HETEROCYCLES, Vol. 91, No. 2, 2015, pp. 388 - 397. © 2015 The Japan Institute of Heterocyclic Chemistry
Received, 1st December, 2014, Accepted, 9th January, 2015, Published online, 13th January, 2015
DOI: 10.3987/COM-14-13141

SELECTIVE SYNTHESIS OF 2,3-DIHYDROFURAN OR CYCLOPROPANE DERIVATIVES VIA TANDEM REACTION OF β,γ-UNSATURATED α-KETOESTERS WITH HALIDES

Dong Cheng,[a,*] Xiangzhen Meng,[a,b] Guoxu Qin,[a] and Yimin Hu[b,*]

[a]School of Chemical Engineering & Life Science, Chaohu College, Chaohu Anhui, People's Republic of China

[b]Laboratory of Functional Molecular Solids, Ministry of Education, Anhui Laboratory of Molecule-Base Materials Institute of Organic Chemistry, School of Chemistry and Materials Science, Anhui Normal University, Wuhu Anhui, China; E-mail: mxzcd79@163.com

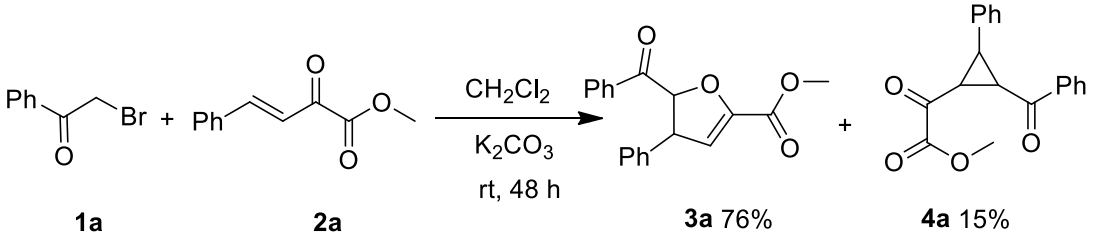
Abstract – 2,3-Dihydrofuran or cyclopropane derivatives were prepared with high selectivity via reaction of β,γ-unsaturated α-ketoesters with α-phenacyl bromide in different conditions.

Dihydrofuran derivatives which are commonly found in the molecular skeleton of natural products and bioactive substances have been studied for many years.[1-3] Cyclopropane derivatives are also important in the field of organic synthesis.[4,5] A number of methods for the synthesis of them have been reported in the literature.[6-9] Among them, stereoselective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via the reaction of ylides with different α, β-unsaturated compounds have been reported.[10-14] However, there is no report on selective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via the same starting materials under different conditions.

As a sort of multi-functionalized building blocks, β,γ-unsaturated α-ketoester has recently been found useful utility in organic synthesis.[15,16] In this work, we report the selective synthesis of 2,3-dihydrofuran or cyclopropane derivatives via reaction of β,γ-unsaturated α-ketoesters with α-phenacyl bromide in different conditions.

We initiated our study by treatment of 2-bromo-1-phenylethanone **(1a)**, (*E*)-methyl

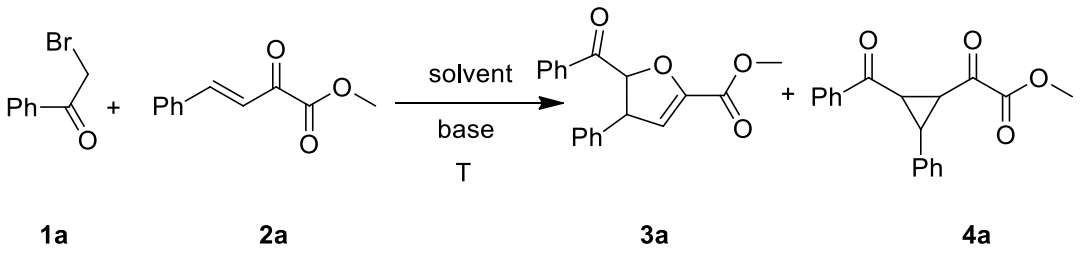
2-oxo-4-phenylbut-3-enoate **(2a)** with K_2CO_3 in CH_2Cl_2 at room temperature for 48 h (Scheme 1), the reaction afforded 2,3-dihydrofuran derivative **(3a)** in 76% yield and a single cyclopropane derivative isomer in 15% yield **(4a)**.



Scheme 1. Formation of the 2,3-dihydrofuran and cyclopropane derivatives

Further, we carried out this reaction in different conditions (Table 1). It was found that when NaOH or Et_3N was employed as base, (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **(2a)** was full consumed but neither traces of **3a** nor **4a** was formed (entries 2 and 3). Completely no reaction occurred between **1a** and **2a** in the presence of DABCO in CH_2Cl_2 (entry 4). When the reaction was treated in the presence of DBU (3 eq) at room temperature, **3a** was obtained in 88% and only a few trace of cyclopropanes was detected (entry 5). When the reaction was quenched at 1.5 h, the reaction become complex and the yield of 2,3-dihydrofuran derivative reduced to 24% (entry 6). The combination of DABCO with K_2CO_3 as base did not obtain **3a**, the major product was **4a** (entry 7). CH_2Cl_2 was found to be the best solvent of choice for the synthesis of **3a**, other solvents such as THF, toluene, MeCN and DMF gave **3a** in a moderate yield (entries 8-11).

Table 1. Selective synthesis of **3a** and **4a**[a]



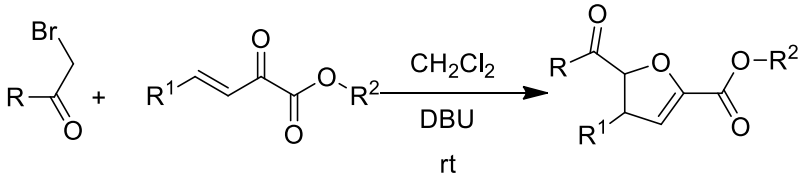
entry	base	solvent	time (h)	Yield 3a (%)[b]	dr (3a)[c]	yield 4a (%) [b]
1	K_2CO_3	CH_2Cl_2	48	76	1:1	15
2	NaOH	CH_2Cl_2	1	--		--
3	Et_3N	CH_2Cl_2	48	--		--

4	DABCO	CH_2Cl_2	48	--		--
5	DBU[d]	CH_2Cl_2	0.5	88	1:1	trace
6	DBU[d]	CH_2Cl_2	1.5	24	--	--
7	DABCO/K_2CO_3(1:1)	CH_2Cl_2	48	--		60[e]
8	DBU[d]	THF	0.2	76	1:1	trace
9	DBU[d]	toluene	0.3	70	1:1	trace
10	DBU[d]	MeCN	0.2	73	1:1	trace
11	DBU[d]	DMF	0.2	78	1:1	trace
12	DABCO/K_2CO_3(1:1)	THF	48	--		56[e]
13	DABCO/K_2CO_3(1:1)	MeCN	48	--		52[e]

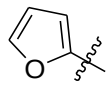
[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), (*E*)-methyl 2-oxo-4-phenylbut-3-enoate (**2a**, 1.0 mmol), base (1.5 mmol), and solvent (3 mL). [b]isolated yield. [c]determined by ^{1}H NMR. [d]base (3.0 equiv). [e]major isomer of cyclopropane derivatives.

Having established optimal reaction conditions for the synthesis of **3a**, we investigated the scope and limitation of substrates by employing various β,γ-unsaturated α-ketoesters and halides (Table 2). It was observed that aromatic substrates bearing an electron-donating groups (entries 2 and 4), and electron-withdrawing groups (entries 3 and 5) all gave the corresponding 2,3-dihydrofuran derivatives. However, (*E*)-methyl 4-(furan-2-yl)-2-oxobut-3-enoate was not suitable for such transformation and no desired product was observed (entry 6). The ester groups in R^2 have less effect on the yield (entry 7). 1-Bromopropan-2-one could also react with (*E*)-methyl 2-oxo-4-phenylbut-3-enoate to afford corresponding product (entry 8).

Table 2. Synthesis of 2,3-dihydrofuran derivatives[a]



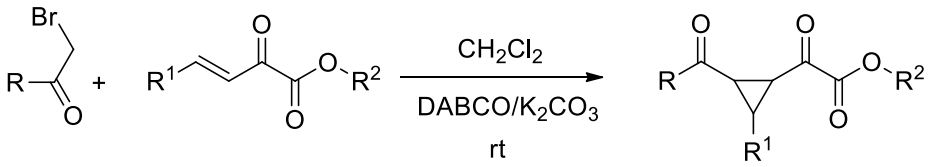
entry	R	R^1	R^2	time (h)	dr[b]	product	yield(%)[c]
1	Ph	Ph	Me	0.3	1:1	3a	88
2	*p*-MeC_6H_4	Ph	Me	0.3	1:0.8	3b	82

3	*p*-ClC_6H_4	Ph	Me	0.2	1:0.9	3c	83
4	Ph	*p*-MeC_6H_4	Me	0.2	1:1	3d	80
5	Ph	*p*-ClC_6H_4	Me	0.2	1:0.5	3e	82
6	Ph		Me	0.4	---		--
7	Ph	Ph		0.3	1:0.8	3f	84
8.	Me	Ph	Me	0.2	1:1	3g	86

[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), β,γ-unsaturated α-ketoester (1.0 mmol), DBU (3.0 mmol), solvent (3.0 mL) . [b]determined by ^{1}H NMR. [c]isolated yield.

Further, we synthesized various cyclopropane derivatives by using various β,γ-unsaturated α-ketoesters and halides with the combination of DABCO and K_2CO_3 as base in CH_2Cl_2 at room temperature (Table 3). To our delight, smooth reactions were observed for all substrate and delivered the final products in moderate yields (entries 1-6). However, the reaction of 1-bromopropan-2-one with (*E*)-methyl 2-oxo-4-phenylbut-3-enoate did not give the desired product (entry 7).

Table 3. Synthesis of cyclopropane derivatives [a]

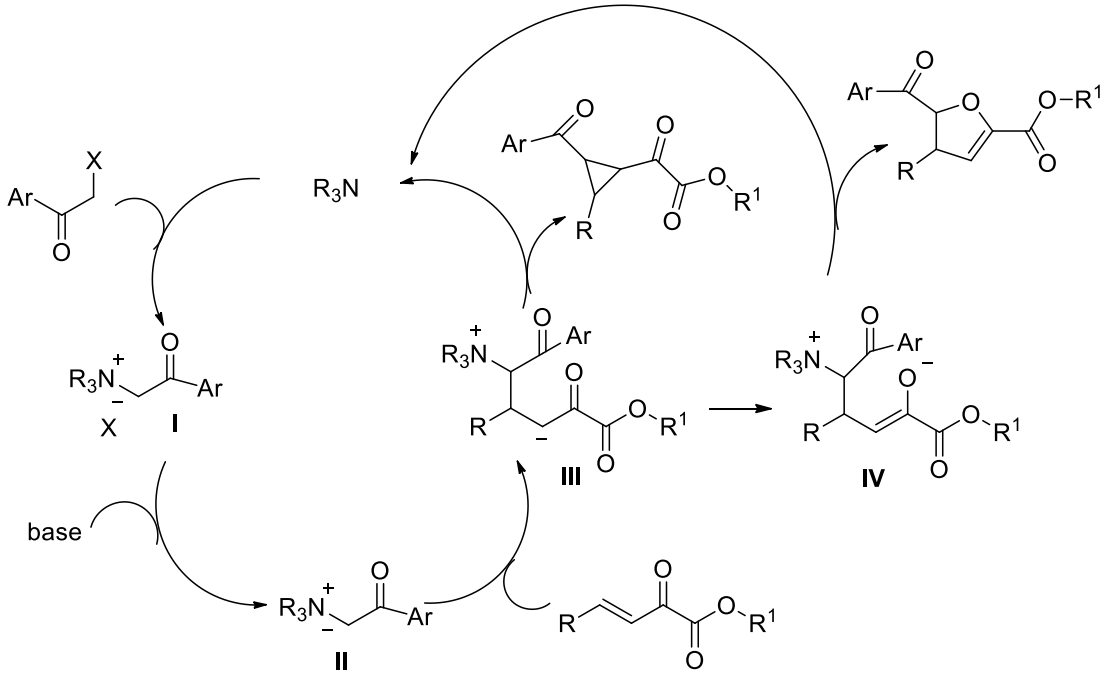


entry	R	R^1	R^2	time (h)	dr[b]	product	yield(%)[c]
1	Ph	Ph	Me	48	0.8:1:6	4a	64
2	*p*-MeC_6H_4	Ph	Me	48	1:1:5	4b	52
3	*p*-ClC_6H_4	Ph	Me	48	1:1:5	4c	54
4	Ph	*p*-MeC_6H_4	Me	48	1:1:6	4d	58
5	Ph	*p*-ClC_6H_4	Me	48	1:1:5	4e	50
6	Ph	Ph		48	0.5:1:6	4f	66

7.	Me	Ph	Me	48	--	--

[a]reaction conditions: 2-bromo-1-phenylethanone (**1a** 1.5 mmol), β,γ-unsaturated α-ketoesters (1.0 mmol), DABCO (1.5 mmol), K_2CO_3 (1.5 mmol), solvent (3.0 mL). [b]determined by isolated weight. [c]isolated yield of the major isomer of cyclopropane derivatives.

A plausible reaction mechanism is proposed in Scheme 2. First, the quaternary ammoonium salt **I** was produced from the addition of α-phenacyl bromide to the tertiary amine. Deprotonation of **I** with base forms the ylide **II**, which undergoes Michael addition with β,γ-unsaturated α-ketoester to afford the intermediate **III**. The intermediate **III** under ring-closing reaction by internal S_N2 reactions forms cyclopropane derivatives, whereas tautomerization of the intermediate **III** leads to generation of **IV**, followed by intramolecular cyclization of **IV** to form 2,3-dihydrofurans.



Scheme 2. Formation of dihydrofurans and cyclopropanes

In summary, we have developed a convenient and efficient method for the synthesis of 2,3-dihydrofuran and cyclopropane derivatives. The reaction takes place via [4+1] or [2+1]-cycloaddition of β,γ-unsaturated α-ketoesters with α-phenacyl bromide. We believe that this method would give a new viable entry to highly functionalized dihydrofurans and cyclopropanes.

EXPERIMENTAL

Column chromatography was carried out on silica gel. The ^{1}H and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively. All reagents were used directly as obtained commercially unless otherwise noted.

General procedure for the synthesis of 2,3-dihydrofuran derivatives

DBU (3.0 mmol) was added to a solution of 2-bromo-1-phenylethanone **1a** (1.5 mmol) and (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **2a** (1.0 mmol) in CH_2Cl_2 (3 mL) at room temperature. The reaction was then stirred and followed by TLC. Upon full consumption of 2-oxo-4-phenylbut-3-enoate **2a.** The solvent was evaporated under reduced pressure. The residue was purified by column chromatography on silica (EtOAc/petroleum ether = 1:6-1:4) to give 2,3-dihydrofuran derivatives.

General procedure for the synthesis of cyclopropane derivatives

K_2CO_3 (3.0 mmol) was added to a solution of 2-bromo-1-phenylethanone **1a** (1.5 mmol), (*E*)-methyl 2-oxo-4-phenylbut-3-enoate **2a** (1.0 mmol) and DABCO (1.5 mmol) in CH_2Cl_2 (3.0 mL) at room temperature. The reaction was then stirred and followed by TLC. Upon full consumption of 2-oxo-4-phenylbut-3-enoate **2a.** The reaction was quenched with 5 mL of water and extracted with CH_2Cl_2 (3×5 mL). The combined organic extracts were washed with water and brine, and dried ($MgSO_4$). After evaporating the solvent under reduced pressure, the residue was purified on silica gel (gelusing EtOAc/petroleum ether = 1:6-1:4) to give cyclopropane derivatives.

Methyl 5-benzoyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3a)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.03 (d, *J* = 6.9, 2H), 7.63–7.26 (m, 8H), 7.26 (d, *J* = 16.2, 1H), 6.66 (d, *J* = 16.2, 1H), 4.21 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.9, 166.8, 135.2, 135.1, 134.2, 133.8, 128.9, 128.8, 128.5, 126.9, 120.9, 65.7, 63.1, 52.9.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.91 (d, *J* = 7.2, 2H), 7.62–7.57 (m, 3H), 7.49–7.44 (m, 5H), 6.80 (d, *J* = 16.2, 1H), 6.40 (d, *J* = 16.2, 1H), 4.63 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.2, 168.3, 135.7, 135.3, 135.2, 134.2, 129.0, 128.5128.5, 128.3, 127.0, 115.8, 64.8, 61.5, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{16}O_4$, 308.1049; found, 308.1047.

Methyl 5-(4-methylbenzoyl)-4-phenyl-4,5-dihydrofuran-2-carboxylate (3b)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.82 (d, *J* = 6.9, 2H), 7.28–7.20 (m, 7H), 6.80 (d, *J* = 15.9, 1H), 6.39 (d, *J* = 15.9, 1H), 4.61 (s, 1H), 3.92 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 189.6, 168.4, 145.4, 135.6, 135.4, 132.7, 129.6, 128.7, 128.5, 128.4, 126.9, 116.0, 64.9, 61.4, 53.4, 21.8.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.93–7.86 (m, 2H), 7.43–7.29 (m, 7H), 6.90 (d, *J* = 15.9, 1H), 6.66 (d, *J* = 15.9, 1H), 4.20 (s, 1H), 3.68 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.4, 166.9, 145.4, 135.2, 133.7, 132.6, 129.6, 128.8, 128.7, 126.9, 121.0, 65.7, 63.1, 52.9, 21.9.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1204.

Methyl 5-(4-chlorobenzoyl)-4-phenyl-4,5-dihydrofuran-2-carboxylate (3c)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.99–7.97 (d, *J* = 8.1, 2H), 7.50–7.43 (m, 4H), 7.38–7.25 (m, 3H), 6.89 (d, *J* = 16.2, 1H), 6.64 (d, *J* = 16.2, 1H), 4.15 (s, 1H), 3.68 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.0, 166.7, 140.8, 135.1, 133.8, 133.4, 130.0, 129.3, 128.9, 128.8, 126.9, 120.6, 65.7, 63.1, 53.0.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.86 (d, *J* = 7.5, 2H), 7.46–7.43 (m, 2H), 7.34–7.25 (m, 5H), 6.76 (d, *J* = 15.9, 1H), 6.37 (d, *J* = 15.9, 1H), 4.58 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 189.2, 166.1, 140.8, 135.7, 135.2, 133.5, 129.7, 129.3, 128.6, 126.9, 115.6, 64.7, 61.4, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0654.

Methyl 5-benzoyl-4-*p*-tolyl-4,5-dihydrofuran-2-carboxylate (3d)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.02 (d, *J* = 7.2, 2H), 7.63–7.61 (m, 1H), 7.53–7.48 (m, 2H), 7.35–7.33 (m, 2H), 7.17–7.15 (m, 2H), 6.88 (d, *J* = 16.2, 1H), 6.59 (d, *J* = 16.2, 1H), 4.21 (s, 1H), 3.68 (s, 3H), 2.35 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 191.0, 166.9, 138.9, 135.1, 134.2, 133.8, 132.4, 129.5, 128.9, 128.5, 126.9, 119.8, 65.7, 63.3, 52.9, 21.3.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.79 (m, 2H), 7.60–7.47 (m, 3H), 7.15–7.04 (m, 4H), 6.76 (d, *J* = 15.6, 1H), 6.76 (d, *J* = 15.9, 1H), 4.16 (s, 1H), 3.93 (s, 3H), 2.29 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.2, 168.4, 138.5, 135.6, 135.2, 134.2, 132.5, 129.2, 128.9, 128.3, 126.9, 114.7, 64.9, 61.5, 53.4, 21.2.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1203.

Methyl 5-benzoyl-4-(4-chlorophenyl)-4,5-dihydrofuran-2-carboxylate (3e)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.01 (d, *J* = 7.2, 2H), 7.62–7.60 (m, 1H), 7.52–7.47 (m, 2H), 7.37–7.29 (m, 4H), 6.85 (d, *J* = 15.9, 1H), 6.64 (d, *J* = 15.9, 1H), 4.16 (s, 1H), 3.66 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.8, 166.7, 135.0, 134.5, 134.3, 133.9, 132.5, 129.0, 128.9, 128.5, 128.2, 121.6, 65.7, 63.0, 53.0.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.89 (d, *J* = 7.5, 2H), 7.80–7.56 (m, 3H), 7.48–7.03 (m, 4H), 6.74 (d, *J* = 16.2, 1H), 6.38 (d, *J* = 15.9, 1H), 4.64 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.1, 168.1, 135.1, 134.4, 134.3, 133.8, 129.0, 128.7, 128.3, 128.2, 128.2, 116.5, 64.8, 61.3, 53.5.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0658.

Isopropyl 5-benzoyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3f)

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06–7.90 (m, 2H), 7.63–7.25 (m, 8H), 6.93–6.34 (m, 2H), 5.28–5.22 (m, 1H), 4.58–4.21 (m, 1H), 1.41–1.01 (m, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 190.6, 190.4, 167.3, 165.7, 135.5, 135.5, 135.3, 135.3,135.1, 134.2, 134.1, 133.7,128.9, 128.9, 128.8, 128.7, 128.6, 128.5, 128.4, 128.3, 126.9 121.3, 116.2, 70.7, 70.3, 66.0, 64.8, 62.8, 61.6, 21.7, 21.4, 21.3.

HRMS EI (*m/z*): calcd for $C_{21}H_{20}O_4$, 336.1362; found, 336.1362.

Methyl 5-acetyl-4-phenyl-4,5-dihydrofuran-2-carboxylate (3g)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34-7.23 (m, 5H), 6.88–6.82 (m, 1H), 6.46–6.41 (m, 1H), 3.94–3.55 (4H), 2.24–2.06 (3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 201.51, 200.58, 167.96, 166.85, 135.52, 135.13, 133.55, 128.72, 126.90, 126.87, 121.15, 116.44, 66.66, 65.31, 63.09, 60.91, 53.26, 53.01, 28.31, 27.57, 23.46, 22.67.

HRMS EI (*m/z*): calcd for $C_{16}H_{18}O_4$, 274.1205; found, 274.1201.

Methyl 2-(2-benzoyl-3-phenylcyclopropyl)-2-oxoacetate (4a)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.93 (m, 2H), 7.57–7.23 (m, 7H), 3.87 (s, 3H), 3.46–3.41 (m, 2H), 3.33–3.30 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 194.2, 188.7, 161.0, 137.4, 136.0, 133.8, 128.9, 128.8, 128.6, 127.6, 126.5, 53.2, 39.5, 34.8, 32.2.

HRMS EI (*m/z*): calcd for $C_{19}H_{16}O_4$, 308.1049; found, 308.1046.

Methyl 2-(2-(4-methylbenzoyl)-3-phenylcyclopropyl)-2-oxoacetate (4b)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.87–7.84 (m, 2H), 7.35–7.24 (m, 7H), 3.87 (s, 3H), 3.45–3.42 (m, 2H), 3.30–3.27 (m, 1H), 2.39 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.8, 188.8, 161.0, 144.8, 137.6, 133.6, 129.5, 128.9, 128.8, 127.5, 126.5, 53.2, 39.6, 34.7, 32.0, 21.8.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1199.

Methyl 2-(2-(4-chlorobenzoyl)-3-phenylcyclopropyl)-2-oxoacetate (4c)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90–7.87 (m, 2H), 7.43–7.23 (m, 7H), 3.88 (s, 3H), 3.42–3.33 (m, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.0, 188.5, 160.9, 140.3, 137.2, 134.4, 130.0, 129.1, 129.0, 127.7, 126.4, 53.3, 39.3, 34.8, 32.3.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0657.

Methyl 2-(2-benzoyl-3-*p*-tolylcyclopropyl)-2-oxoacetate (4d)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.96–7.93 (m, 2H), 7.57–7.55 (m, 1H), 7.46–7.41 (m, 2H), 7.25–7.15 (m, 4H), 3.88 (s, 3H), 3.43–3.39 (m, 2H), 3.29–3.27 (m, 1H), 2.45 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ

194.3, 188.8, 161.0, 137.3, 136.1, 134.4, 133.8, 129.6, 128.8, 128.6, 126.4, 53.2, 39.8, 34.8, 32.1, 21.1.

HRMS EI (*m/z*): calcd for $C_{20}H_{18}O_4$, 322.1205; found, 322.1203.

Methyl 2-(2-benzoyl-3-(4-chlorophenyl)cyclopropyl)-2-oxoacetate (4e)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.94–7.91 (m, 2H), 7.60–7.55 (m, 1H), 7.47–7.42 (m, 2H), 7.34–7.31 (m, 2H), 7.19–7.17 (m, 2H), 3.87 (s, 3H), 3.42–3.38 (m, 2H), 3.30–3.25 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 193.9, 188.3, 160.9, 136.0, 135.9, 133.9, 133.3, 129.1, 128.8, 128.6, 127.9, 53.3, 39.3, 34.7, 31.4.

HRMS EI (*m/z*): calcd for $C_{19}H_{15}ClO_4$, 342.0659; found, 342.0656.

Isopropyl 2-(2-benzoyl-3-phenylcyclopropyl)-2-oxoacetate (4f)

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.98–7.96 (m, 2H), 7.57–7.25 (m, 8H), 5.16–5.12 (m, 1H), 3.45–3.42 (m, 2H), 3.33–3.28 (m, 1H), 1.33–1.31 (m, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 194.0, 189.1, 160.1, 137.6, 136.2, 133.7, 128.9, 128.7, 128.6, 128.3, 127.5, 126.5, 70.8, 39.0, 35.1, 32.1, 29.7, 21.6.

HRMS EI (*m/z*): calcd for $C_{21}H_{20}O_4$, 336.1362; found, 336.1360.

ACKNOWLEDGEMENTS

Project was supported by the Natural Science Foundation of Anhui Higher Education Institution (no. KJ2013B166, KJ2013Z232) and Chaohu College Foundation for Doctor in China.

REFERENCES AND NOTES

1. M. M. Faul and B. E. Huff, *Chem. Rev.*, 2000, **100**, 2407.

2. A. Schoop, H. Greiving, and A. Gohrt, *Tetrahedron Lett.*, 2000, **41**, 1913.

3. S. Schabbert and E. Schaumann, *Eur. J. Org. Chem.*, 1998, 1873.

4. T. Tsuji and S. Nishida, 'The Chemistry of the Cyclopropyl Group,' ed. by S. Patai, Wiley and Sons Press, Inc., New York, 1987.

5. F. Gnad and O. Reiser, *Chem. Rev.*, 2003, **103**, 1603.

6. J. W. Lee and Y. Dong, *Heterocycles*, 1990, **31**, 1417.

7. K. S. Feldman and M. L. Wrobleski, *J. Org. Chem.*, 2000, **65**, 8659.

8. H. Lebel, J. F. Marcoux, C. Molinaro, and A. B. Charette, *Chem. Rev.*, 2003, **103**, 977.

9. J. Krysiak, T. Kato, H. Gornizka, A. Baceiredo, M. Mikolajczyk, and G. Bertrand, *J. Org. Chem.*, 2001, **66**, 8240.

10. W. Cao, H. Zhang, J. Chen, X. H. Zhou, M. Shao, and C. M. Mark, *Tetrahedron*, 2008, **64**, 163.

11. W. Cao, G. Chen, J. Chen, and R. Chen, *Synth. Commun.*, 2005, **35**, 527.
12. Z. J. Yang, M. J. Fan, R. Z. Mu, W. M. Liu, and Y. M. Liang, *Tetrahedron*, 2005, **61**, 9140.
13. C. Feng, C. F. Lu, Z. X. Chen, N. G. Dong, J. W. Shi, and G. C. Yang, *J. Heterocycl. Chem.*, 2010, **47**, 671.
14. C. P. Chuang and A. I. Tsai, *Synthesis*, 2006, 675.
15. M. Rueping, B. J. Nachtsheim, S. A. Moreth, and M. Bolte, *Angew. Chem. Int. Ed.*, 2008, **47**, 593.
16. Q. G. Wang, X. M. Deng, B. H. Zhu, L.W. Ye, X. L. Sun, C. Y. Zhu, and Y. Tang, *J. Am. Chem. Soc.*, 2008, **130**, 5408.