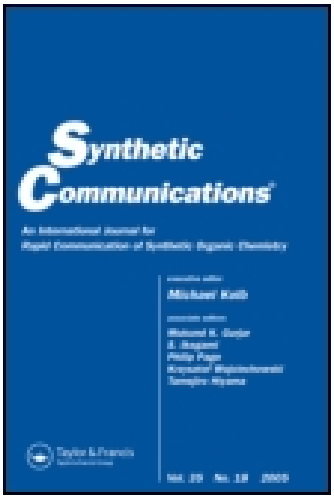

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Proline-Catalyzed Synthesis of 5-Aryl-2-oxazolidinones from Carbon Dioxide and Aziridines Under Solvent-Free Conditions

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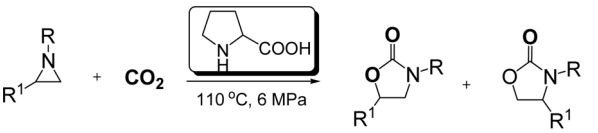
GRAPHICAL ABSTRACT



R^1=aryl, regio-sel$_{(2:3)}$, up to 98:2
R^1=alkyl, regio-sel$_{(2:3)}$, up to 2:98

Abstract *Natural α-amino acids were proven to be ecofriendly and recyclable catalysts for the carboxylation of aziridines with CO_2 without utilization of any organic solvents or additives. Notably, a series of 5-aryl-2-oxazolidinones were obtained in good yield together with excellent chemo- and regioselectivity under mild conditions using proline as the catalyst. Notably, the catalyst could be recycled more than five times after a simple separation procedure without appreciable loss of catalytic activity. This process represents a promising strategy for homogeneous catalyst recycling.*

Keywords 5-Aryl-2-oxazolidinones; aziridines; carbon dioxide; proline

INTRODUCTION

Oxazolidinones are important compounds in synthetic and medicinal chemistry, that can be widely used as chiral auxiliaries,[1–3] intermediates in organic synthesis,[4–8] and building blocks for biologically active pharmaceutical agents.[9–14] Currently, there are three main protocols for the synthesis of oxazolidinones from C1 resources: (i)carbonylation of amino alcohols using phosgene, CO, etc.;[15–21] (ii) reaction of propargylamines or propargylic alcohols with CO_2; [22–26] (iii) carboxylation of aziridines with CO_2.[27–39] Recently, Li et al. demonstrated that the oxazolidinones can be synthesized through the copper-catalyzed coupling of aldehydes, amines, terminal alkynes, and CO_2.[40] Method (iii) is a high-atom-efficiency reac-

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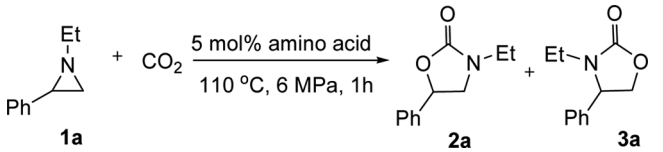
tion, utilizing renewable, abundant, and nontoxic CO_2 as a building block, and it has attracted much attention from the viewpoint of green chemistry. In past decades, numerous homogeneous catalytic systems including salen Cr(III)/dimethylaminopyridine (DMAP),[27] phenol/DMAP,[28] alkali metal halide[29,30] or tetraalkylammonium halide system,[31] iodine,[32,33] $PEG_{6000}NBu_4Br$,[37] zirconyl chloride,[38] and α-amino acid[39] have been reported to be effective for the coupling of aziridines and CO_2. Besides, an electrochemical procedure is an alternative for this transformation.[34] Nonetheless, poisonous solvent is generally required to achieve a good yield. Halides or other toxic components such as phenol and DMAP are required in most of the catalysts and/or cocatalysts, thus creating a negative effect on the environment. On the other hand, it is difficult to separate a homogeneous catalyst from the product. Therefore, development of a biocompatible, recyclable catalytic system for solvent-free synthesis of 5-substituted oxazolidinones is highly desirable and still remains a challenge.

As readily accessible chiral molecules, natural α-amino acids possess the merits of diverse structures, low cost, high thermal stability, biocompatibility, easy regeneration, and biodegradability. Many catalytic reactions have been smoothly performed using amino acids as catalysts or auxiliaries.[41–45] In particular, proline is a remarkable candidate for the asymmetric reactions.[46–50] Amino acid with a carbonyl and an amino group can behave both as an acid and a base to facilitate chemical reactions. Jiang et al. reported the synthesis of cyclic carbonates from CO_2 and epoxides catalyzed by amino acids.[41] In the framework of our continuous effort to chemically fix CO_2, herein we report an efficient process for the synthesis of 5-aryl-2-oxazolidinones via coupling reaction of CO_2 and aziridine by employing amino acids as efficient and recyclable catalysts.

RESULTS AND DISCUSSION

The reaction of 1-ethyl-2-phenylaziridine **1a** with CO_2 was chosen as the model reaction to investigate the catalytic performance of diverse α-amino acids (Scheme 1).

As shown in Table 1, the reaction barely took place without any catalyst (entry 1, Table 1). Among the surveyed amino acids, L-proline gave the greatest yield of **2a** under identical reaction conditions (entry 13 vs. entries 2–12), which is presumably because of its unique molecular structure.[46] As a pyrrolidine-based amino acid, proline with a secondary amino group is able to be dissolved in the reaction mixture, whereas other amino acids could act as heterogeneous catalysts, which was confirmed by the phase behavior of the reaction visually inspected through a sapphire window attached to the autoclave.



Scheme 1. Carboxylation of aziridine with CO_2 catalyzed by different amino acids.

Table 1. Carboxylation of 1-ethyl-2-phenylaziridine **1a** with CO_2 catalyzed by different amino acids[a]

Entry	Catalyst	Conv. (%)[b]	Yield of **2a** (%)[b]	Regio-sel. (%)[c]
1	None	2	Trace	—
2	L-Arginine	17	5	96:4
3	L-Lysine	10	8	95:5
4	L-Glutamic acid	29	6	94:6
5	L-Valine	18	8	95:5
6	L-Serine	31	7	95:5
7	L-Alanine	17	5	95:5
8	L-Tryptophan	17	5	95:5
9	L-Phenylalanine	19	4	94:6
10	L-Histidine	14	5	95:5
11	L-Glutamine	15	8	92:8
12	L-Cysteine	40	6	96:4
13	L-Proline	57	32	94:6

[a]Reaction conditions: amino acids (0.1 mmol, 5 mol% with respect to **1a**), **1a** (294 mg, 2 mmol), 110 °C, 6 MPa, 1 h.

[b]The conversion of **1a** and the yield of **2a** were determined by GC using biphenyl as an internal standard.

[c]Molar ratio of **2a** to **3a**.

The reaction conditions were also optimized with 5 mol% L-proline as the catalyst. The reaction was performed at 110 °C under 6 MPa CO_2 pressure. The results listed in Table 2 reveal that the reaction proceeded smoothly within first 8 h (Table 2, entries 1–4). It is worth mentioning that within 8 h, almost full conversion together with 91% yield of **2a** was obtained, and the regioselectivity was 93:7 (**2a**/**3a**). Moreover, the yield and selectivity were almost invariant when the reaction time was prolonged to 12 h (entry 4 vs. 5). In other words, a reaction time of 8 h is required to complete the reaction. It is also interesting that the chemoselectivity of **2a** also rose from 56% to 91% as reaction time was prolonged from 1 to 8 h, which could be explained by backbiting from the oligomers or copolymerization between aziridines and CO_2, as depicted in the literature.[36–38,51,52]

The effect of reaction temperature on the reaction was studied at the pressure of 6 MPa for 8 h (entries 4, 6, and 7). The reaction temperature had a remarkable effect on the reactivity. The yield of **2a** was increased from 64% to 91% with temperature rising from 90 to 110 °C (entries 6 vs. 4). The by-products were found to be slight amounts of 1,4-diethyl-2,5-diphenylpiperazine and 1,4-diethyl-2,3-diphenylpiperazine (i.e., dimers of **2a**,) gas chromatography–mass spectrometry detected by (GC-MS) and ^{1}H NMR (see the experimental section). There was no significant change at a higher reaction temperature (entry 7). This reaction is also very sensitive to CO_2 pressure. When CO_2 pressure was varied from 2 to 6 MPa, yield of **2a** increased from 70% to 91% (entries 8 and 4). While higher pressure may suppress the interaction between the substrate and the catalyst, and it may also cause a low concentration of aziridine around the catalyst, thereby leading to lower activity (entry 9).[37] Furthermore, a series of catalytic cycles were performed to survey the reusability of the catalyst (entries 10–14). The particular polarity of proline could provide a convenient protocol for the catalyst recovery. In each cycle, the catalyst

Table 2. Effects of reaction parameters on the reaction[a]

Entry	Time/h	Temp./°C	Pressure/MPa	Conv. (%)[b]	Yield (%)[c]	Regio-sel. (%)[d]
1	1	110	6	57	32	92:8
2	3	110	6	91	53	94:6
3	6	110	6	>99	80	94:6
4	8	110	6	>99	91	93:7
5	12	110	6	>99	91	94:6
6	8	90	6	83	64	92:8
7	8	130	6	>99	92	93:7
8	8	110	2	82	70	96:4
9	8	110	13	86	66	92:8
10[e]	8	110	6	100	92	94:6
11[f]	8	110	6	>99	92	94:6
12[g]	8	110	6	>99	93	96:4
13[h]	8	110	6	>99	92	95:5
14[i]	8	110	6	>99	93	96:4
15[j]	8	110	6	51	42	92:8
16[k]	8	110	6	37	17	92:8

[a]Reaction conditions: **1a** (294 mg, 2 mmol) and proline (0.1 mmol, 5 mmol% relative to **1a**).
[b]Determined by GC.
[c]The yield of **2a**.
[d]Molar ratio of **2a** to **3a**.
[e]The first run of the catalyst, proline (20 mmol% with respect to **1a**).
[f]The second run of the catalyst.
[g]The third run of the catalyst.
[h]The fourth run of the catalyst.
[i]The fifth run of the catalyst.
[j]The catalyst loading was 1 mol%.
[k]The catalyst loading was 3 mol%.

could be easily precipitated by addition of ether, recovered by simple filtration, and reused for the next run without further purification under the same conditions. The results listed in Table 2 indicate that no significant drop in either **2a** yield or selectivity was detected after five successive cycles. On the other hand, the influence of catalyst loading on **2a** synthesis was also tested. As easily seen, the catalyst amount has a considerable influence on **2a** yield in the range of 1 to 5 mol% (entries 4, 15, and 16). In particular, yield of **2a** was 17% when 1 mol% catalyst was used, also indicating that catalyst leaching would be negligible. Therefore, easy recovery of the catalyst (proline) from the product offers a nice strategy for homogeneous catalyst recycling.

The utility and generality of proline were also examined. As shown in Table 3, the cycloaddition reactions of various aziridines with CO_2 were conducted under the optimized reaction conditions (Scheme 2). It was revealed that steric hindrance of the N-substituted group cause lower activity (Table 3, entries 1, and 3–7). A relatively poor yield was obtained when the substrate was 1-methyl-2-phenylaziridine (**1b**). This is understandable because highly active aziridine is prone to form self-oligomers (entry 2). The aziridines with electron-withdrawing or electron-donating substituent groups on the aryl ring were good substrates (entries 9 and 10). However, the nature of R^1 of the substrates would play a key role in dominating the selective formation of

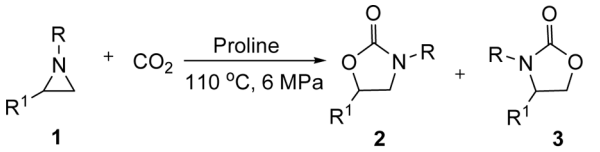
Table 3. Substrate scope[a]

Entry	Substrate	Time (h)	Conv. (%)[b]	Yield of **2a–k** (%)[b]	Regio-sel. (%)[c]
1	**1a**	8	>99	96	97:3
2	**1b**	12	93	70	90:10
3	**1c**	10	>99	91	95:5
4	**1d**	12	95	86	95:5
5	**1e**	12	26	24	98:2
6	**1f**	12	33	25	94:6
7	**1g**	12	69	61	94:6
8	**1h**	12	100	89	94:6
9	**1i**	8	96	89	95:5
10	**1j**	8	98	92	96:4
11	**1k**	12	99	94	2:98

[a]Reaction conditions: proline (0.1 mmol, 5 mol% with respect to the substrate), the substrate (2 mmol), 110 °C, 6 MPa.
[b]Determined by GC.
[c]Molar ratio of **2** and **3**.

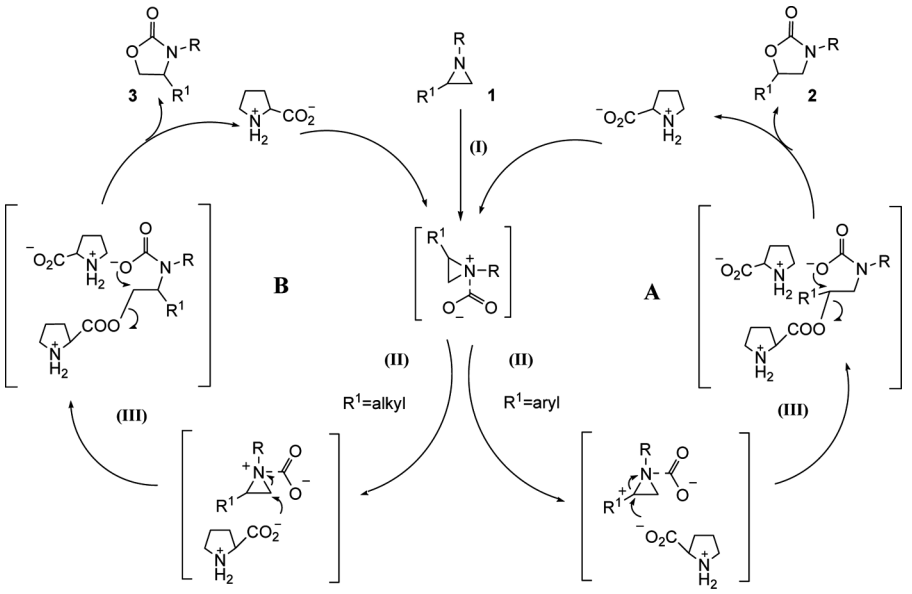
4- or 5-substituted oxazolidinones. When R^1 was altered to an alkyl-like group, 4-substituted oxazolidinone could be obtained with high regioselectivity (2:98) (entry 11), which would be explained by the proposed mechanism as outlined in Scheme 3. In other words, the aryl group of R^1 favors the formation of 5-substituted 2-oxazolidinone **2** while the alkyl group is preferable for producing 4-substituted isomer **3**, which is in good agreement with the previous literature.[27,31,37]

Based on the experimental results and previous reports,[31,37] a hypothetic reaction mechanism for the coupling of CO_2 with aziridines is proposed as depicted in Scheme 3. It has three steps: first, aziridine coordinates with CO_2 to form the intermediate (step 1); then nucleophilic attack at the 2 or 3 position by the carboxylate ion of the proline leads to ring opening of the aziridine (step 2), and finally oxazolidinone is formed by subsequent intramolecular ringclosure and the catalyst is



a: R=Et, R^1=Ph
b: R=Me, R^1=Ph
c: R=*n*-Pr, R^1=Ph
d: R=*n*-Bu, R^1=Ph
e: R=*i*-Pr, R^1=Ph
f: R=cyclopropyl, R^1=Ph
g: R=*i*-Bu, R^1=Ph
h: R=*i*-amyl, R^1=Ph
i: R=Et, R^1=*p*-MePh
j: R=Et, R^1=*p*-ClPh
k: R=Bn, R^1=$ClCH_2$

Scheme 2. L-Proline-catalyzed cycloaddition reaction of CO_2 to aziridines.



Scheme 3. Proposed mechanism.

regenerated (step 3).[41] Aziridine coordination with CO_2 is the rate-dominating step, which is in accordance with substituted group effect on the activity. Substrates bearing bulk-substituted groups on the N atom could hinder interaction of aziridine and CO_2, thus leading to lower activity as a result of the steric hindrance. Interestingly, there exist two different cycles (A or B) depending on the nature of R^1. The cation intermediate favors a more stable state, and the positive-charge center transfers to the more substituted carbon when R^1 is an aryl group or stays on the nitrogen atom when R^1 is an alkyl group, resulting in two ring-opening ways and 4- or 5-substituted isomers.

CONCLUSIONS

In conclusion, natural α-amino acids were proven to be biocompatible catalysts for carboxylation of aziridines with CO_2 under solvent-free conditions. Proline exhibited higher reactivity than other surveyed α-amino acids. The catalyst can be conveniently recovered, and excellent catalyst performance was retained after five successive recycles. This process represents a simple and green protocol for highly efficient synthesis of oxazolidinones.

EXPERIMENTAL

Reagents

The amino acids were commercially supplied by Guangfu Chemical Reagents Co. Ltd. Diethyl ether was freshly distilled over sodium under nitrogen.

Dichloromethane was distilled from calcium hydride. Silica gel (particle size 200–300 mesh) in this study was commercially supplied by Qingdao Haiyang Chemical Reagents Co. Ltd. Other reagents were analytical grade and were used as received.

Aziridines Preparation

Aziridines **1a–j** were prepared according to the published methods,[53] as shown in Scheme 4.

The typical procedure is described. The bromine (32.0 g, 0.2 mol) in dry CH_2Cl_2 (40 mL) was added dropwise over 30 min to an ice-cooled 40 mL CH_2Cl_2 solution of dimethyl sulfide (12.4 g, 0.2 mol). During the addition, light orange crystals of bromodimethyl sulfonium bromide began to separate. After addition of bromine, the orange crystals **S1** were collected by filtration and then washed with dry diethyl ether and dried under vacuum. Yield: 80%, mp 80 °C (dec).

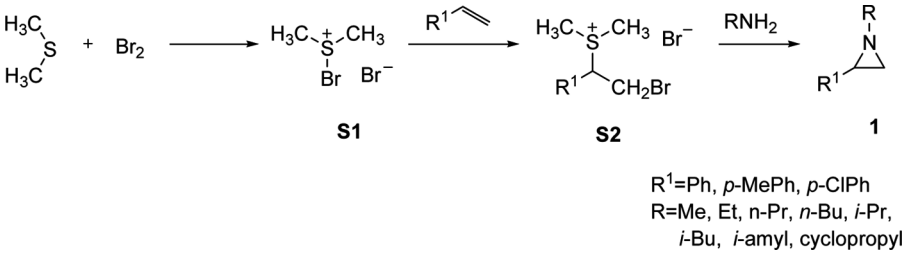
Olefin (160 mmol) was added dropwise to the 160 mL CH_3CN solution of **S1** (35.56 g, 160 mmol) in an ice-water bath. During the addition, the white solid began to separate. The solution was further stirred for 10 min. The crystals **S2** were collected by filtration and dried under vacuum. Yield: 32–38.6%.

A solution of amine (20–50 mmol) in water was added dropwise to a stirred solution of compound **S2** (10 mmol) in 20 mL of H_2O at rt, and the resulting mixture was stirred overnight. The mixture was added to 20 mL of saturated brine, extracted with diethyl ether (3×20 mL), dried with anhydrous $MgSO_4$ overnight, and evaporated under reduced pressure. Aziridine was obtained by distillation under reduced pressure. Yield: 85–100%.

Aziridine (**1k**) was synthesized according to the published procedure.[37]

Carboxylation of Aziridines with CO_2

In a typical reaction, the carboxylation of aziridines with CO_2 was carried out in a 25-mL stainless steel autoclave. Amino acid (0.1 mmol) and aziridine (2 mmol) were charged into the reactor at room temperature. CO_2 was introduced into the autoclave, and then the mixture was stirred at a predetermined temperature for 15 min to reach equilibration. The pressure was then adjusted to the desired pressure, and the mixture was stirred continuously. When the reaction finished, the reactor was cooled in ice water, and CO_2 was ejected slowly. An aliquot of sample was taken



Scheme 4. Preparation of N-alkyl phenylaziridines (**1a–j**).

from the resultant mixture and dissolved in dry CH_2Cl_2 for GC analysis [GC analyses were performed on a Shimadzu GC-2014, equipped with a capillary column (RTX-5, 30 m × 0.25 μm × 0.25 mm) using a flame ionization detector]. The residue was purified by column chromatography on silica gel (eluting with 8:1 to 1:1 petroleum ether/ethyl acetate) to afford the product. The products were further identified by ^{1}H NMR, ^{13}C NMR, and MS, which are consistent with those reported in the literature[27,37] and in good agreement with the assigned structures.

Spectral Characteristics of the Products

^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruck 300 or Varian Mercury-Plus 400 spectrometer in $CDCl_3$. Chemical shifts were given as δ values referenced in parts per million (ppm) from tetramethylsilane (TMS) as an internal standard. GC-MS was measured on a Finnigan HP G1800A. Liquid chromatography–mass spectrometry (LC-MS) was performed on a Thermo Finnigan LCQ Advantage spectrometer in electrospray ionozation (ESI) model (ESI-MS) with spray voltage 4.8 kV and atmospheric pressure chemical ionization (APCI-MS). High-resolution mass spectrometry (HRMS) was conducted using an Ionspec 7.0 T spectrometer by the ESI-FTICR technique. Melting points were measured on an X4 apparatus and uncorrected. Spectral characteristics of the products (oxazolidinones **2a–k**) in Table 3 were provided as follows:

3-Ethyl-5-phenyloxazolidin-2-one (2a). Colorless liquid; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.17 (t, $J = 7.2$ Hz, 3H), 3.29–3.45 (m, 3H), 3.92 (t, $J = 8.7$ Hz, 1H), 5.48 (t, $J = 7.8$ Hz, 1H), 7.34–7.42 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 12.4, 38.8, 51.5, 74.2, 125.4, 128.6, 128.8, 138.8, 157.5. MS (ESI) calcd. for $C_{11}H_{13}NO_2$ 191.09 found 192.29 $(M + H)^+$, 214.38 $(M + Na)^+$, 405.01 $(2M + Na)^+$.

3-Ethyl-4-phenyloxazolidin-2-one (3a). Colorless liquid; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.05 (t, $J = 5.4$ Hz, 3H), 2.79–2.88 (m, 1H), 3.48–3.57(m, 1H), 4.10 (t, $J = 6.0$ Hz, 1H), 4.62 (t, $J = 6.6$ Hz, 1H), 4.81 (t, $J = 5.4$ Hz, 1H), 7.30 −7.44 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 12.1, 36.9, 59.4, 69.8, 127.0, 129.0, 129.2, 137.9, 158.1. MS (ESI) calcd. for $C_{11}H_{13}NO_2$ 191.09; found 192.29 $(M + H)^+$, 214.38 $(M + Na)^+$.

3-Methyl-5-phenyloxazolidin-2-one (2b). White crystals. Mp. 50–52 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.89 (s, 3H), 3.42 (t, $J = 8.4$ Hz, 1H), 3.90 (t, $J = 8.4$ Hz, 1H), 5.45 (t, $J = 8.0$ Hz, 1H), 7.33–7.38 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 30.7, 54.0, 73.0, 125.3, 128.5, 128.6, 138.4, 157.9. ESI-MS calcd. for $C_{10}H_{11}NO_2$ 177.08, found 178.21 $(M + H)^+$, 200.25 $(M + Na)^+$, 377.00 $(2M + Na)^+$.

5-Phenyl-3-propyloxazolidin-2-one (2c). Colorless liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.91 (t, $J = 7.2$ Hz, 3H), 1.52–1.61 (m, 2H), 3.18–3.31 (m, 2H), 3.40 (t, $J = 8.0$ Hz, 1H), 3.90 (t, $J = 8.8$ Hz, 1H), 5.46 (t, $J = 8.0$ Hz, 1H), 7.31–7.37 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 10.7, 20.3, 45.5, 51.8, 74.0, 125.2, 128.4, 128.5, 138.7,157.6. ESI-MS calcd. for $C_{12}H_{15}NO_2$ 205.11; found 206.30 $(M + H)^+$, 228.30 $(M + Na)^+$, 433.04 $(2M + Na)^+$.

3-Butyl-5-phenyloxazolidin-2-one (2d). Colorless liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.94 (t, $J = 7.2$ Hz, 3H), 1.31–140 (m, 2H), 1.51–1.58 (m, 2H), 3.23–3.38 (m, 2H), 3.43 (t, $J = 8.0$ Hz, 1H), 3.92 (t, $J = 8.8$ Hz, 1H), 5.49 (t, $J = 8.0$ Hz, 1H), 7.28–7.42 (m, 5H). ^{13}C NMR (75 MHz, CDC_{13}): δ 13.4, 19.5, 29.1, 43.6, 51.8, 74.1, 125.2, 128.4,128.5, 138.7, 157.7. ESI-MS calcd. for $C_{13}H_{17}NO_2$ 219.13; found 220.34 $(M + H)^+$, 259.48 $(M+K)^+$, 461.05 $(2M + Na)^+$.

3-Isopropyl-5-phenyloxazolidin-2-one (2e). Colorless liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.16 (d, $J = 6.8$ Hz, 3H), 1.22 (d, $J = 6.8$ Hz, 3H), 3.37 (t, $J = 8.0$ Hz, 1H), 3.87 (t, $J = 8.8$ Hz, 1H), 4.13–4.23 (m, 1H), 5.48 (t, $J = 8.0$ Hz, 1H), 7.34–7.42 (m, 5H). ^{13}C NMR (75 MHz, CDC_{13}): δ 19.1, 19.6, 44.5, 47.0, 74.2, 125.1, 128.3, 128.5, 138.7,156.7. ESI-MS calcd. for $C_{12}H_{15}NO_2$ 205.11; found 206.29 $(M + H)^+$, 433.08 $(2M + Na)^+$.

3-Cyclopropyl-5-phenyloxazolidin-2-one (2f). White crystals; mp 52–55 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.75 (s, 4H), 2.55–2.59 (m, 1H), 3.43 (t, $J = 8.1$ Hz, 1H), 3.88 (t, $J = 8.7$ Hz, 1H), 5.42 (t, $J = 8.1$ Hz, 1H), 7.28–7.37 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 5.4, 5.8, 25.7, 53.3, 74.3, 125.4, 128.6, 128.7, 138.5, 157.9. ESI-MS calcd. for $C_{12}H_{13}NO_2$ 203.09; found 429.27 $(2M + Na)^+$, 631.80 $(3M + Na)^+$.

3-Isobutyl-5-phenyloxazolidin-2-one (2g). White crystals; mp 38–42 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.91 (d, $J = 4.8$ Hz, 3H), 0.93 (d, $J = 4.8$ Hz, 3H), 1.81–1.95 (m, 1H), 3.02–3.16 (m, 2H), 3.42 (dd, $J = 8.7$ Hz, $J = 7.5$ Hz, 1H), 3.91 (t, $J = 8.7$ Hz, 1H),5.48 (t, $J = 8.4$ Hz, 1H), 7.32–7.41 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 19.7, 19.8,26.7, 51.6, 52.6, 74.1, 125.3, 128.5, 128.7, 138.8, 158.0. ESI-MS calcd. for $C_{13}H_{17}NO_2$ 219.13; found 461.22 $(2M + Na)^+$, 679.70 $(3M + Na)^+$. HRMS: calcd. for $C_{13}H_{17}NO_2$ $(M + H)^+$ 220.1332; found 220.1339.

3-Isopentyl-5-phenyloxazolidin-2-one (2h). Colorless liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.92 (d, $J = 3.3$ Hz, 3H), 0.94 (d, $J = 3.3$ Hz, 3H), 1.43 (q, $J = 7.5$ Hz, 2H), 1.54–1.65 (m, 1H), 3.22–3.36 (m, 2H), 3.41 (t, $J = 7.8$ Hz, 1H), 3.91 (t, $J = 8.7$ Hz, 1H), 5.46 (t, $J = 8.1$ Hz, 1H), 7.33–7.39 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 22.2, 22.3,25.6, 35.9, 42.4, 52.0, 74.2, 125.3, 128.6, 128.7, 138.8, 157.7. ESI-MS calcd. for $C_{14}H_{19}NO_2$ 233.14; found 489.17 $(2M + Na)^+$, 721.97 $(3M + Na)^+$. HRMS: calcd. for $C_{14}H_{19}NO_2$ $(M + H)^+$ 234.1489; found 234.1489.

3-Ethyl-5-p-tolyloxazolidin-2-one (2i). White crystals; mp 49–53 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.18 (t, $J = 7.2$ Hz, 3H), 2.36 (s, 3H), 3.29–3.45 (m, 3H), 3.89 (t, $J = 8.7$ Hz, 1H), 5.45 (t, $J = 8.1$ Hz, 1H), 7.19–7.24 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$): δ12.6, 21.2, 38.9, 51.6, 74.4, 125.6, 129.5, 135.9, 138.7, 157.7. ESI-MS calcd. for $C_{12}H_{15}NO_2$ 205.11; found 206.15 $(M + H)^+$, 433.92 $(2M + Na)^+$.

5-(4-Chlorophenyl)-3-ethyloxazolidin-2-one (2j). White crystals; mp 73–77 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.18 (t, $J = 15$ Hz, 3H), 3.32–3.42 (m, 3H), 3.92 (t, $J = 9$ Hz, 1H), 5.46 (t, $J = 6$ Hz, 1H), 7.28–7.40 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 12.5, 38.9,51.5, 73.5, 126.9, 129.1, 134.6, 137.4, 157.3, 162.3. ESI-MS calcd. for $C_{11}H_{12}NO_2Cl$ 225.06; found 226.17 $(M + H)^+$.

3-Benzyl-4-(chloromethyl)oxazolidin-2-one (2k). Colorless liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.52 (d, 2H), 3.86–3.94 (m, 1H), 4.17 (d, $J = 15.3$ Hz, 1H), 4.24 (t, $J = 8.9$ Hz, 1H), 4.23 (q, $J = 9.0$ Hz, $J = 5.3$ Hz, 1H), 4.82 (d, $J = 15.3$ Hz, 1H), 7.29–7.37 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 43.4, 46.5, 54.8, 65.3, 128.1, 128.3, 129.0, 135.5, 158.0. ESI-MS calcd for $C_{11}H_{12}NO_2Cl$ 225.67; found 472.90 $(2M + Na)^+$. HRMS: calcd. for $C_{11}H_{12}NO_2Cl$ $(M + Na)^+$ 248.0449; found 248.0454.

1,4-Diethyl-2,5-diphenylpiperazine. White crystals; mp 115–119 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.91 (t, $J = 7.2$ Hz, 6H), 1.99–2.05 (m, 2H), 2.30 (t, $J = 10.8$ Hz, 2H), 2.54–2.62 (m, 2H), 3.08 (dd, $J = 11.6$ Hz, $J = 2.4$ Hz, 2H), 3.45 (dd, $J = 2.0$ Hz, $J = 12.0$ Hz, 2H), 7.29–7.43 (m, 10H). LC-MS calcd. for $C_{20}H_{26}N_2$ 294.21; found 295.35 $(M + H)^+$.

1,4-Diethyl-2,3-diphenylpiperazine. Colorless liquid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.01 (t, $J = 7.2$ Hz, 6H), 2.17–2.26 (m, 2H), 2.26–2.33 (m, 2H), 2.65–2.69 (m, 2H), 2.95–2.99 (q, $J = 6.0$ Hz, 2H), 3.73 (s, 2H), 7.27–7.38 (m, 6H), 7.69–7.71 (d, $J = 7.2$ Hz, 4H). LC-MS calcd. for $C_{20}H_{26}N_2$ 294.21; found 295.31$(M + H)^+$.

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