H NMR and ^{13}C NMR spectra for compounds **4a** and **5**. The Supporting Information is available free of charge via the Internet at <http://sioc-journal.cn>.

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