A One-pot Green Synthesis of Alkylidenesuccinimides

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A mild and facile Wittig reaction between *N*-substituted maleimides and aldehydes has been developed. Various synthetically valuable alkylidenesuccinimides were obtained from this one-pot reaction in high yields (up to 99%). The product was obtained by simple filtration and no extra purification was necessary. Ethanol, an environment-benign solvent, was found to be a suitable reaction medium.

Keywords alkylidenesuccinimides, *N*-substituted maleimides, aldehydes, Wittig reaction, one-pot

Introduction

Alkylidenesuccinimides are recognized as useful intermediates as they contain condensed functionalities such as activated exocyclic double bond and enolizable amide moieties, which can act as either nucleophiles or electrophiles under different reaction conditions. For instance, *N*-itaconimides bearing a 1,1-disubstituted exocyclic double bond, an important class of alkylidenesuccinimides, have been used as electrophiles. They can react with diarylphosphine oxides or thiols in bicyclic guanidine-catalyzed enantioselective protonation reactions.[1] And their nucleophilic ability has been demonstrated in bicyclic guanidine-catalyzed asymmetric allylic addition to *N*-Eoc imines as well.[2] They were also used as building blocks in the synthesis of a range of bioactive compounds, such as dispiropyrrolidines which exhibit potent antibacterial activity.[3]

The preparation of alkylidenesuccinimides could go through the Wittig reaction between aldehydes and phosphorus ylides.[4] In this two-step and non-one-pot protocol, the phosphorus ylides were firstly generated from *N*-maleimides and triphenylphosphine in acetic acid, which should be purified before reacting with aldehydes as the second step. At the same time, the yields were unsatisfying. Thus, this protocol was not practical for large scale synthesis at all. Pyridinium methylide as *N*-ylide was also developed in the preparation of the alkylidenesuccinimides. However, the methodology was only utilized to prepare *N*-itaconimides due to the limitation of *N*-ylide.[5] Consequently, the phosphoniosilylation of *N*-maleimides via Wittig reaction was a more complicated protocol and gave poor yields.[6] Most recently, the synthesis of dispiropyrrolidines from *N*-methyl maleimides and aldehydes with triphenyl phosphine by an one-pot process has been described.[3,7] However, these methods required flash column chromatography (FC) separation and high temperature. It is cleary that these methods also can not be applied in the large scale preparation. Therefore, it is of a synthetic interest to develop a convenient, practical and green synthetic protocol for preparing alkylidenesuccinimides. Herein, we report a one-pot Wittig reaction for the green synthesis of alkylidenesuccinimides in high yields with a simple purification technique. Environment-benign ethanol is used as a solvent and eluent for the reaction.

Results and discussion

We proposed that the Wittig reaction goes through the formation of the phosphrous ylides from *N*-substituted maleimides and triphenylphosphine (Scheme 1). We postulated that protic solvents would accelerate the proton shift and the reaction might proceed without heating. Since alkylidenesuccinimides have poor solubilities in protic solvents,[4] the products could be purified and collected via a simple filtration, making it a practical approach for scale-up reactions.

Our initial investigation was carried out with benzaldehyde (**1a**), *N*-phenyl maleimide (**2a**), and Ph_3P in 1.2∶1.0∶1.2 molar ratio at room temperature. Among the solvents screened (Table 1, Entries 1—5), ethanol gave the best result, which was consistent with our hypothesis that protic solvent should accelerate the rate of proton shift (Scheme 1). The desired product **3a** was obtained in 75% yield using FC after 6 h (Table 1, Entry 1). The use of water as solvent led to the desired product, but in poor yield (Table 1, Entry 2). We suspected that the poor solubilities of starting materials in water might

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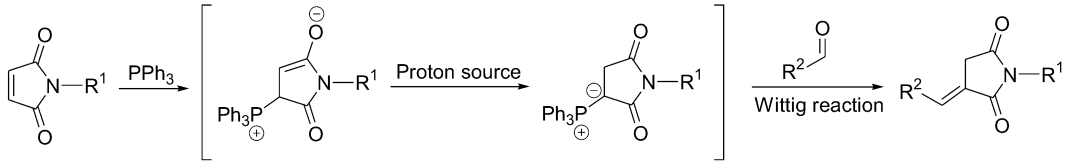
Received March 26, 2011; revised April 30, 2011; accepted May 10, 2011.
Project supported by the National Natural Science Foundation of China (No. 21072044) and International Cooperation Foundation of Henan Province (No. 104300510062).

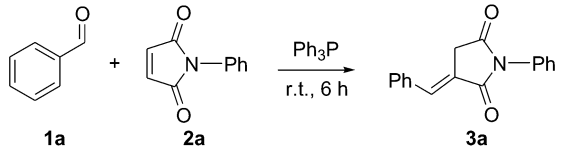
CHINESE JOURNAL OF CHEMISTRY

Scheme 1 Proposed mechanism of Wittig reaction



impede the reaction. Furthermore, the reaction in aprotic solvents, such as dichloromethane and toluene, proceeded in moderate yield (Table 1, Entries 3, 4). We also examined the yield of **3a** by changing the ratio of **1a**, **2a**, and Ph_3P in ethanol as solvent (Table 1, Entries 6—8). It was shown that the best ratio of **1a**∶**2a**∶Ph_3P was 1.4∶1.0∶1.2 for the reaction (Table 1, Entry 8). As expected, the product **3a** could be efficiently isolated in 82% yield by filtration due to its poor solubility in ethanol.

Table 1 Investigation of reaction conditions[a]



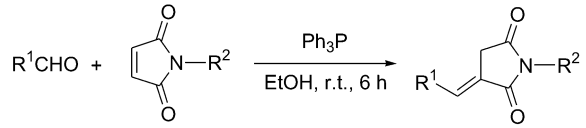
1a **2a** **3a**

Entry	Ratio of **1a**∶**2a**∶Ph_3P	Solvent	Yield[b]/%
1	1.2∶1.0∶1.2	EtOH	75
2	1.2∶1.0∶1.2	H_2O	16
3	1.2∶1.0∶1.2	DCM	66
4	1.2∶1.0∶1.2	Toluene	60
5	1.2∶1.0∶1.2	THF	12
6	1.0∶1.0∶1.2	EtOH	70
7	1.0∶1.2∶1.2	EtOH	80
8	1.4∶1.0∶1.2	EtOH	93 (82)[c]

[a] Reactions were conducted with 0.025 mmol scale. [b] Flash column chromatography (FC) yield. [c] Filtration yield, 0.25 mmol scale.

With the optimized conditions in hand, we started to explore the reaction scope. First, a variety of aromatic aldehydes (**1b**—**1l**) were investigated with *N*-phenyl maleimide **2a** and triphenylphosphine (Table 2, Entries 1—11). It was found that all of these reactions were completed in 6 h to afford excellent yields of **3b**—**3l** by either purification methods (filtration or FC). The electronic effect of the substituent on the aromatic ring was not obvious. Subsequently, aliphatic aldehydes **1m**—**1o** were subjected to the Wittig reaction condition (Table 2, Entries 12—14). The desired products (**3m**, **3n**) were isolated in better yields by filtration than by FC. Only in the case of **3o**, flash chromatography was needed for its isolation. Finally, we investigated the reactions of benzylaldehyde **1a** with *N*-benzyl maleimide **2b** (Table 2, Entry 15) and *N*-cyclohexyl maleimide **2c** (Table 2, Entry 16) in the presence of triphenylphosphine. Both yields from filtration or FC were good to excellent.

Table 2 The synthesis of different alkylidenesuccinimides[a]



1b – 1o **2a – 2c** **3b – 3q**

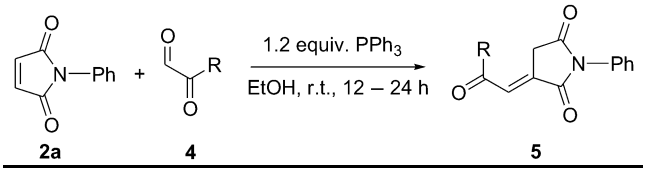
Entry	R^1	Reactant	R^2	Reactant	Product	Yield[b]/%
1	*p*-$CF_3C_6H_4$	**1b**	Ph	**2a**	**3b**	83 (64)
2	*m*-$CF_3C_6H_4$	**1c**	Ph	**2a**	**3c**	70 (83)
3	*p*-FC_6H_4	**1d**	Ph	**2a**	**3d**	84 (82)
4	*p*-BrC_6H_4	**1e**	Ph	**2a**	**3e**	74 (73)
5	*o*-ClC_6H_4	**1f**	Ph	**2a**	**3f**	70 (68)
6	*p*-MeC_6H_4	**1g**	Ph	**2a**	**3g**	78 (97)
7	*p*-*i*PrC_6H_4	**1h**	Ph	**2a**	**3h**	80 (82)
8	1-Naphthyl	**1i**	Ph	**2a**	**3i**	78 (88)
9	*m*-$MeOC_6H_4$	**1j**	Ph	**2a**	**3j**	85 (97)
10	*p*-$MeOC_6H_4$	**1k**	Ph	**2a**	**3k**	84 (93)
11	3-thienyl	**1l**	Ph	**2a**	**3l**	75 (94)
12	$PhCH_2CH_2$	**1m**	Ph	**2a**	**3m**	77 (96)
13	$PhCH_2$	**1n**	Ph	**2a**	**3n**	59 (99)
14	$CH_3(CH_2)_3$	**1o**	Ph	**2a**	**3o**	— (88)[c]
15	Ph	**1a**	Bn	**2b**	**3p**	83 (91)
16	Ph	**1a**	Cy	**2c**	**3q**	80 (87)

[a] Reactions were conducted with 0.25 mmol scale, the ratio of **1**∶**2**∶Ph_3P=1.4∶1.0∶1.2. [b] Filtration yield (in parentheses of FC yield). [c] The product can not be filtered using ethanol as eluent.

Activated aldehydes **4** with aromatic ketones located at the alpha position of the aldehyde were conducted under the same conditions (Table 3). The reactions could be completed smoothly with excellent filtration yields. However, prolonged reaction time (12 to 24 h) was necessary. It was worth noting that only single isomers were detected by ^1H NMR spectra in all the products. The double bond in the products was assigned to *E* configuration by NOE analysis.[2]

In these reactions, the environment-benign ethanol, which was used as solvent and eluent, can be recycled

Table 3 The synthesis of different alkylidenesuccinimides under established reaction conditions[a]

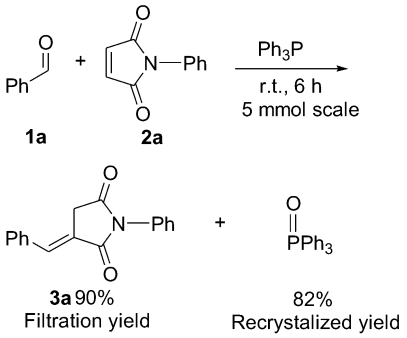


Entry	R	Reactant	Product	Yield[b]/%
1	Ph	**4a**	**5a**	99
2	*p*-$CF_3C_6H_4$	**4b**	**5b**	92
3	1-Naphthyl	**4c**	**5c**	87
4	*m*-$MeOC_6H_4$	**4d**	**5d**	93
5	*p*-$MeOC_6H_4$	**4e**	**5e**	89

[a] Reactions were conducted with 0.25 mmol scale, the ratio of **4**∶**2a**∶Ph_3P=1.4∶1.0∶1.2. [b] Filtration yields.

by a simple distillation. We also conducted gram-scale synthesis of **3a**, which could be obtained in excellent yield by filtration (90%). Furthermore, triphenylphosphine oxide was obtained in 82% yield after recrystalization as the only side product (Scheme 2). It was well known that triphenylphosphine oxide is a versatile and useful Lewis base.[8] Therefore, we believed that this efficient protocol belongs to the domain of green chemistry.[9]

Scheme 2 The gram-scale synthesis of **3a**



Conclusions

In summary, we have developed a mild and convenient one-pot Wittig reaction for the green synthesis of alkylidenesuccinimides. Under the established reaction conditions, a number of alkylidenesuccinimides derived from various *N*-substituted maleimides and aldehydes were synthesized in high yields by FC or filtration (up to 99%) as well as in high *E*-diasteroselectivities. The gram-scale synthesis of **3a** was demonstrated through a direct filtration purification technique. To expand the scope of this synthetic methodology, the reactions are under investigation in our laboratory by using ketones and linear activated alkenes as the corresponding starting materials to prepare interesting synthetic intermediates.

Experimental section

General methods

Experiments involving moisture and/or air sensitive components were performed under a positive pressure of nitrogen in oven-dried glassware equipped with a rubber septum inlet. Dried solvents and liquid reagents were transferred by oven-dried syringes or hypodermic syringe cooled to ambient temperature in a desiccator. Moisture in non-volatile reagents/compounds was removed in high *vacuo* by means of an oil pump and subsequent purging with nitrogen. All experiments were monitored by analytical thin layer chromatography (TLC). Columns for flash chromatography (FC) contained silica gel (200—300 mesh). ^1H (400 MHz), ^{13}C (100 MHz) with complete proton decoupling, were performed on a Bruker AVANCE-III (400MHz) spectrometer. Chemical shifts are reported using the residual solvent signal as an internal standard: $CDCl_3$ (^1H NMR: δ 7.26, singlet; ^{13}C NMR: δ 77.0, triplet). Low resolution mass spectra were obtained on a Finnigan/TraceDse2 spectrometer in EI mode. Melting points were determined on an X-6 microscopic melting point apparatus. All commercial reagents were purchased from Aladdin® and Darui® of the highest purity grade. They were used without further purification unless specified.

Representative procedure

N-Phenyl maleimide **2a** (866 mg, 5 mmol) and PPh_3 (1.573 g, 6 mmol) were dissolved in ethanol (40.0 mL) and stirred at room temperature for about 5 min, then benzaldehyde **1a** (707 μL, 7 mmol) was added. The reaction mixture was stirred at room temperature and monitored by TLC. After 6 h, upon complete consumption of **2a**, the resultant mass was filtered through Buckner funnel, and the resulted solid was rinsed with ethanol. Finally, 1.184 g **3a** was obtained with 90% yield as white solid after pump dried. The surplus ethanol was distilled and reused as solvent and eluent. 1.148 g triphenylphosphine oxide (82% yield) was achieved after recrystalization using ethyl acetate and petroleum ether.

Characterization data

3-Benzylidene-1-phenyl-pyrrolidine-2,5-dione (**3a**) White solid, m.p. 202—204 ℃; ^1H NMR ($CDCl_3$, 400 MHz) δ: 7.75 (t, J=2.4 Hz, 1H), 7.56—7.38 (m, 10H), 3.78 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.0, 170.0, 135.3, 133.9, 131.9, 130.3, 130.2, 129.2, 129.1, 128.5, 126.4, 123.0, 34.2; LRMS (EI) *m*/*z*: 262.9 (M^+).

1-Phenyl-3-(4-trifluoromethyl-benzylidene)-pyrrolidine-2,5-dione (**3b**) White solid, m.p. 222—224 ℃; ^1H NMR ($CDCl_3$, 400 MHz) δ: 7.77—7.73 (m, 3H), 7.64 (d, J=8.0 Hz, 2H), 7.52 (d, J=8.0 Hz, 2H), 7.43—7.37 (m, 3H), 3.78 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.4, 169.5, 137.3, 133.5, 131.8, 130.2,

129.2, 128.7, 126.4, 126.1 (two peaks), 126.0, 125.7, 34.1; LRMS (EI) *m/z*: 330.9 (M^+).

1-Phenyl-3-(3-trifluoromethyl-benzylidene)-pyrrolidine-2,5-dione (**3c**) White solid, m.p. 160—162 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.76—7.60 (m, 5H), 7.52—7.37 (m, 5H), 3.78 (d, J=2.0 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.5, 169.5, 134.7, 133.5, 133.0, 131.8, 129.7, 129.2, 128.7, 126.7, 126.6, 126.5 (two peaks), 126.3, 125.1, 34.0; LRMS (EI) *m/z*: 330.9 (M^+).

3-(4-Fluoro-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3d**) White solid, m.p. 232—233 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.71 (t, J=2.4 Hz, 1H), 7.55—7.37 (m, 7H), 7.18 (t, J=8.6 Hz, 2H), 3.73 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.8, 169.9, 164.9, 162.4, 134.1, 132.3, 132.2, 132.0, 130.4 (two peaks), 129.2, 128.6, 122.7, 116.6, 116.4, 34.1; LRMS (EI) *m/z*: 280.9 (M^+).

3-(4-Bromo-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3e**) White solid, m.p. 235—236 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.68 (t, J=2.4 Hz, 1H), 7.63—7.37 (m, 9H), 3.72 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.6, 169.8, 134.0, 132.9, 132.5, 131.9, 131.5, 129.2, 128.6, 126.4, 124.9, 123.8, 34.2; LRMS (EI) *m/z*: 340.8 (M^+).

3-(2-Chloro-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3f**) White solid, m.p. 145—147 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.10 (t, J=2.4 Hz, 1H), 7.51—7.33 (m, 9H), 3.67 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.7, 169.3, 135.8, 132.2, 131.8, 131.5, 131.0, 130.4, 129.1 (two peaks), 128.5, 127.0, 126.3, 125.7, 33.7; LRMS (EI) *m/z*: 296.9 (M^+).

3-(4-Methyl-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3g**) White solid, m.p. 204—205 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.74 (t, J=2.3 Hz, 1H), 7.54—7.30 (m, 9H), 3.77 (d, J=2.3 Hz, 2H), 2.44 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.2, 170.2, 141.0, 135.5, 132.1, 131.4, 130.4, 130.0, 129.1, 128.5, 126.5, 121.9, 34.4, 21.5; LRMS (EI) *m/z*: 276.9 (M^+).

3-(4-Isopropyl-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3h**) White solid, m.p. 167—169 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.75 (t, J=2.2 Hz, 1H), 7.54—7.36 (m, 9H), 3.76 (d, J=2.2 Hz, 2H), 3.03—2.96 (m, 1H), 1.32 (d, J=6.9 Hz, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.2, 170.2, 151.8, 135.4, 132.1, 131.8, 130.5, 129.1, 128.5, 127.3, 126.5, 122.0, 34.4, 34.1, 23.7; LRMS (EI) *m/z*: 305.0 (M^+).

3-Naphthalen-1-yl-methylene-1-phenyl-pyrrolidine-2,5-dione (**3i**) White solid, m.p. 170—172 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.52 (t, J=2.3 Hz, 1H), 8.18 (d, J=8.2 Hz, 1H), 7.97—7.93 (m, 2H), 7.63—7.43 (m, 9H), 3.71 (d, J=2.3 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.1, 169.6, 133.6, 132.5, 131.9, 131.8, 130.7, 130.5, 129.1, 128.8, 128.5, 127.1, 126.5, 126.4, 125.6, 125.1, 123.6, 33.9; LRMS (EI) *m/z*: 313.0 (M^+).

3-(3-Methoxy-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3j**) White solid, m.p. 191—192 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.70 (t, J=2.4 Hz, 1H), 7.51 (t, J=7.6 Hz, 2H), 7.43—7.37 (m, 4H), 7.13 (d, J=7.6 Hz, 1H), 7.04 (s, 1H), 7.00 (dd, J=7.6, 2.4 Hz, 1H), 3.86 (s, 3H), 3.76 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.0, 170.0, 159.9, 135.4, 135.3, 131.9, 130.1, 129.1, 128.6, 126.4, 123.2, 122.6, 116.0, 115.5, 55.3, 34.3; LRMS (EI) *m/z*: 293.0 (M^+).

3-(4-Methoxy-benzylidene)-1-phenyl-pyrrolidine-2,5-dione (**3k**) White solid, m.p. 175—177 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.69 (t, J=2.4 Hz, 1H), 7.52—7.48 (m, 4H), 7.42—7.37 (m, 3H), 7.00 (d, J=8.8 Hz, 2H), 3.87 (s, 3H), 3.72 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 1173.2, 170.3, 161.2, 135.1, 132.1, 132.0, 129.1, 128.4, 126.8, 126.4, 120.1, 114.6, 55.4, 34.3; LRMS (EI) *m/z*: 292.9 (M^+).

1-Phenyl-3-thiophen-3-yl-methylene-pyrrolidine-2,5-dione (**3l**) White solid, m.p. 202—204 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.76 (t, J=2.4 Hz, 1H), 7.62 (d, J=2.4 Hz, 1H), 7.52—7.37 (m, 6H), 7.29 (dd, J=5.0, 1.0 Hz, 1H), 3.69 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.9, 170.0, 136.4, 132.0, 130.1, 129.1, 128.8, 128.5, 127.4, 127.3, 126.4, 121.4, 34.2; LRMS (EI) *m/z*: 268.9 (M^+).

1-Phenyl-3-(3-phenyl-propylidene)-pyrrolidine-2,5-dione (**3m**) White solid, m.p. 145—147 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.50—7.20 (m, 10H), 7.00—6.95 (m, 1H), 3.18 (t, J=1.2 Hz, 2H), 2.85 (t, J=7.4 Hz, 2H), 2.56 (q, J=7.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.0, 168.6, 140.2, 138.4, 131.8, 129.0, 128.5, 128.4, 128.3, 126.4, 126.3, 126.0, 34.1, 31.9, 31.8; LRMS (EI) *m/z*: 291.0 (M^+).

3-Phenethylidene-1-phenyl-pyrrolidine-2,5-dione (**3n**) White solid, m.p. 165—167 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.53—7.12 (m, 11H), 3.61 (t, J=4.8 Hz, 2H), 3.43 (d, J=4.8 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.0, 168.8, 137.6, 137.2, 132.0, 129.1, 129.0, 128.6, 127.0, 126.5, 126.0, 36.1, 32.2; LRMS (EI) *m/z*: 277.0 (M^+).

3-Pentylidene-1-phenyl-pyrrolidine-2,5-dione (**3o**) White solid, m.p. 115—116 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.49—7.30 (m, 5H), 6.97—6.92 (m, 1H), 3.39 (t, J=1.2 Hz, 2H), 2.24 (q, J=7.2 Hz, 2H), 1.56—1.34 (m, 4H), 0.94 (t, J=7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.1, 168.9, 140.2, 131.9, 129.0, 128.4, 126.4, 125.1, 32.1, 30.1, 29.6, 22.4, 13.8; LRMS (EI) *m/z*: 242.9 (M^+).

1-Benzyl-3-benzylidene-pyrrolidine-2,5-dione (**3p**) White solid, m.p. 208—210 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.62 (t, J=2.4 Hz, 1H), 7.48—7.27 (m, 10H), 4.78 (s, 2H), 3.55 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 173.6, 170.6, 135.8, 134.5, 134.0, 130.1 (two peaks), 129.0, 128.8, 128.6, 127.9, 123.3, 42.4, 34.0; LRMS (EI) *m/z*: 276.9 (M^+).

3-Benzylidene-1-cyclohexyl-pyrrolidine-2,5-dione (**3q**) White solid, m.p. 177—179 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.56 (t, J=2.4 Hz, 1H), 7.48—7.37 (m, 5H), 4.14—4.06 (m, 1H), 3.51 (d, J=2.4 Hz, 2H), 2.26—2.16 (m, 2H), 1.86—1.62 (m, 5H), 1.39—1.22 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 174.1, 171.0,

134.2, 133.7, 130.0, 129.9, 129.0, 123.5, 51.7, 34.0, 28.9, 25.8, 25.0; LRMS (EI) *m*/*z*: 269.0 (M^+).

3-(2-Oxo-2-phenyl-ethylidene)-1-phenyl-pyrrolidine-2,5-dione (**5a**) Yellow solid, m.p. 169—171 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.08—8.06 (m, 2H), 8.03 (t, J=2.4 Hz, 1H), 7.68—7.36 (m, 8H), 4.00 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 189.6, 173.0, 168.8, 139.3, 137.2, 134.1, 131.6, 129.2, 129.0, 128.9, 128.6, 126.3, 124.0, 34.9; LRMS (EI) *m*/*z*: 290.9 (M^+).

3-[2-Oxo-2-(4-trifluoromethyl-phenyl)-ethylidene]-1-phenyl-pyrrolidine-2,5-dione (**5b**) Yellow solid, m.p. 179—181 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.18 (d, J=8.0 Hz, 2H), 8.00 (t, J=2.6 Hz, 1H), 7.82 (d, J=8.0 Hz, 2H), 7.53 (t, J=7.6 Hz, 2H), 7.46 (d, J=7.6 Hz, 1H), 7.37 (d, J=7.6 Hz, 2H), 4.01 (d, J=2.6 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 188.7, 172.7, 168.5, 140.7, 139.8, 131.4, 129.3, 129.0, 128.9, 126.2, 126.1 (two peaks), 123.0, 35.0; LRMS (EI) *m*/*z*: 359.1 (M^+).

3-(2-Naphthalen-1-yl-2-oxo-ethylidene)-1-phenyl-pyrrolidine-2,5-dione (**5c**) Yellow solid, m.p. 168—170 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.68 (d, J=8.4 Hz, 1H), 8.09 (d, J=8.4 Hz, 1H), 8.03 (d, J=6.8 Hz, 1H), 7.34 (t, J=2.8 Hz, 1H), 7.69—7.38 (m, 8H), 4.04 (d, J=2.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 192.6, 173.0, 168.8, 138.7, 135.2, 134.2, 134.0, 131.6, 130.3, 129.4, 129.2, 128.9, 128.7, 128.6, 127.6, 126.9, 126.3, 125.4, 124.5, 34.8; LRMS (EI) *m*/*z*: 341.1 (M^+).

3-[2-(3-Methoxy-phenyl)-2-oxo-ethylidene]-1-phenyl-pyrrolidine-2,5-dione (**5d**) Yellow solid, m.p. 180—181 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.00 (t, J=2.4 Hz, 1H), 7.66 (d, J=8.0 Hz, 1H), 7.57—7.36 (m, 7H), 7.20 (dd, J=2.4, 8.0 Hz, 1H), 3.99 (d, J=2.4 Hz, 2H), 3.89 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 189.4, 173.0, 168.8, 160.2, 139.3, 138.6, 131.6, 130.0, 129.2, 128.9, 126.3, 124.1, 121.3, 120.9, 112.4, 55.5, 34.9; LRMS (EI) *m*/*z*: 321.1 (M^+).

3-[2-(4-Methoxy-phenyl)-2-oxo-ethylidene]-1-phenyl-pyrrolidine-2,5-dione (**5e**) Yellow solid, m.p. 159—161 ℃; ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.06 (d, J=8.8 Hz, 2H), 8.00 (t, J=2.4 Hz, 1H), 7.51 (t, J=7.6 Hz, 2H), 7.43 (t, J=7.6 Hz, 1H), 7.37 (d, J=7.6 Hz, 2H), 7.00 (d, J=8.8 Hz, 2H), 3.98 (d, J=2.4 Hz, 2H), 3.90 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 187.8, 173.2, 169.0, 164.4, 138.5, 131.6, 131.1, 130.4, 129.2, 128.8, 126.3, 124.3, 114.2, 55.6, 34.8; LRMS (EI) *m*/*z*: 321.1 (M^+).

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(E1103261 Sun, H.; Zheng, G.)

