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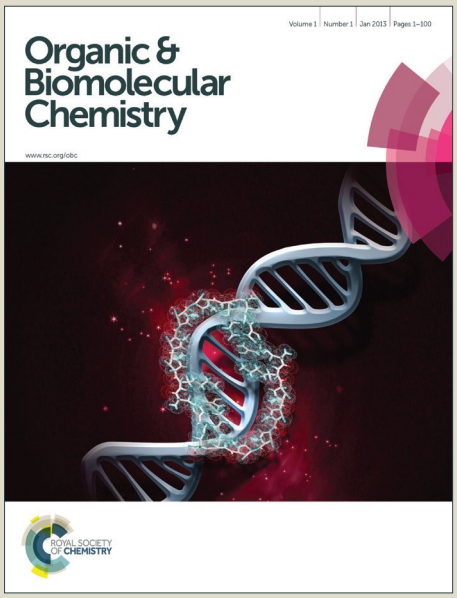

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Efficient Synthesis of Pyrrolo[1,2-a]quinoxalines Catalyzed by Brønsted Acid through Cleavage of C-C Bond

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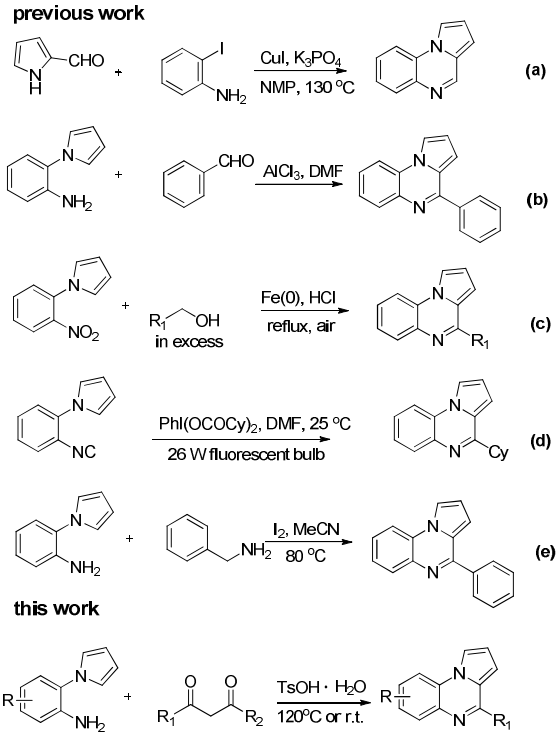
An efficient and convenient one-pot domino reaction of the direct synthesis of pyrrolo[1,2-*a*]quinoxaline has been developed. This approach utilizes imine formation reaction, S_EAr reaction and cleavage of C-C bond catalyzed by Brønsted acid. *β*-Diketones and *β*-keto esters are both well adaptive to give the corresponding products in moderate to excellent yields.

Introduction

The quinoxaline skeleton is a key structure unit in various compounds with biological activities.[1] Pyrrolo[1,2-*a*]quinoxaline as an indispensable part of quinoxalines exhibits a wide range of biological and medical properties. For example, ferrocenyl pyrrolo[1,2-*a*]quinoxaline plays an effective role in fighting against malaria,[2] and 4-substituted pyrrolo[1,2-*a*]quinoxalines are anti-leishmania agents.[3] Furthermore, extensive uses have been proved, such as the human protein kinase CK2 inhibitors,[4] 5-HTR affinities,[5] anticancer[6] and glucagon receptor antagonists.[7]

Due to their wide applications, there emerged some synthetic methods of pyrrolo[1,2-*a*]quinoxaline in recent years (Scheme 1). Reaves and co-workers reported a strategy of Cu-catalyzed annulation of 2-formylazoles with *o*-aminoiodorarenes in 2010 (**a**).[8] Besides, based on 2-(1*H*-pyrrol-1-yl)aniline used by Cheeseman in 1965 to synthesize this kind of coumpouds,[9] many strategies have been reported. It could react with benzaldenyde,[10] aliphatic or benzylic alcohols[11] and benzylamines[12] to obtain the desirable compounds catalyzed by Lewis acids (**b, c, e**). In 2014, Jamison and co-workers proposed a method using visible-light photoredox catalysis (**d**).[13] In addition, many other methods have also been reported.[14] However, these methods suffered from several disadvantages, like unsatisfactory yields, excessive reactants, transition metal catalysts, unstable reactants and limitations of the product structure. Our group has been dedicating to building this skeletal structure, and quite remarkable progresses have been made (Scheme 2).[15]



Scheme 1 synthesis of pyrrolo[1,2-*a*]quinoxaline derivatives

Recently, Bao and co-workers reported an efficient protocol to synthesize a series of benzothiazoles and benzimidazoles through Brønsted acid catalyzed cylization reaction.[16a-b] We envisioned that a reaction strategy of C-C bond cleavage will become a feasible and efficient synthetic option of pyrrolo[1,2-*a*]quinoxaline derivatives. Different from their limitation of *β*-diketones, we discovered that the reaction of *β*-keto esters could also be applied to this strategy, so that the reaction scope and generality were greatly improved. Based on these points and our previous works on synthesizing

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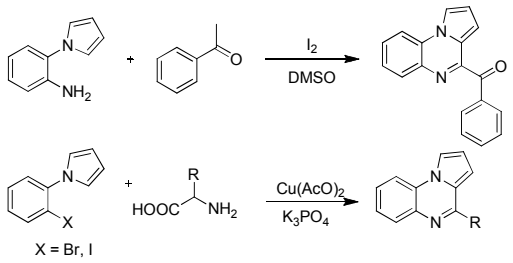


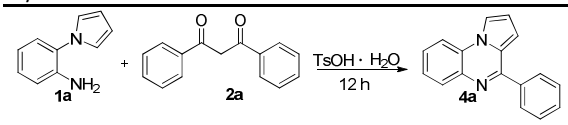
Scheme 2 our previous works on synthesis of the compound

heterocyclic compounds, we report an efficient, convenient and low-toxic one-pot reaction for the synthesis of pyrrolo[1,2-*a*]quinoxaline derivatives (Scheme 1).

Results and discussion

We initiated our proposal with exploring the optimized reaction conditions using 2-(1*H*-pyrrol-1-yl)aniline (**1a**) and 1,3-diphenylpropane-1,3-dione (**2a**) as the model substrates. In the presence of TsOH·H_2O (0.095 g, 0.5 mmol) in DMSO at 110 °C, the desired product **4a** was furnished in 78% (Table 1, entry 1). Next a series of Brønsted acids, namely PivOH, AcOH, CF_3COOH and CH_3SO_3H, were investigated and none was better than TsOH·H_2O (Table 1, entries 2-5). Then several solvents were screened in the reaction, and the reaction in DMSO produced the best yield of the product (Table 1, entries 1, 6-8). Furthermore, when the temperature was changed, to our delight, an enhancement in product yield was observed in 120 °C (Table 1, entries 1, 9 and 10). Subsequently, the dosages of catalyst were examined and the reaction with 50 mol% TsOH·H_2O gave the highest yield of 89% (Table 1, entries 11-13). And when the **1a** / **2a** ratio was changed, the reaction of 0.5 mmol **1a** with 0.75 mmol **2a** gave the best yield (Table 1, entries 1, 15-16). For further investigation, the reaction was protected by O_2 or N_2 with a balloon, but did not significantly affect this reaction (Table 1, entries 17-18).

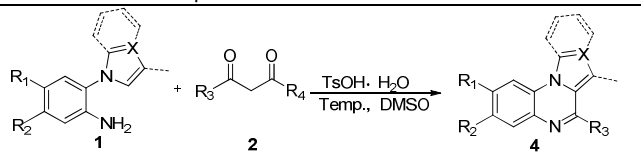
Table 1 Optimization of reaction conditions for the one-pot synthesis of **4a**[a]



Entry	Catalyst / mol %	T / °C	Solvent	Yield (%)[b]
1	TsOH / 100	110	DMSO	78
2	PivOH / 100	110	DMSO	27
3	AcOH / 100	110	DMSO	N. R.
4	CF_3COOH / 100	110	DMSO	71
5	CH_3SO_3H / 100	110	DMSO	75
6	TsOH·H_2O/ 100	110	CH_3CN	56
7	TsOH·H_2O / 100	110	DMF	66
8	TsOH·H_2O / 100	110	Toluene	49
9	TsOH·H_2O / 100	120	DMSO	87
10	TsOH·H_2O / 100	130	DMSO	67
11	TsOH·H_2O / 200	120	DMSO	60
12	TsOH·H_2O / 50	120	DMSO	89
13	TsOH·H_2O / 20	120	DMSO	67
14	none	120	DMSO	13
15	TsOH·H_2O / 50	120	DMSO	74[c]
16	TsOH·H_2O / 50	120	DMSO	88[d]
17	TsOH·H_2O /100 /O_2	120	DMSO	81[e]
18	TsOH·H_2O / 100 / N_2	120	DMSO	71[e]

[a]Reaction conditions: **1a** (0.079 g, 0.5 mmol.), **2a** (0.168 g, 0.75 mmol), solvent (2 mL). [b]Isolated yields. [c] **1a** (0.079 g, 0.5 mmol.), **2a** (0.112 g, 0.5 mmol). [d] **1a** (0.079 g, 0.5 mmol.), **2a** (0.224 g, 1 mmol). [e]The gas was in the balloon.

Table 2 Substrate scope of *β*-diketones [a]



Entry	**1**(R_1 / R_2)	**2** (R_3 / R_4)	Product	Yield(%)[b]
1	H / H	Ph / Ph	**4a**	89[d]
2	H / Me	Ph / Ph	**4b**	78[d]
3	H / OMe	Ph / Ph	**4c**	83[d]
4	H/ Cl	Ph / Ph	**4d**	94[d]
5	Cl / H	Ph / Ph	**4e**	91[d]
6	H / F	Ph / Ph	**4f**	96[d]
7	F / H	Ph / Ph	**4g**	87[d]
8	2-(1*H*-imidazol-1-yl)aniline	Ph / Ph	**4h**	0[d]
9	2-(1*H*-indol-1-yl)aniline	Ph / Ph	**4i**	46[d]
10	2-(3-methyl-1*H*-indol-1-yl)aniline	Ph / Ph	**4j**	75[d]
11	H / H	Me / Ph	**4k**	87[c]
12	H / H	Me / Me	**4k**	90[c]
13	H / H	Et / Et	**4l**	89[c]
14	H / H	t-Bu / t-Bu	**4m**	0[c,d]
15	H / Me	Me / Ph	**4n**	79[c]
16	H / Cl	Me / Ph	**4o**	89[c]
17	H / OMe	Me / Ph	**4p**	78[c]
18	H / H	CF_3 / Me	**4k**	76[c]

[a]Reaction conditions: **1** (0.5 mmol.), **2** (0.75 mmol), solvent (2 mL), TsOH·H_2O (0.048 g, 0.25 mmol) 12 h. [b]Isolated yields. [c]Reaction occurred at room temperature. [d]Reaction occurred at 120 °C.

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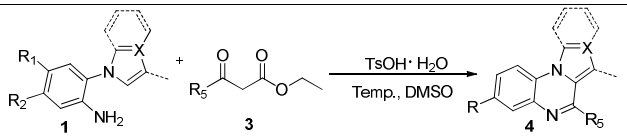
With the optimized reaction conditions, the substrate scope of this method was investigated. In general, compound **1** bearing electron-withdrawing groups provided better yields than electron-donating groups (Table 2, entries 1-7). It was worth mentioning that 2-(1*H*-indol-1-yl)aniline proceeded well and the reaction of 2-(3-methyl-1*H*-indol-1-yl)aniline with an electron-donating methyl group at 3-position afforded a better yield (Table 2, entries 9-10). However, reaction of electron-deficient 2-(1*H*-imidazol-1-yl)aniline failed to give any desired product (Table 2, entry 8). This phenomenon was similar to a previous study reported by Chardra.[10] Then the reactions of 2-(1*H*-pyrrol-1-yl)aniline with *β*-diketones were examined, and the desired products were obtained in good to excellent yields. To our delight, *β*-diketones bearing aliphatic groups (any of R_3 and R_4 or both of them) reacted at room temperature to give satisfactory yields (Table 2, entries 11-13, 15-17). But 2,2,6,6-tetramethylheptane-3,5-dione failed to give any product at any temperature possibly because of stereo-hindrance effect (Table 2, entry 14). Besides, reactions of unsymmetrical β -diketones showed that the main products carry alkyl group (Table 2, entries 11, 15-17). Then, 1,1,1-trifluoropentane-2,4-dione was used and the obtained product suggested the part with electron-withdrawing group was the leaving group (Table 2, entry 18).

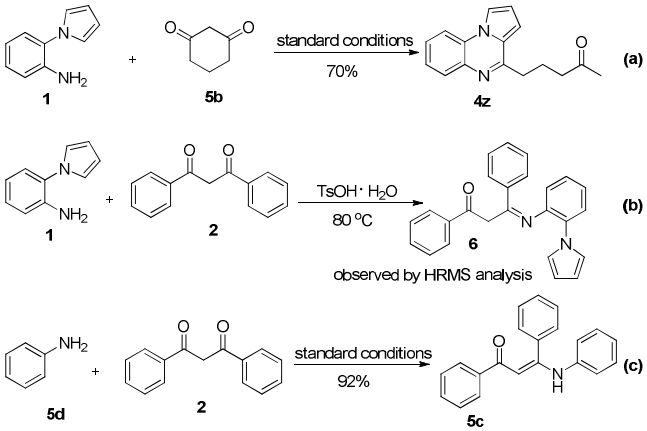
Similar results were obtained when β-keto esters substituted for *β*-diketones as reaction substrates. Compound **1** with a variety of substituents (H, CH_3, OCH_3, Cl and F) reacting with ethyl 3-oxo-3-phenylpropanoate furnished the products in moderate to good yields (Table 3, entries 1-5). Ethyl 3-oxobutanoate and ethyl 3-oxopentanoate also preceeded well (Table 3, entries 6-7). In addition, ethyl 3-oxo-3-phenylpropanoate with a fluorine group gave a better yield than that with a methoxy group (Table 3, entries 8 and 10). And the yields had no significant differences between fluorine in *ortho*-position and *meta*-position (Table 3, entries 9 and 10). But 2-(1*H*-indol-1-yl)aniline and 2-(3-methyl-1*H*-indol-1-yl)aniline reacted with ethyl 3-oxo-3-phenyl-propanoate (1a) to afford product in low yield of 34% and 57%, respectively. Finally benzhydryl 3-oxobutanoate with a sterically hindered ester group also gave a satisfying yield of 84% (Table 3, entry 23).

Table 3 Substrate scope of *β*-keto esters [a]

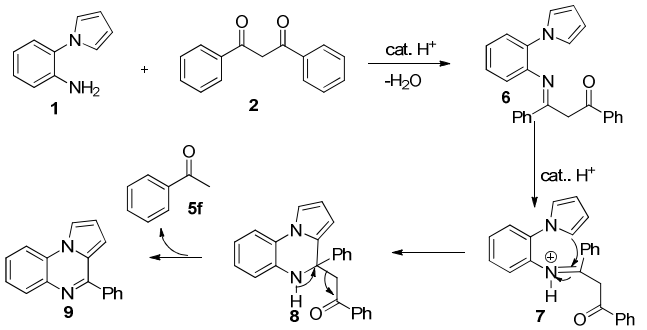


Entry	**1** (R_1 / R_2)	**3** (R_5)	Product	Yield(%)[b]
1	H / H	Ph	**4a**	84
2	H / Me	Ph	**4b**	79
3	H / OMe	Ph	**4c**	81
4	H / Cl	Ph	**4d**	91
5	H / F	Ph	**4f**	64
6	H / H	Me	**4k**	87
7	H / H	Et	**4l**	54
8	H / H	*p*-Methoxyphenyl	**4q**	71
9	H / H	*m*-fluorophenyl	**4r**	87
10	H / H	*p*-fluorophenyl	**4s**	84
11	H / Cl	Me	**4o**	87
12	H / Me	Me	**4n**	82
13	H / OMe	Me	**4p**	85
14	H / Me	*p*-fluorophenyl	**4t**	86
15	H / Me	*p*-Methoxyphenyl	**4u**	69
16	H / Cl	*m*-fluorophenyl	**4v**	90
18	H / Cl	*p*-fluorophenyl	**4w**	84
19	H / OMe	*p*-Methoxyphenyl	**4x**	74
20	H / OMe	*m*-fluorophenyl	**4y**	82
21	2-(1*H*-indol-1-yl)aniline	Ph	**4i**	34
22	2-(3-methyl-1*H*indol-1-yl)aniline	Ph	**4j**	57
23	H	**5a**[c]	**4k**	84

[a]Reaction conditions: **1** (0.5 mmol.), **2** (0.75 mmol), TsOH·H_2O (0.048 g, 0.25 mmol), 12 h.[b]Isolated yields. [c]**5a** = benzhydryl 3-oxobutanoate.



Scheme 3 Control experiments.



Scheme 4 Plausible mechanism for formation of pyrrolo[1,2-*a*]quinoxalines.

Subsequently, to further extend this proposal, several control experiments were carried out (Scheme 3). Cyclohexane-1,3-dione and 2-(1*H*-pyrrol-1-yl)aniline were treated with TsOH·H_2O at 120 °C

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in DMSO, and the product 5-(pyrrolo[1,2-*a*]quinoxalin-4-yl)pentan-2-one **4z** was obtained in 70% (**a**), which showed that circular diketone compounds were also appropriate for this proposal and the by-products were the corroding ketones. Then we observed the imine intermediate **6** by HRMS analysis successfully at 80 °C (**b**). Besides, the imine **5c** was easily obtained under standard conditions (**c**), which confirmed our conjecture of the mechanism.

On the basis of the previous literatures[16, 17], a possible mechanism for the generation of pyrrolo[1,2-*a*]quinoxaline was proposed (Scheme 4). The TsOH·H_2O catalyzed the condensation of compounds **1** and **2** to generate the imine intermediate **6**. Then **6** would convert into **7** in the presence of acid. And an intramolecular nucleophilic addition occurred to the intermediate **8**. At last, C-C bond parted and the desired product **9** was generated.

Conclusions

In summary, we have developed an efficient and straightforward one-pot domino reaction for the formation of pyrrolo[1,2-*a*]quinoxalines without metal catalyst. A variety of pyrrolo[1,2-*a*]quinoxaline derivatives were synthesized in moderate to excellent yields. This one-pot metal-free process for the construction of pyrrolo[1,2-*a*]quinoxalines has potential applications in the synthesis of biologically and medicinally relevant compounds.

Experimental

General procedure

^{1}H and ^{13}C NMR spectra were recorded with a 300 MHz Bruker instrument or a 400 MHz Bruker instrument in $CDCl_3$ or DMSO-d_6,and and tetramethylsilane (TMS) was used as the internal standard. HRMS spectra were determined on a Q-TOF spectrograph. Compounds **1** and Benzhydryl 3-oxobutanoate were prepared according to the literature (see supporting information). Other reagents were commercially available and were used without further purification. All reactions were monitored by thin-layer chromatography (TLC).

General experimental procedure for 4-phenylpyrrolo[1,2-*a*]quinoxaline (4a)

To a solution of DMSO (2 ml), 2-(1*H*-pyrrol-1-yl)aniline (0.079 g, 0.5 mmol) , 1,3-diphenylpropane-1,3-dione (0.168 g, 0.75 mmol) and TsOH·H_2O (0.048 g, 0.25 mmol) were added and stirred for 12 h at 120 °C, Then cooled to room temperature. Brine (30 ml) was poured into the solution and the mixture was extracted with EtOAc (3 × 30 mL). The organic layers were combined and dried by anhydrous $MgSO_4$. The product was purified by flash chromatography on silica gel (petroleum ether / EtOAc = 20: 1). Compound **4a** was obtained as light yellow solid in 89% yield (0.109 g). Light yellw solid. Mp: 99-100 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.07-7.97 (m, 4H), 7.89 (dd, *J* = 8.1 Hz, 1.5 Hz, 1H), 7.58-7.43 (m,5H), 7.25 (s, 1H), 7.00 (dd, *J* = 12 Hz, 1.2 Hz, 1H), 6.90-6.88 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 154.1, 138.46, 136.26, 130.26, 129.80, 128.64, 128.59, 127.48, 127.18, 125.42, 125.28, 114.62, 113.99, 113.63, 108.74, 77.4; HRMS calcd for $C_{17}H_{12}N_2$ [(M+H)$^+$]: 245.1073; found, 245.1073.

7-methyl-4-phenylpyrrolo[1,2-*a*]quinoxaline (4b)

Light yellow solid. Mp: 93-95 ºC. ^{1}H NMR (300 MHz, $CDCl_3$): δ =7.94-7.70 (m, 2H), 7.85-7.83 (m, *J* = 1.2 Hz, 1H), 7.76 (d, *J* = 0.6 Hz, 1H), 7.66 (d, *J* = 8.4 Hz, 1H), 7.48-7.39 (m, 3H), 7.23 (dd, *J* = 8.4 Hz, 1.5 Hz, 1H), 6.88 (dd, *J* = 3.9 Hz, 1.2 Hz 1H), 6.77 (m, 1H), 2.40 (s, 3H); ^{13}C NMR (75 MHz ,$CDCl_3$): δ = 153.25, 137.57, 135.17, 133.98, 129.01, 128.65, 127.58, 127.54, 127.49, 127.14, 124.65, 124.27, 123.98, 113.31, 112.64, 112.28, 107.35, 20.06; HRMS calcd for $C_{18}H_{14}N_2$ [(M+H)$^+$]: 259.1230; found, 259.1230.

7-methoxy-4-phenylpyrrolo[1,2-*a*]quinoxaline (4c)

Light yellow solid. Mp: 117-118 ºC. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.03-7.97 (m, 2H), 7.95-7.93(m, 1H), 7.81 (d, *J* = 9.0 Hz, 1H), 7.58-7.49 (m, 4H), 7.16 (dd, *J* = 9.0 Hz, 3 Hz, 1H), 6.99 (dd, *J* = 3.9 Hz, 0.9 Hz, 1H), 6.88 (dd, *J* = 3.9 Hz, 2.7 Hz), 3.93 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 157.25, 154.70, 129.84, 128.64, 128.60, 125.11, 121.47, 116.79, 114.60, 114.37, 113.77, 111.29, 108.50, 55.76; HRMS calcd for $C_{18}H_{14}N_2O$ [(M+H)$^+$]: 275.1179; found, 275.1179.

7-chloro-4-phenylpyrrolo[1,2-*a*]quinoxaline (4d)

Light yellow solid. Mp: 154-155 ºC. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.05 (s, 1H), 8.01-7.97 (m, 3H), 7.81 (d, *J* = 8.7 Hz, 1H), 7.59-7.53 (m, 3H), 7.48 (dd, *J* = 8.7 Hz, 2.1 Hz, 1H), 7.03 (d, *J* = 3.6 Hz, 1H), 6.92-6.90 (m, 1H), ^{13}C NMR (75 MHz, $CDCl_3$): δ = 155.38, 137.05, 130.45, 130.17, 129.47, 128.65, 127.49, 125.78, 125.24, 115.07, 114.79, 114.47, 109.52; HRMS calcd for $C_{17}H_{11}N_2Cl$ [(M+H)$^+$]: 279.0684; found, 279.0695.

8-chloro-4-phenylpyrrolo[1,2-a]quinoxaline (4e)

Light yellow solid. Mp: 189-191 ºC. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.01-7.93 (m, 3H), 7.91 (dd, *J* = 2.7Hz, 1.2Hz, 1H), 7.84 (d, *J* = 2.1 Hz, 1H), 7.58-7.50 (m, 3H), 7.41 (dd, *J* = 8.7 Hz, 2.1 Hz, 1H), 7.01 (dd, *J* = 4.2 Hz, 1.2 Hz, 1H), 6.91 (dd, *J* = 3.9 Hz, 2.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 154.48, 138.12, 134.82, 132.81, 131.36, 130.01, 128.64, 128.59, 127.71, 125.68, 125.25, 114.85, 114.54, 113.78, 109.25; HRMS calcd for $C_{17}H_{11}N_2Cl$ [(M+H)$^+$]: 279.0684; found, 279.0689.

7-fluoro-4-phenylpyrrolo[1,2-*a*]quinoxaline (4f)

White solid. Mp: 135-136 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ =8.00-7.94 (m, 3H), 7.84-7.80 (m, 1H), 7.56 -7.52 (m, 3H), 7,73 (dd, *J* = 9.5 Hz, 2.8 Hz, 1H), 7.26-7.21 (m, 1H), 7.01 (dd, *J* = 4.0 Hz, 1.1 Hz, 1H), 6.89 (dd, *J* = 4.0 Hz, 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) : δ = 161.16 ($^1J_{C,F}$ = 243 Hz), 155.48, 138.15, 137.55 ($^3J_{C,F}$ = 11 Hz), 130.05, 128.64 ($^4J_{C,F}$ =2 Hz), 125.21, 123.87, 123.85, 115.55 ($^2J_{C,F}$ = 23 Hz), 115.27, 115.03, 114.85, 114.79, 114.69, 114.14, 109.19; HRMS calcd for $C_{17}H_{11}FN_2$[(M+H)$^+$]: 263.0979 ; found, 263.0977.

8-fluoro-4-phenylpyrrolo[1,2-*a*]quinoxaline (4g)

Yellow solid. Mp: 144-145 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.04-7.95 (m, 3H), 7.86 (dd, *J* = 2.7 Hz, 1.2 Hz, 1H), 7.58-7.51 (m, 4H), 7.20 (td, *J* = 8.7 Hz, 2.7 Hz, 1H), 7.00 (dd, *J* = 3.9 Hz, 1.2 Hz, 1H), 6.91 (dd, *J* = 3.6 Hz, 2.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 163.45 ($^1J_{C,F}$ = 247 Hz), 153.99 ($^4J_{C,F}$ =2 Hz), 138.59, 133.23, 132.49 ($^3J_{C,F}$ = 10 Hz), 130.29, 129.04, 128.97, 128.27 ($^3J_{C,F}$ = 11 Hz), 125.46,

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115.20 ($^2J_{C,F}$ = 23 Hz), 113.76 ($^2J_{C,F}$ = 22 Hz), 109.37, 101.05, 100.69. HRMS calcd for $C_{17}H_{11}FN_2$[(M+H)$^+$]: 263.0979 ; found, 263.0991.

6-phenylindolo[1,2-*a*]quinoxaline (4i)

Yellow solid. Mp: 170-171 °C. ^{1}H NMR (300 MHz, DMSO-d_6): δ = 8.78 (d, *J* = 8.7 Hz, 2H), 8.06-8.01 (m, 4H), 7.76- 7.70 (m, 1H), 7.65-7.56 (m, 4H), 7.53-7.47 (m, 2H), 7.36 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6): δ = 155.16, 137.55, 135.51, 132.34, 130.17, 130.03, 129.25, 129.07, 128.69, 128.59, 128.47, 128.11, 124.72, 122.81, 115.15, 114.93, 102.29; HRMS calcd for $C_{21}H_{14}N_2$ [(M+H)$^+$]: 295.1230; found, 295.1230.

7-methyl-6-phenylindolo[1,2-*a*]quinoxaline (4j)

Yellow solid. Mp: 159-161 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.50-8.46 (m, 2H), 8.03 (d, *J* = 7.8 Hz, 1H), 7.91 (d, *J* = 8.1 Hz 1H), 7.65-7.51 (m, 7H), 7.48-7.37 (m, 2H), 2.06 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 157.64, 132.10, 130.58, 130.31, 129.28, 128.60, 128.47, 128.31, 125.74, 124.81, 123.81, 122.06, 120.79, 114.40, 11.12; HRMS calcd for$C_{22}H_{16}N_2$ [(M+H)$^+$]: 309.1386 ; found, 309.1385.

General experimental procedure for 4-methylpyrrolo[1,2-*a*]quinoxaline (4k)

To a solution of DMSO (2 ml), 2-(1*H*-pyrrol-1-yl)aniline (0.079 g, 0.5 mmol), pentane-2,4-dione (0.075 g, 0.75 mmol) and TsOH·H_2O (0.048 g, 0.25 mmol) were added and stirred at room temperature, until no 2-(1*H*-pyrrol-1-yl)aniline left, and was monitored by thin-layer chromatography (TLC). Then it was cooled to room temperature. Brine (30 ml) was poured into the solution and the mixture was extracted with EtOAc (3 × 30 mL). The organic layers were combined and dried by anhydrous $MgSO_4$. The product was purified by flash chromatography on silica gel (petroleum ether / EtOAc = 10: 1). Compound **4k** was obtained as light yellow solids in 87%. Light yellow solid. Mp: 137-138 °C. ^{1}H NMR (300 MHz, DMSO-d_6): δ = 8.43 (dd, *J* = 2.7 Hz, 1.2 Hz, 1H), 8.26 (dd, *J* = 8.1 Hz, 0.9Hz, 1H), 7.83 (dd, *J* = 8.1 Hz, 1.5 Hz, 1H), 7.57-7.52 (m, 1H), 7.48-7.43 (m, 1H), 7.03 (dd, *J* = 3.9 Hz, 0.9 Hz, 1H), 6.92-6.89 (m, 1H), 2.65 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 153.59, 135.80, 129.13, 127.52, 127.33, 125.88, 125.59, 116.32, 115.06, 114.03, 107.21, 21.99; HRMS calcd for $C_{12}H_{10}N_2$ [(M+H)$^+$]: 183.0917 ; found, 183.0916.

4-ethylpyrrolo[1,2-*a*]quinoxaline (4l)

Light yellow solid. Mp: 73-74 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.93-7.90 (m, 1H), 7.88-7.85 (m, 1H), 7.78 (d, *J* = 6.6 Hz, 1H), 7.45-7.37 (m, 2H), 6.88-6.80 (m, 2H), 3.08 (q, *J* = 7.5 Hz), 1.48 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.29, 136.07, 129.48, 126.80, 125.71, 124.99, 114.05, 113.55, 113.38, 106.04, 28.90, 12.50; HRMS calcd for $C_{13}H_{12}N_2$ [(M+H)$^+$]: 197.1073; found, 197.1073.

4,7-dimethylpyrrolo[1,2-*a*]quinoxaline (4n)

Light yellow solid. Mp: 141-142 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83-7.82 (m, 1H), 7.69-7.66 (m, 2H), 7.27-7.24 (m, 1H), 6.85 (dd, *J* = 4.0 Hz, 1.2 Hz), 6.81-6.79 (m, 1H), 2.70 (s, 3H), 2.47 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.51, 135.83, 134.85, 129.11, 127.98, 126.19, 125.14, 114.00, 113.33, 106.22, 21.99, 21.12; HRMS calcd for $C_{13}H_{12}N_2$ [(M+H)$^+$]: 197.1073; found,197.1072.

7-chloro-4-methylpyrrolo[1,2-*a*]quinoxaline (4o)

Light yellow solid. Mp: 173-175 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.85-7.80 (m, 1H), 7.68 (d, *J* = 8.8 Hz, 1H), 7.38 (dd, *J* = 8.7 Hz, 2.2 Hz, 1H), 6.89-6.82 (m, 2H), 2.69 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.81, 136.64, 130.17, 128.55, 126.89, 126.04, 125.82, 114.70, 114.62, 113.94, 107.24, 21.92; HRMS calcd for $C_{12}H_9ClN_2$ [(M+H)$^+$]: 217.0527; found, 217.0528.

7-methoxy-4-methylpyrrolo[1,2-*a*]quinoxaline (4p)

Light yellow solid. Mp: 81-82 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83-7.82 (m, 1H), 7.73 (d, *J* = 9.0 Hz,1H), 7.41-7.26 (m, 1H), 7.09 (dd, *J* = 9.0 Hz, 2.8 Hz, 1H), 6.89 (m, 1H), 6.82 (m, 1H), 3.91 (s, 3H), 2.73 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ =157.16, 153.89, 136.59, 125.89, 121.53, 116.10, 114.58, 114.17, 113.33, 110.42, 106.57, 55.69, 21.79; HRMS calcd for $C_{13}H_{12}N_2O$ [(M+H)$^+$]: 213.1022; found,213.1026.

4-(4-methoxyphenyl)pyrrolo[1,2-*a*]quinoxaline (4q)

Light yellow solid. Mp: 112-113 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ =8.03-7.97 (m, 4H), 7.87 (d, *J* = 7.5 Hz, 1H), 7.51-7.41 (m, 2H), 7.07 (d, *J* = 8.7 Hz, 2H), 7.01 (d, *J* = 3.3 Hz, 1H), 6.89-6.87 (m, 1H), 3.89 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 161.19, 123.73, 135.95, 130.22, 129.80, 127.27, 125.33, 125.27, 114.83, 114.08, 114.03, 113.60, 109.11, 55.44; HRMS calcd for [(M+H)$^+$]: 275.1179; found, 275.1179.

4-(3-fluorophenyl)pyrrolo[1,2-*a*]quinoxaline (4r)

Light yellow solid. Mp: 125-127 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.05-8.01 (m, 2H), 7.90 (dd, *J* = 8.2 Hz, 1H), 7.81 (d, *J* = 7.7 Hz, 1H), 7.74-7.71 (m, 1H), 7.56-7.45 (m, 3H), 7.25-7.20 (m, 1H), 7.00 (dd, *J* = 4.0 Hz, 1.0 Hz, 1H), 6.92-6.90 (m, 1H)； ^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.12 ($^1J_{C,F}$ = 245 Hz), 152.96 ($^4J_{C,F}$ = 3 Hz), 140.60 ($^3J_{C,F}$ = 8 Hz), 136.05, 130.34, 130.21 ($^3J_{C,F}$ = 8 Hz), 127.82, 127.20, 125.41, 125.09, 124.37 ($^4J_{C,F}$ = 3 Hz), 116.85 ($^2J_{C,F}$ = 21 Hz), 115.84 ($^2J_{C,F}$ = 23 Hz), 114.85, 114.16, 113.67, 108.56; HRMS calcd for $C_{17}H_{11}FN_2$ [(M+H)$^+$]: 263.0979; found, 263.0951.

4-(4-fluorophenyl)pyrrolo[1,2-*a*]quinoxaline (4s)

Light yellow solid. Mp: 158-160 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.06-8.02 (m, 4H), 7.92 (d, *J* = 8.0 Hz), 7.57-7.53 (m, 1H), 7.51-7.47 (m, 1H), 7.28-7.24 (m, 2H), 6.99 (d, *J* = 4.8 Hz), 6.94-6.92 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.07 ($^1J_{C,F}$ = 243 Hz), 153.24, 136.19, 134.61, 130.60 ($^3J_{C,F}$ = 8 Hz), 130.23, 127.57, 127.13, 125.36, 125.24, 115.71 ($^2J_{C,F}$ = 22 Hz), 114.74, 114.06, 113.65, 108.52; HRMS calcd for $C_{17}H_{11}FN_2$ [(M+H)$^+$]: 263.0979; found, 263.0977.

4-(4-fluorophenyl)-7-methylpyrrolo[1,2-*a*]quinoxaline (4t)

White solid. Mp: 158-160 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.03-7.97 (m, 2H), 7.96-7.94 (m, 1H), 7.83 (d, *J* = 0.9Hz, 1H), 7.77 (d, *J* = 8.4 Hz, 1H), 7.34 (dd, *J* = 8.0 Hz, 1.8 Hz, 1H), 7.25-7.18 (m, 2H), 6.94-6.92 (m, 1H), 6.88-6.86 (m, 1H), 2.50 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 165.03 ($^1J_{C,F}$ = 248 Hz)，153.13, 136.12, 135.16, 134.75 ($^4J_{C,F}$ = 4 Hz), 130.59 ($^3J_{C,F}$ = 9 Hz), 130.00, 128.71, 125.14, 124.98, 115.66 ($^2J_{C,F}$ = 22 Hz), 114.52, 113.78, 113.36, 108.23, 21.10; HRMS calcd for $C_{18}H_{13}FN_2$ [(M+H)$^+$]: 277.1136; found, 277.1137.

4-(4-methoxyphenyl)-7-methylpyrrolo[1,2-*a*]quinoxaline (4u)

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Light brown solid. Mp: 102-104 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.98 (d, *J* = 8.6 Hz, 2H), 7.89-7.81 (m, 2H), 7.70 (d, *J* = 8.3 Hz, 1H), 7.27-7.24 (m, 1H), 7.05 (d, *J* = 8.6 Hz, 2H), 6.96 (d, *J* = 3.4 Hz, 1H), 6.81-6.83 (m, 1H), 3.87 (s, 3H), 2.47 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 160.99, 153.74, 136.27, 134.95, 131.22, 130.09, 129.86, 128.28, 125.28, 124.92, 114.29, 113.95, 113.60, 113.29, 108.32, 55.41, 21.11; HRMS calcd for $C_{19}H_{16}N_2O$ [$(M+H)^+$]: 289.1335; found, 289.1341.

7-chloro-4-(3-fluorophenyl)pyrrolo[1,2-*a*]quinoxaline (4v)

Off white solid. Mp: 163-165 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.03-7.97 (m, 2H), 7.81-7.78 (m, 2H), 7.72 (dt, *J* = 9.7 Hz, 2.3 Hz, 1H), 7.54-7.46 (m, 1H), 7.03 (dd, *J* = 4.0 Hz, 0.9 Hz, 1H), 6.93-6.92 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.09 ($^1J_{C,F}$ = 245 Hz)，153.94, 140.04, 136.93, 130.56, 130.29 ($^3J_{C,F}$ = 8 Hz), 129.61, 127.81, 125.81, 124.94, 124.38 ($^2J_{C,F}$ = 22 Hz), 115.85 ($^2J_{C,F}$ = 23 Hz), 115.24, 114.83, 114.60, 109.25; HRMS calcd for $C_{17}H_{10}ClFN_2$ [$(M+H)^+$]: 297.0589; found, 297.0587.

7-chloro-4-(4-fluorophenyl)pyrrolo[1,2-*a*]quinoxaline (4w)

Light yellow solid. Mp: 219-221 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01-7.94 (m, 4H), 7.78 (d, *J* = 8.8 Hz, 1H), 7.46 (dd, *J* = 8.8 Hz, 2,2 Hz, 1H), 7.24-7.19 (m, 2H), 6.98 (d, *J* = 4.0 Hz, 1H), 6.89-6.91 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ =165.28 ($^1J_{C,F}$ = 248 Hz), 154.15, 137.14, 134.21, 130.65 ($^3J_{C,F}$ = 9 Hz), 129.55, 127.49, 125.76, 125.14, 115.68 ($^2J_{C,F}$ = 22 Hz)，115.04, 114.70, 114.42, 109.14; HRMS calcd for $C_{17}H_{10}ClFN_2$ [$(M+H)^+$]: 297.0589; found, 297.0586.

7-methoxy-4-(4-methoxyphenyl)pyrrolo[1,2-*a*]quinoxaline (4x)

Light yellow solid. Mp: 106-107 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.00-7.95 (m, 2H), 7.92-7.90 (m, 1H), 7.79 (d, *J* = 9.3 Hz, 1H), 7.50 (d, *J* = 2.7 Hz, 1H), 7.13-7.07 (m, 1H), 7.07-7.03 (m, 2H), 6.99 (dd, *J* = 4.2 Hz, 1.2 Hz, 1H), 6.87 (dd, *J* = 4.2 Hz, 2.7 Hz, 1H), 3.92 (s, 3H), 3.90 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 161.01, 157.19, 154.21, 137.35, 131.05, 130.08, 125.08, 121.38, 116.39, 114.53, 114.21, 113.97, 113.60, 111.18, 108.34, 55.74, 55.43; HRMS calcd for $C_{19}H_{16}O_2N_2$ [$(M+H)^+$]: 305.1285; found, 305.1284.

4-(3-fluorophenyl)-7-methoxypyrrolo[1,2-*a*]quinoxaline (4y)

Light yellow solid. Mp: 147-149 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.90-7.89 (m, 1H), 7.79-7.69 (m, 3H), 7.52-7.46 (m, 2H), 7.25-7.19 (m, 1H), 7.13 (dd, *J* = 9.0 Hz, 2.8 Hz, 1H), 6.96 (dd, *J* = 4.0 Hz, 1.1 Hz, 1H), 6.86-6.84 (m, 1H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 164.10 ($^1J_{C,F}$ = 244 Hz), 157.28, 153.23 ($^4J_{C,F}$ = 2 Hz), 140.67 ($^3J_{C,F}$ = 7 Hz), 137.13, 130.20 ($^3J_{C,F}$ = 8 Hz), 124.79, 124.35 ($^4J_{C,F}$ = 3 Hz), 121.48, 117.05, 116.81 ($^2J_{C,F}$ = 21 Hz), 115.82 ($^2J_{C,F}$ = 23 Hz), 114.59, 114.47, 113.84, 111.38, 108.16, 55.73; HRMS calcd for $C_{18}H_{13}ON_2F$ [$(M+H)^+$]: 293.1085; found, 293.1084.

5-(pyrrolo[1,2-*a*]quinoxalin-4-yl)pentan-2-one (4z)

Light yellow solid. Mp: 71-72 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.91 (dd, *J* = 5.7 Hz, 1.8 Hz, 2H), 7.82 (d, *J* = 8.1 Hz, 1H), 7.49-7.38 (m, 2H), 6.95 (d, *J* = 3.9 Hz, 1H), 6.85-6.83 (m, 1H), 3.05 (t, *J* = 7.2 Hz, 2H), 2.62 (t, *J* = 7.2 Hz, 2H), 2.23-2.13 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.50, 156.41, 135.84, 129.45, 127.28, 127.00, 125.92, 125.06, 114.24, 113.62, 113.58, 106.42, 42.95, 34.59, 29.99, 22.13; HRMS calcd for $C_{16}H_{16}ON_2$ [$(M+H)^+$]: 253.1335; found, 253.1331.

(Z)-1,3-diphenyl-3-(phenylamino)prop-2-en-1-one (5c)

Yellow solid. Mp: 144-145 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.99-7.95 (m, 2H), 7.55-7.30 (M, 8H), 7.14-7.09 (m, 2H), 7.01-7.96 (t, *J* = 7.5 Hz, 1H), 6.86-6.78 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 189.69, 161.49, 139.92, 139.50, 135.88, 131.28, 129.67, 128.71, 128.56, 128.38, 128.36, 127.27, 127.18, 124.12, 123.21, 97.05; HRMS calcd for $C_{21}H_{17}NO$[$(M+H)^+$]: 300.1383 ; found,300.1376.

Acetophenone (5f)

Light yellow liquid, ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.95-7.91 (m, 2H), 7.55-7.49 (m, 1H), 7.44-7.39 (m, 2H), 2.55 (s, 3H).

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