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Oxidative Amidation of Activated Alkenes Using $Pd(OAc)_2$ as a Catalyst Precursor

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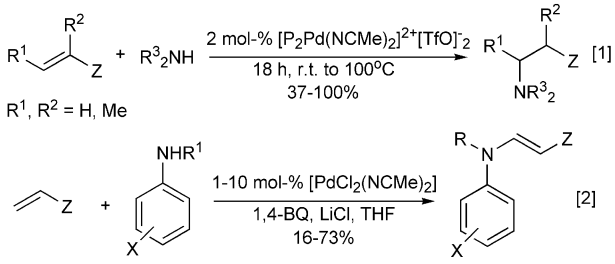
Keywords: Homogeneous catalysis / Palladium / Amides / Alkenes / Enamines

A new "chloride-free" protocol was developed for oxidative amidation reactions between cyclic and acyclic amides and carbamates with activated olefins, conducted under Pd/Cu catalysis, using air as a terminal oxidant. The presence of TsOH is important for catalytic activity. The scope of the reaction includes the addition of primary amides, carbamates, as well as cyclic oxazolidinone and pyrrolidinone. The reactions are found to be sensitive to steric demand of the *N*-nucleophile, and *E*-selectivity can be achieved exclusively with cyclic *N*-nucleophiles. The products can be easily hydrogenated to afford the saturated product in high yields.

Introduction

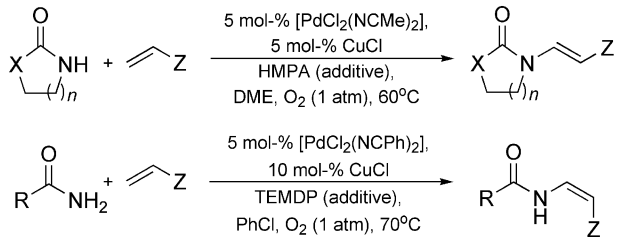
Under certain conditions, Pd-catalysed addition of N–H to C=C bonds can proceed via hydroamination or oxidative amination pathways, to give amine or enamine products, respectively.[1] Previously, we reported the use of dicationic palladium(II) catalysts for the addition of aliphatic and aromatic amines to electron-deficient olefins; see Scheme 1 and Equation (1)].[2] Prior to that, the synthesis of enamines from reactions of olefins and secondary aromatic amines had been reported by Hegedus and co-workers, by using a neutral Pd^{II} catalyst and benzoquinone as an oxidant; see Scheme 1 and Equation (2).[3]



Scheme 1. Pd-catalysed oxidative hydroamination of electron-deficient olefins (Z = CN, CO_2Me).

As amides are substantially less nucleophilic than amines, their direct addition to activated alkenes (hydroamidation) does not occur easily; reactions are largely limited to additions to activated α,β-unsaturated enones, which could be catalysed by $[PdCl_2(NCPh)_2]$ at 60 °C,[4a] vanadyl triflate at room temperature,[4b] or *p*TsOH under high pressure.[4c] In comparison, hydroamidation reactions of α,β-unsaturated esters require much harsher conditions; only reported to occur at 130 °C under microwave irradiation, in the presence of K_2CO_3 and tetra-*n*-butylammonium bromide as a phase-transfer reagent.[5]

On the other hand, oxidative amidation of electron-deficient alkenes (including enones, as well as α,β-unsaturated esters, amides and nitriles) can be achieved by Pd catalysis. In the presence of a CuCl co-catalyst, O_2 may be employed as the terminal oxidant, effectively replacing the need for stoichiometric oxidants such as 1,4-benzoquinone or peroxides (Scheme 2). First examples of these reactions were provided by Hosokawa and Murahashi,[6] where cyclic carbamates and amides reacted with electron-deficient alkenes to give *E*-enamides, whilst the reaction of acyclic methyl carbamate was much slower, giving a mixture of *E*/*Z* isomers. In some reactions, the addition of (highly toxic) HMPA is necessary. More recently, a very similar protocol has been reported for the addition of primary amides to electron-deficient alkenes.[7] In these reactions, tetraethylmethylenediphosphonate (TEMDP) replaces HMPA as an additive. Although *Z*-enamides were obtained as predominant products in moderate to good yields, reactions of cyclic N–H substrates was not described.



Scheme 2. Pd-catalysed oxidative amidation of activated alkenes.

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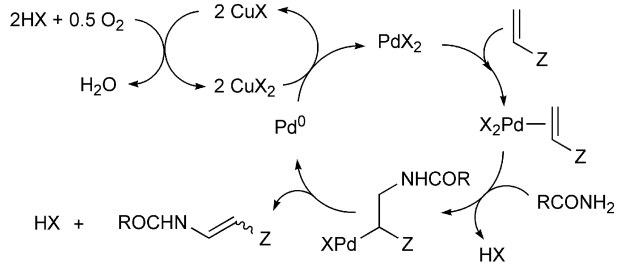
In both of these reactions, $PdCl_2$ precursors were used. A general catalytic cycle was proposed (Scheme 3),[7] where the alkene was activated by η^2-coordination to the metal centre. This allows C–N bond formation to occur via nucleophilic attack of the amide. Following β-hydride elimination and release of the enamide product, the Pd^{II} precursor is regenerated by copper(II), which is, in turn, re-oxidised aerobically.



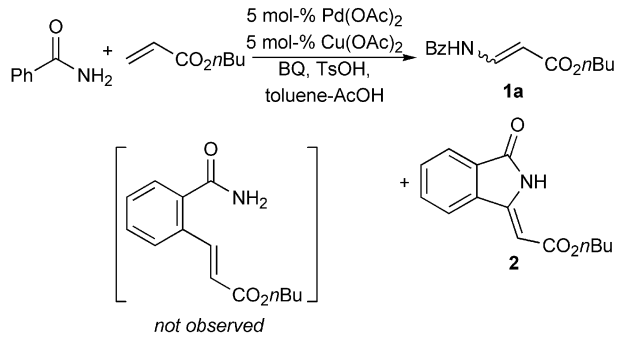
Scheme 3. Proposed catalytic cycle.

The oxidative amidation reaction formally substitutes a C–H bond of an alkene by a C–N bond, generating water as the only by-product. Given that pre-activation of the alkene is not required, it is a more attractive strategy for enamide synthesis than cross-coupling reactions, where amides and alkenyl halides/boronic acids were employed in the presence of Cu or Pd catalysts.[8] Herein, we describe a new catalytic protocol that allows oxidative amidation reactions to be conducted in open air. In contrast to previous reports, the procedure utilises $Pd(OAc)_2$ as a catalyst precursor and TsOH as an additive, effectively offering "chloride-free" conditions. The new procedure allows acyclic and cyclic amides, carbamates and imides to be employed as substrates, without the need for additives.

Results and Discussion

The work initiated with a serendipitous discovery: Under conditions described for oxidative C–C coupling,[9] benzamide and *n*-butyl acrylate did not undergo *ortho*-olefination, but an oxidative amidation reaction to give a mixture of products **1a** and **2** (Scheme 4). The result was unexpected, given that oxidative amidation reactions were associated entirely with the use of $PdCl_2$ catalysts. For this reason, we initiated a study to examine the feasibility of a "chloride-free" catalytic protocol for these reactions. We envisage that such a procedure may have certain advantages, e.g. $Pd(OAc)_2$ is generally more soluble than $PdCl_2$ compounds in most organic solvents; the new procedure may also offer complementary scope.

The first task was to interrogate each component of the catalytic system, to examine their effect on the reaction (Table 1). The isoindolinone derivative **2** appears to be a secondary product of the reaction; its formation can be suppressed by conducting the reaction at ambient temperature, yielding **1a** as the only product (Table 1, entries 1 and 2). Notably, the presence of toluenesulfonic acid was found to be critical for catalytic activity (entry 3). In line with previous reports,[9] TsOH is most likely acting as a ligand and/or counteranion in the process, having the unique ability to stabilise Pd under oxidative conditions. The preparation and use of isolated $Pd(OTs)_2$ as a catalytic precursor for C–H activation reactions had been described.[10]



Scheme 4. Reaction of benzamide and butyl acrylate under Pd-catalysed oxidative coupling conditions.

Table 1. Identification necessary reaction components.[a]

Entry	[Pd]/[Cu]	Additive	Oxidant	*t* /h	**1a** (**2**) /%[b]
1	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	BQ (1)	20	– (18)[c]
2	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	BQ (1)	20	30 (–)
3	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	none	BQ (1)	26	–
4	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	none	26	37 (3)
5	$Pd(OAc)_2$ (5)	TsOH	BQ (1)	26	12 (–)
6	$Pd(OAc)_2$ (5)	TsOH	none	15	8 (–)
7	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	$PhCO_3tBu$	16	8 (<1)
8	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	*t*BuOOH	16	21 (–)
9	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	TsOH	air	16	30 (1)
10	$Pd(OAc)_2$ (5)/ CuCl (5)	TsOH	air	18	3 (–)
11	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	H_3PO_4	air	13	–
12	$Pd(OAc)_2$ (5)/ $Cu(OAc)_2$ (5)	CSA	air	13	18 (–)
13	none	TsOH	air	15	–
14	$Cu(OAc)_2$ (5)	TsOH	air	14	–

[a] Typical procedure: Benzamide (0.5 mmol, 1 equiv.), butyl acrylate (0.55 mmol, 1.1 equiv.), additive (0.5 mmol, 1 equiv.), room temperature, AcOH-toluene (3:1, 2 mL). [b] Determined by ^1H NMR spectroscopy. Product **1** was observed as a mixture of *E*/*Z* isomers, the yield of **2** is provided in parenthesis. [c] 70 °C.

The yield of **1a** is lower in the absence of Cu^{II} co-catalyst, regardless of whether benzoquinone is present (entries 4–6). After screening of some oxidants, air was found to be the most effective (entries 7–9). Attempts to replace $Cu(OAc)_2$ with CuCl (previously used as a co-catalyst, Scheme 2), and TsOH with phosphoric and camphor sulfonic acids, did not lead to any improvement (entries 10–12). Last but not least, appropriate controls were performed, to rule out possible operation of Brønsted acid- or copper-catalysis (entries 13 and 14).

Having identified the key components necessary for the reaction, further optimisation was achieved by judicious adjustment of stoichiometry, reaction medium and temperature, aided by parallel experimentation (Table 2). The first goal was to remove acetic acid from the solvent system, which causes competitive side reactions to occur at 50 °C. Polar solvents were examined to ensure homogeneity. At room temperature, the reaction was sequestered by DMSO, dioxane afforded an inferior yield, while THF, DMF and diglyme afforded similar conversions (entries 3, 4, 5, 9 and 13). These results revealed an important solvent effect on selectivity: while reactions conducted in THF and diglyme gave ca. 1:1 mixtures of isomers, DMF clearly favoured the *E*-isomer (10:1, entry 9), in contrast to the *Z*-selectivity obtained by using AcOH-toluene (1:11, entry 1). Raising temperature to 50 °C improved reactions in DMF and diglyme, but a further increase induced competitive polymerisation (entries 6 vs. 7, 10 vs. 11, and 14 vs. 15). Finally, further improvements were obtained by increasing the amount of alkene to 3 equivalents (entries 16 and 17), and by diluting the reaction mixture (entry 18).

Table 2. Reaction optimisation.[a]

Entry	Solvent	Alkene	*T* /°C	*t* /h	Yield /%[b]	*E*/*Z*
1	AcOH/toluene	1.05	r.t.	15	25	1:11
2		1.05	50	15	–[c]	–
3	DMSO	1.05	r.t.	15	–	–
4	dioxane	1.05	r.t.	14	12	1:3[f]
5	THF	1.05	r.t.	15	26	1:1
6		1.05	50	15	23	1:1.3
7		1.05	70	16	14[d]	1:2.5
8		3	50	16	33	1:1.5
9	DMF	1.05	r.t.	15	21	10:1
10		1.05	50	15	42	6:1
11		1.05	70	16	32[d]	4.3:1
12		3	50	16	35	5:1
13	diglyme	1.05	r.t.	15	22	1.2:1
14		1.05	50	15	49	1:1.2
15		1.05	70	16	53[d]	1:1.5
16		3	50	16	60	1:1.3
17		3	50	65	76	1:1.3
18		3	50	16	72[e]	1:1.3

[a] Typical procedure: $Pd(OAc)_2$ (0.025 mmol, 5 mol-%), $Cu(OAc)_2$ (0.025 mmol, 5 mol-%), benzamide (0.5 mmol, 1 equiv.), butyl acrylate (1.05 or 3 equiv.), TsOH (0.5 mmol, 1 equiv.), solvent (2 mL). [b] Determined by ^{1}H NMR spectroscopy. [c] Predominantly polymerised product. [d] Competitive polymerisation detected. [e] 5 mL of diglyme. [f] An unknown impurity was detected.

Other N–H substrates were also subjected to reactions with *n*-butyl acrylate (Table 3). Substituted benzamides were first examined: the oxidative amidation reaction of the electron-deficient 4-chlorobenzamide proceeded in low yield, even with double catalyst loading (entries 2 and 3). On the other hand, sluggish addition of 4-methoxybenzamide can be improved by using 10 mol-% of the catalyst (entries 4 and 5). A similar pattern of activity can be observed in the addition of acyclic aliphatic amides. While acetamide and butyramide gave reasonable yields of enamides **3a** and **3b**, respectively (entries 6–8), trifluoroacetamide did not afford any product (entry 9). Steric effect also proved to be important, as the reaction of cyclohexyl carboxamide gave a very low yield (entries 10 and 11). Overall, product yields are similar to that obtained previously for the addition of acyclic amides to ethyl acrylate (53–85% using 5–10 mol-% catalyst loading).[7]

Variable results were obtained with alkyl carbamates.[11] An acceptable 70% yield was obtained for the addition of methyl carbamate (entry 12), but benzyl carbamate was unreactive under these conditions (entry 13). The addition of *tert*-butyl carbamate furnished a modest yield (entry 14). At higher catalytic loading, competitive decomposition of product **4c** led to not net gain in yield (entry 15).

So far, our experiments showed that N–H nucleophile is important in these reactions. This was further verified by comparing results obtained with unsubstituted and *N*-substituted benzamides (entries 1 vs. 22) and acetamides (entries 6 vs. 23). No significant product formation was obtained with the secondary amides despite their higher nucleophilicity, thus reactions are sensitive to the steric hindrance at nitrogen.

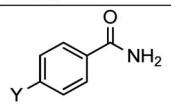
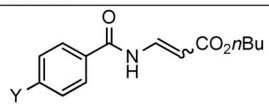
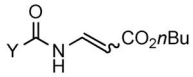
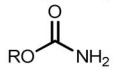
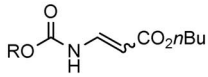
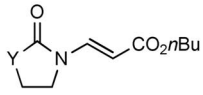
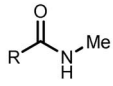
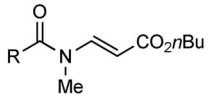
This being the case, cyclic amides, carbamates and ureas are sterically less hindered and should give better yields. Indeed, corresponding oxidative amidation reactions with pyridinone, oxazolidine and imidazolidinone were much more successful. Excellent yields of their corresponding enamide products were isolated exclusively as *E*-isomers (entries 16–19). Expanding the ring size to piperidinone led to a marked decrease in reaction yield, however, although the selectivity was maintained (entries 20 and 21).

In the earlier system reported by Murahashi,[5] the reaction of 2-pyrrolidinone was found to be much slower than 2-oxazaolidinone, due to the presence of an inductive period, which can be eliminated by the use of HMPA as additive. In the present system, reactions of these cyclic substrates were essentially complete within 48 h (entries 16 and 17). By monitoring the addition of 2-oxaziridine and pyrrolidinone to *n*-butyl acrylate over the course of the reaction by ^{1}H NMR spectroscopy (Figure 1), it is clear that neither of these reactions exhibit induction periods, i.e. competitive binding of the amide to the metal centre is not significant. Furthermore, the reaction of 2-pyrrolidinone appeared to be faster than 2-oxazolidinone. As the former is more nucleophilic, this suggests that the nucleophilic attack of the amide is likely to be turnover-limiting in this particular system.

Oxidative amidation products can be subjected to hydrogenation, achieving a hydroamidation reaction formally in two steps, avoiding harsh reaction conditions.[4] This is demonstrated by the reduction of **1a** using H_2 catalysed by 10% Pd/C. Reaction was complete within 3 h, to give the amido ester **6** in a quantitative yield (Scheme 5).

Reactions of oxazolidinone with different alkenes (methyl methacrylate, methyl crotonate, *N*,*N*-dimethylacrylamide and acrylonitrile) were examined. So far, product formation was only observed with unsubstituted alkenes (selected examples are given in Table 4). We attribute this to the ability of alkenes to bind to palladium, which is generally favoured by sterically unhindered, electron-poor alkenes. The addition of benzamide to *tert*-butyl acrylate is

Table 3. Reactions of amides, carbamates and imides with *n*-butyl acrylate.[a]

Entry	Amide	Conditions	Enamide	Yield[b] (*E*:*Z*), %
				
1	Y = H	48h, 50 °C	**1a**	78 (1:1.4)
2	Y = Cl	40 h, 50 °C	**1b**	34 (1:1.3)
3	Y = Cl	48h, 50 °C		30 (1:0.8)[c],[d]
4	Y = OMe	40 h, 50 °C	**1c**	36 (1:1.1)
5	Y = OMe	48h, 50 °C		67 (1:1)[c]
				
6	Y = CH_3	48 h, 50 °C	**3a**	58 (2:1)
7		48 h, 50 °C	**3a**	58 (3:1)[c]
8	Y = *n*-C_3H_7	48 h, 50 °C	**3b**	73 (1:2)
9	Y = CF_3	16 h, 50 °C	**3c**	n.r.
10	Y = cyclohexyl	48 h, 50 °C	**3d**	12 (1:1)
11	Y = cyclohexyl	48h, 50 °C		15 (1:1.1)[c],[d]
				
12	R = Me	48 h, 50 °C	**4a**	70 (1.5:1)
13	R = Bn	48 h, 50 °C	**4b**	n.r.
14	R = *tert*-butyl	48 h, 50 °C	**4c**	41 (1.2:1)
15	R = *tert*-butyl	48h, 50 °C		48 (1.3:1)[c]
				
16	Y = CH_2	48 h, 50 °C	**5a**	94 (*E* only)
17	Y = O	48 h, 50 °C	**5b**	90 (*E* only)
18	Y = NH	48 h, 50 °C	**5c**	73[e] (*E* only)
19		48 h, 50 °C		78[f] (*E* only)
20	Y = CH_2CH_2	48 h, 50 °C	**5d**	24 (*E* only)
21		48 h, 50 °C		36[c] (*E* only)
				
22	R = Ph	48 h, 50 °C	**6a**	5
23	R = Me	48 h, 50 °C	**6b**	< 5

[a] General reaction conditions: Amide substrate (1 mmol, 1 equiv.), butyl acrylate (3 mmol, 3 equiv.), $Pd(OAc)_2$ (0.05 mmol, 5 mol-%), $Cu(OAc)_2$ (0.05 mmol, 5 mol-%), TsOH (1 mmol, 1 equiv.), diglyme (10 mL). [b] Isolated yield after column chromatography. *E*/*Z* ratio given in parenthesis. [c] 10 mol-% $Pd(OAc)_2$, 10 mol-% $Cu(OAc)_2$. [d] Competitive polymerisation. [e] Ratio di-/mono-substituted product = 1:2. [f] 6 equiv. of alkene, ratio of di-/mono-substituted product, 1:2.

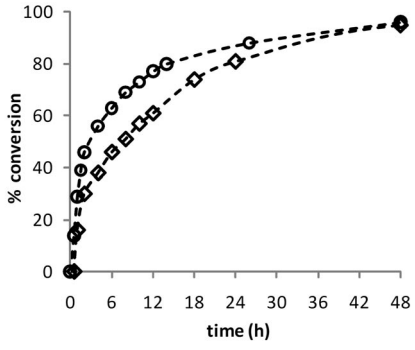
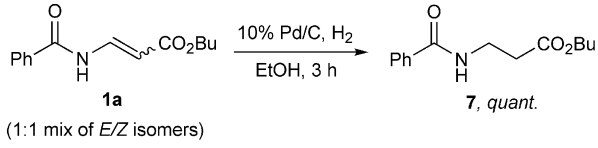


Figure 1. Rate of conversion of the reaction between 2-oxazolidinone (◇) and 2-pyrrolidinone (○) with *n*-butyl acrylate under conditions described in footnote [a] of Table 3.

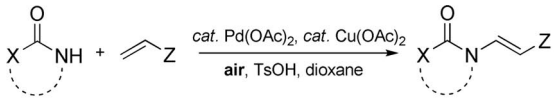


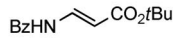
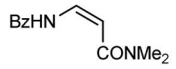
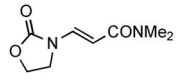
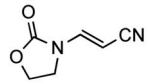
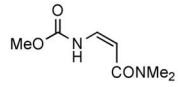
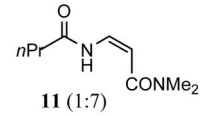
Scheme 5. Hydrogenation of enamide **1a**.

virtually identical to that obtained with *n*-butylacrylate (Table 4, entry 1 vs. Table 2, entry 1); the size of the ester substituent does not exert any effect. In contrast, reactions with *N*,*N*-dimethylacrylamide and acrylonitrile gave disappointingly low yields (entries 2–6). Nevertheless, it is interesting to note that reactions of the acyclic *N*-nucleophiles with *N*,*N*-dimethylacrylamide favours formation of the *Z*-isomer (entries 2, 5 and 6), while the cyclic *N*-nucleophiles

still favour the *E*-isomer exclusively (entries 3 and 4). Thus, the reaction appears to be highly substrate-dependent, thus re-optimisation of each oxidative amidation reaction may be necessary.

Table 4. Oxidative amidation with different alkenes.[a]



Entry	Amide	Z	Product[b]	*t* /h	Yield (*E*/*Z*) /%[c]
1	$BzNH_2$	CO_2tBu	 **8a** (1:1.7)	48	74
2	$BzNH_2$	$CONMe_2$	 **8b** (*Z* only)	48	23
3		$CONMe_2$	 **9a** (*E* only)	16	25
4		CN	 **9b** (*E* only)	48	11
5	MeO_2CNH_2	$CONMe_2$	 **10** (*Z* only)	48	36
6	*n*-$C_3H_7CONH_2$	$CONMe_2$	 **11** (1:7)	48	25

[a] Reactions conditions as described in previous Table. [b] *E*/*Z* ratio indicated in parenthesis. [c] Isolated yield.

Conclusions

We have discovered a new catalytic protocol for the oxidative amidation of butyl acrylate under "chloride-free" conditions, using a mixture of $Pd(OAc)_2$/$Cu(OAc)_2$ as catalysts and air as terminal oxidant. Under optimised reaction conditions, addition of cyclic or acyclic amides, carbamates, pyridinone, oxazolidine and imidazolidinone can be achieved with excellent yields, effectively replacing toxic HMPA[5] with TsOH. Moderate yields were also obtained with primary acyclic amides and carbamates, as long as steric hindrance is not an issue. Overall, reactions are sensitive to the electronic and steric nature of the substrates, requiring modification of reaction conditions to achieved optimal yields and selectivity. Nevertheless, given the tools of parallel synthesis available to a modern laboratory, this is not longer an insurmountable problem.

Experimental Section

General Experimental Procedure for the Pd-Catalysed Oxidative Amidation of Butyl Acrylate: A thick-walled test tube was charged with a magnetic stir bar, the requisite amide (1 mmol, 1 equiv.), toluenesulfonic acid (190 mg, 1 mmol, 1 equiv.), $Pd(OAc)_2$ (11.2 mg, 0.05 mmol, 5 mol-%), and $Cu(OAc)_2$ (9.6 mg, 0.05 mmol, 5 mol-%). Diglyme (10 mL) was added to generate a homogeneous solution. The reaction tube was positioned in an aluminium block and stirred in opened air, while the temperature of the solution was adjusted to 50 °C. *n*-Butyl acrylate (480 μL, 3 mmol, 3 equiv.) was then added, and heating was continued at 50 °C for 48 h. After cooling to room temperature, the mixture was dilute with EtOAc (100 mL) and washed successively with aq. $NaHCO_3$ (2 × 15 mL), brine (15 mL), dried ($MgSO_4$) and concentrated in vacuo. The crude product was purified by column chromatography.

(*E*)-Butyl 3-Benzamidoacrylate (*E*-1a): White solid; m.p. 80–81 °C; R_f = 0.35, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3310, 1701, 1673, 1630, 1267, 1138 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.36 [d, ^3J(H,H) = 11.5 Hz, 1 H, NH], 8.23 (dd, $^3J_{H,H}$ = 14.0, 11.5 Hz, 1 H, =CHN), 7.85 (m, 2 H, Ar), 7.62–7.55 (m, 1 H, Ar), 7.51–7.47 (m, 2 H, Ar), 5.63 (d, $^3J_{H,H}$ = 14.0 Hz, 1 H, =CH), 4.15 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.71–1.60 (m, 2 H), 1.46–1.34 (m, 2 H), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H) ppm. ^{13}C NMR: δ = 167.5, 165.0, 138.0, 132.8, 132.4, 128.9, 127.5, 102.6, 64.2, 30.8, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 247 (20) [M^+], 146 (27), 105 (100), 77 (50). HRMS-ESI calcd. for $C_{14}H_{18}NO_3$ [MH]$^+$: 248.1287; found 248.1283. $C_{14}H_{17}NO_3$ (247.13): calcd. C 68.00, H 6.93, N 5.66; found C 68.08, H 7.02, N 5.64.

(*Z*)-Butyl 3-Benzamidoacrylate (*Z*-1a): White solid; m.p. 49–50 °C; R_f = 0.65, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3326, 1697, 1678, 1626, 1199 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.52 (d, $^3J_{H,H}$ = 11.1 Hz, 1 H, NH), 8.00–7.92 (m, 2 H, Ar), 7.74 (dd, $^3J_{H,H}$ = 11.1, 8.8 Hz, 1 H, =CHN), 7.60–7.56 (m, 1 H, Ar), 7.51–7.47 (m, 2 H, Ar), 5.27 (d, $^3J_{H,H}$ = 8.8 Hz, 1 H, =CH), 4.18 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.75–1.60 (m, 2 H, CH_2), 1.48–1.37 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 169.8, 164.5, 138.8, 132.9, 132.2, 128.9, 127.7, 97.2, 64.2, 30.7, 19.1, 13.7 ppm. MS (EI): *m*/*z* (%) = 247 (22) [M^+], 146 (30), 105 (100), 77 (46). HRMS-ESI calcd. for $C_{14}H_{18}NO_3$ [MH]$^+$: 248.1287; found 248.1287. $C_{14}H_{17}NO_3$ (247.13): calcd. C 68.00, H 6.93, N 5.66; found C 68.05, H 6.96, N 5.70.

(*E*)-Butyl 3-(4-Chlorobenzamido)acrylate (*E*-1b): White solid; m.p. 90–91 °C; R_f = 0.35, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3311, 1717, 1679, 1628, 1203 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.34 (d, $^3J_{H,H}$ = 11.6 Hz, 1 H, NH), 8.20 (dd, $^3J_{H,H}$ = 14.1, 11.6 Hz, 1 H, =CHN), 7.83–7.77 (m, 2 H, Ar), 7.50–7.43 (m, 2 H, Ar), 5.64 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.15 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.70–1.60 (m, 2 H, CH_2), 1.45–1.36 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 167.2, 163.8, 139.4, 137.6, 130.8, 129.3, 128.9, 103.0, 64.3, 30.8, 19.2, 13.7 ppm. 281 (M^+, 14%), 180 (40), 139 (100), 111 (37). HRMS-ESI calcd. for $C_{14}H_{17}ClNO_3$ [MH]$^+$: 282.0897; found: 282.0896. $C_{14}H_{16}ClNO_3$ (281.09): calcd. C 59.68, H 5.72, N 4.97; found C 59.73, H 5.74, N 4.93.

(*Z*)-Butyl 3-(4-Chlorobenzamido)acrylate (*Z*-1b): White solid; m.p. 46–47 °C; R_f = 0.65, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3322, 1696, 1677, 1623, 1194 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.53 (d, $^3J_{H,H}$ = 10.9 Hz, 1 H, NH), 7.92–7.86 (m, 2 H, Ar), 7.71 (dd, $^3J_{H,H}$ = 10.9, 8.8 Hz, 1 H, =CHN), 7.50–7.44 (m, 2 H, Ar), 5.28 (d, $^3J_{H,H}$ = 8.8 Hz, 1 H, =CH), 4.18 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.71–1.64 (m, 2 H, CH_2), 1.48–1.37 (m, 2 H, CH_2), 0.96

(t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 169.8, 163.5, 139.6, 138.6, 130.6, 129.2, 129.1, 97.6, 64.3, 30.7, 19.1, 13.7 ppm. MS (EI): *m/z* (%) = 281 (22) [M^+], 180 (40), 139 (100), 111 (39). HRMS-ESI calcd. for $C_{14}H_{17}ClNO_3$ [MH]$^+$: 282.0897; found 282.0891. $C_{14}H_{16}ClNO_3$ (281.09): calcd. C 59.68, H 5.72, N 4.97; found C 59.73, H 5.75, N 4.96.

(*E*)-Butyl 3-(4-Methoxybenzamido)acrylate (*E*-1c): White solid; m.p. 114–115 °C; R_f = 0.15, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3345, 1705, 1684, 1605, 1258, 1140 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.45 (d, $^3J_{H,H}$ = 11.8 Hz, 1 H, NH), 8.26 (dd, $^3J_{H,H}$ = 14.1, 11.8 Hz, 1 H, =CHN), 7.85 (d, $^3J_{H,H}$ = 8.9 Hz, 2 H, Ar), 7.00 (d, $^3J_{H,H}$ = 8.9 Hz, 2 H, Ar), 5.61 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.18 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.87 (s, 3 H, OMe), 1.74–1.62 (m, 2 H, CH_2), 1.48–1.39 (m, 2 H, CH_2), 0.97 (t, $^3J_{H,H}$ = 7.3 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 167.4, 164.1, 163.3, 138.1, 129.5, 124.6, 114.2, 101.9, 64.1, 55.5, 30.9, 19.2, 13.8 ppm. MS (EI): *m/z* (%) = 277 (12) [M^+], 143 (42), 91 (100), 68 (32). HRMS-ESI calcd. for $C_{15}H_{20}NO_4$ [MH]$^+$: 278.1392; found 278.1392. $C_{15}H_{19}NO_4$ (277.14): calcd. C 64.97, H 6.91, N 5.05; found C 64.95, H 6.97, N 5.11.

(*Z*)-Butyl 3-(4-Methoxybenzamido)acrylate (*Z*-1c): White solid; m.p. 50–51 °C; R_f = 0.25, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3330, 1678, 1621, 1605, 1196, 1173 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.45 (d, $^3J_{H,H}$ = 11.0 Hz, 1 H, NH), 7.93 (d, $^3J_{H,H}$ = 8.9 Hz, 2 H, Ar), 7.74 (dd, $^3J_{H,H}$ = 11.0, 8.8 Hz, 1 H, =CHN), 6.98 (d, $^3J_{H,H}$ = 8.9 Hz, 2 H, Ar), 5.23 (d, $^3J_{H,H}$ = 8.8 Hz, 1 H, =CH), 4.17 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.88 (s, 3 H, OMe), 1.71–1.64 (m, 2 H, CH_2), 1.47–1.38 (m, 2 H, CH_2), 0.96 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 169.9, 164.0, 163.4, 139.1, 129.8, 124.5, 114.1, 96.5, 64.2, 55.5, 30.7, 19.1, 13.7 ppm. MS (EI): *m/z* (%) = 277 (20) [M^+], 135 (100). HRMS-EI calcd. for $C_{15}H_{19}NO_4$ [M]$^+$: 277.1314; found 277.1316. $C_{15}H_{19}NO_4$ (277.13): calcd. C 64.97, H 6.91, N 5.05; found C 65.03, H 6.94, N 5.06.

Butyl [3-Oxo-2,3-dihydroisoindol-(1*Z*)-ylidene]acetate (2): White solid; m.p. 100–101 °C; R_f = 0.5, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3311, 1712, 1688, 1650, 1181 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 9.63 (s, 1 H, NH), 7.89–7.87 (m, 1 H, Ar), 7.71–7.68 (m, 1 H, Ar), 7.67–7.59 (m, 2 H, Ar), 5.78 (s, 1 H, =CH), 4.22 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.75–1.63 (m, 2 H, CH_2), 1.50–1.36 (m, 2 H, CH_2), 0.97 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 168.1, 167.7, 147.4, 136.5, 132.8, 131.6, 129.6, 124.1, 121.0, 91.8, 64.6, 30.7, 19.2, 13.8 ppm. MS (EI): *m/z* (%) = 245 (39) [M^+], 189 (79), 172 (100), 145 (78), 130 (38). HRMS-ESI calcd. for $C_{14}H_{16}NO_3$ [MH]$^+$: 246.1130; found 246.1127. $C_{14}H_{15}NO_3$ (245.11): calcd. C 68.56, H 6.16, N 5.71; found C 68.60, H 6.15, N 5.75.

(*E*)-Butyl 3-Acetamidoacrylate (*E*-3a): Colourless solid; m.p. 71–72 °C; R_f = 0.15, hexane/EtOAc (1:1). IR: $\tilde{\nu}_{max}$ = 3290, 1741, 1686, 1630, 1256, 1136 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.91 (d, $^3J_{H,H}$ = 11.2 Hz, 1 H, NH), 8.01 (dd, $^3J_{H,H}$ = 14.1, 11.2 Hz, 1 H, =CHN), 5.47 (t, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.13 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 2.14 (s, 3 H, Ac), 1.70–1.55 (m, 2 H, CH_2), 1.45–1.31 (m, 2 H, CH_2), 0.93 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR: δ = 168.8, 168.0, 137.8, 101.3, 64.3, 30.7, 23.6, 19.2, 13.7 ppm. MS (EI): *m/z* (%) = 185 (35) [M^+], 112 (47), 87 (100), 70 (99), 43 (92). HRMS-EI calcd. for $C_9H_{15}NO_3$ [M]$^+$: 185.1052; found 185.1053. $C_9H_{15}NO_3$ (185.10): calcd. C 58.36, H 8.16, N 7.56; found C 58.41, H 8.22, N 7.49.

(*Z*)-Butyl 3-Acetamidoacrylate (*Z*-3a): Colourless oil; R_f = 0.65, hexane/EtOAc (1:1). IR: $\tilde{\nu}_{max}$ = 3322, 1718, 1682, 1627, 1186 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 10.46 (br. s, 1 H, NH), 7.49 (dd, $^3J_{H,H}$ = 11.3, 9.0 Hz, 1 H, =CHN), 5.14 (d, $^3J_{H,H}$ = 9.0 Hz, 1 H, =CH), 4.13 (t, $^3J_{H,H}$ = 6.6 Hz, 2 H, OCH_2), 2.14 (s, 3 H, Ac), 1.69–1.62 (m, 2 H, CH_2), 1.46–1.37 (m, 2 H, CH_2), 0.96 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.3, 168.3, 138.0, 96.3, 64.1, 30.7, 23.6, 19.1, 13.7 ppm. MS (EI): *m/z* (%) = 185 (18) [M^+], 87 (75), 84 (100), 70 (66), 48 (83). HRMS-EI calcd. for $C_9H_{15}NO_3$ [M]$^+$: 185.1052; found 185.1054. $C_9H_{15}NO_3$ (185.10): calcd. C 58.36, H 8.16, N 7.56; found C 58.39, H 8.17, N 7.50.

(*E*)-Butyl 3-Butyramidoacrylate (*E*-3b): Colourless solid; m.p. 56–57 °C; R_f = 0.25, hexane/EtOAc (2:1). IR: $\tilde{\nu}_{max}$ = 3295, 1716, 1683, 1627, 1136 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.47 (d, $^3J_{H,H}$ = 11.4 Hz, 1 H, NH), 8.01 (dd, $^3J_{H,H}$ = 11.4, 14.1 Hz, 1 H, =CHN), 5.42 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.11 (t, $^3J_{H,H}$ = 6.6 Hz, 2 H, OCH_2), 2.29 (t, $^3J_{H,H}$ = 7.4 Hz, 2 H, CH_2), 1.73–1.65 (m, 2 H), 1.64–1.58 (m, 2 H, CH_2), 1.39–1.34 (m, 2 H, CH_2), 0.94 (t, *J* = 7.4 Hz, 3 H, CH_3), 0.91 (t, *J* = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 171.5, 167.8, 137.8, 101.1, 64.2, 38.4, 30.8, 19.2, 18.6, 13.7 ppm. MS (EI): *m/z* (%) = 213 (25) [M^+], 87 (100), 70 (70). HRMS-ESI calcd. for $C_{11}H_{20}NO_3$ [MH]$^+$: 214.1443; found 214.1438. $C_{11}H_{19}NO_3$ (213.14): calcd. C 61.95, H 8.98, N 6.57; found C 61.99, H 9.02, N 6.53.

(*Z*)-Butyl 3-Butyramidoacrylate (*Z*-3b): Colourless oil; R_f = 0.65, hexane/EtOAc (2:1). IR: $\tilde{\nu}_{max}$ = 3345, 1718, 1684, 1630 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 10.45 (d, $^3J_{H,H}$ = 11.3 Hz, 1 H, NH), 7.49 (dd, $^3J_{H,H}$ = 8.9, 11.3 Hz, 1 H, =CHN), 5.12 (d, $^3J_{H,H}$ = 8.9 Hz, 1 H, =CH), 4.15 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 2.35 (t, $^3J_{H,H}$ = 7.4 Hz, 2 H, CH_2), 1.78–1.67 (m, 2 H, CH_2), 1.67–1.59 (m, 2 H, CH_2), 1.45–1.34 (m, 2 H, CH_2), 0.98 (t, *J* = 7.4 Hz, 3 H, CH_3), 0.94 (t, *J* = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 171.3, 169.4, 138.1, 96.2, 64.1, 38.7, 30.7, 19.1, 18.5, 13.7 ppm. MS (EI): *m/z* (%) = 213 (55) [M^+], 87 (100), 70 (92), 43 (88). HRMS-ESI calcd. for $C_{11}H_{20}NO_3$ [MH]$^+$: 214.1443; found 214.1444. $C_{11}H_{19}NO_3$ (213.14): calcd. C 61.95, H 8.98, N 6.57; found C 62.02, H 9.04, N 6.52.

(*E*)-Butyl 3-(Cyclohexanecarboxamido)acrylate (*E*-3d): Pale yellow solid; m.p. 77–78 °C; R_f = 0.4, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3294, 1717, 1684, 1630, 1199, 1140 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.03 (dd, *J* = 11.3, 14.1 Hz, 1 H, =CHN), 7.75 (d, $^3J_{H,H}$ = 11.3 Hz, 1 H, NH), 5.44 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.18–4.03 (m, 2 H, OCH_2), 2.22–2.16 (m, 1 H, CH), 1.95–1.73 (m, 4 H, CH_2), 1.69–1.66 (m, 1 H, CH_2), 1.64–1.59 (m, 2 H, CH_2), 1.51–1.44 (m, 2 H, CH_2), 1.41–1.35 (m, 2 H, CH_2), 1.30–1.20 (m, 3 H, CH_2), 0.93 (t, *J* = 7.4 Hz, 3 H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 174.0, 167.5, 137.6, 101.4, 64.1, 45.4, 30.7, 29.2, 25.6, 25.5, 19.2, 13.7 ppm. MS (EI): *m/z* (%) = 253 (36) [M^+], 110 (38), 86 (53), 84 (100), 55 (50). HRMS-ESI calcd. for $C_{14}H_{24}NO_3$ [MH]$^+$: 254.1756; found 254.1751. $C_{14}H_{23}NO_3$ (253.17): calcd. C 66.37, H 9.15, N 5.13; found C 66.42, H 9.05, N 5.49.

(*Z*)-Butyl 3-(Cyclohexanecarboxamido)acrylate (*Z*-3d): Pale yellow oil; R_f = 0.75, hexane/EtOAc (3:1). IR: $\tilde{\nu}_{max}$ = 3299, 1738, 1681, 1625 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 10.55 (d, $^3J_{H,H}$ = 10.1 Hz, 1 H, NH), 7.51 (dd, $^3J_{H,H}$ = 11.2, 8.9 Hz, 1 H, =CHN), 5.12 (d, $^3J_{H,H}$ = 8.9 Hz, 1 H, =CH), 4.13 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 2.29–2.22 (m, 1 H, CH), 2.01–1.89 (m, 2 H, CH_2), 1.86–1.74 (m, 2 H, CH_2), 1.70–1.68 (m, 1 H, CH_2), 1.67–1.53 (m, 2 H, CH_2), 1.48–1.45 (m, 2 H, CH_2), 1.42–1.36 (m, 2 H, CH_2), 1.32–1.21 (m, 3 H, CH_2), 0.95 (t, *J* = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 174.3, 169.6, 138.4, 96.2, 64.1, 45.4, 30.7, 29.2, 25.6, 25.5, 19.2, 13.7 ppm. MS (EI): *m/z* (%) = 253 (36) [M^+], 110 (38), 86 (53), 83 (100), 49 (58). HRMS-ESI calcd. for $C_{14}H_{24}NO_3$ [MH]$^+$: 254.1756; found 254.1752. $C_{14}H_{23}NO_3$

(253.17): calcd. C 66.37, H 9.15, N 5.13; found C 66.42, H 9.14, N 5.46.

(*E*)-Butyl 3-(Methoxycarbonylamino)acrylate (*E*-4a): White solid; m.p. 105–106 °C; R_f = 0.1, hexane/EtOAc (4:1). IR: $\tilde{\nu}_{max}$ = 3265, 1739, 1707, 1641 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.80 (dd, $^3J_{H,H}$ = 6.9, 14.0 Hz, 1 H, =CHN), 7.13 (d, $^3J_{H,H}$ = 6.9 Hz, 1 H, NH), 5.38 (d, $^3J_{H,H}$ = 14.0 Hz, 1 H, =CH), 4.12 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.80 (s, 3 H, OMe), 1.67–1.57 (m, 2 H, CH_2), 1.43–1.32 (m, 2 H, CH_2), 0.93 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 167.4, 153.4, 139.3, 100.1, 64.1, 53.3, 30.7, 19.2, 13.8 ppm. MS (EI): *m*/*z* (%) = 201 (18) [M$^+$], 145 (98), 128 (100), 96 (97). HRMS-ESI calcd. for $C_9H_{16}NO_4$ [MH]$^+$: 202.1079; found 202.1078. $C_9H_{15}NO_4$ (201.11): calcd. C 53.72, H 7.51, N 6.96; found C 53.71, H 7.52, N 6.98.

(*Z*)-Butyl 3-(Methoxycarbonylamino)acrylate (*Z*-4a): Colourless liquid; R_f = 0.4, hexane/EtOAc (4:1). IR: $\tilde{\nu}_{max}$ = 3331, 1747, 1683, 1627, 1181 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 9.78 (br. s, 1 H), 7.23–7.28 (m, 1 H, obscured by $CHCl_3$), 5.05 (d, $^3J_{H,H}$ = 8.8 Hz, 1 H, =CH), 4.11 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.79 (s, 3 H, OMe), 1.67–1.59 (m, 2 H, CH_2) 1.43–1.36 (m, 2 H, CH_2), 0.94 (t, *J* = 7.4 Hz, 3 H) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.0, 154.0, 140.0, 95.1, 64.0, 53.0, 30.7, 19.1, 13.7 ppm. MS (EI): *m*/*z* (%) = 201 (32) [M$^+$], 145 (100), 128 (78), 96 (80). HRMS-ESI calcd. for $C_9H_{16}NO_4$ [MH]$^+$: 202.1079; found 202.1073. $C_9H_{15}NO_4$ (201.11): calcd. C 53.72, H 7.51, N 6.96; found C 53.70, H 7.56, N 6.95.

(*E*)-Butyl 3-(*tert*-Butoxycarbonylamino)acrylate (*E*-4c): Pale yellow oil; R_f = 0.2, hexane/EtOAc (7:1). IR: $\tilde{\nu}_{max}$ = 3341, 1739, 1683, 1629, 1140 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.79 (dd, *J* = 11.7, 14.1 Hz, 1 H, =CHN), 6.65 (br. s, 1 H, NH), 5.30 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.13 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.70–1.61 (m, 2 H, CH_2), 1.49 (s, 9 H, *t*Bu), 1.44–1.35 (m, 2 H, CH_2), 0.96 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.3, 152.1, 140.3, 94.0, 81.8, 63.8, 30.7, 28.1, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 243 (17) [M$^+$], 87 (39), 57 (100), 43 (83). HRMS-EI calcd. for $C_{12}H_{21}NO_4$ [M]$^+$: 243.1471; found 243.1469. $C_{12}H_{21}NO_4$ (242.15): calcd. C 59.24, H 8.70, N 5.76; found C 59.19, H 8.68, N 5.81.

(*Z*)-Butyl 3-(*tert*-Butoxycarbonylamino)acrylate (*Z*-4c): Pale yellow oil; R_f = 0.5, hexane/EtOAc (7:1). IR: $\tilde{\nu}_{max}$ = 3345, 1739, 1683, 1629, 1141 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 9.61 (br. s, 1 H, NH), 7.23 (dd, $^3J_{HH}$ = 9.0, 11.1 Hz, 1 H, =CHN), 4.99 (d, $^3J_{H,H}$ = 9.0 Hz, 1 H, =CH), 4.11 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 1.67–1.58 (m, 2 H, CH_2), 1.49 (s, 9 H, *t*Bu), 1.44–1.37 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.3, 152.3, 140.3, 94.0, 81.8, 64.0, 30.7, 28.1, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 243 (15) [M$^+$], 87 (53), 84 (62), 57 (100), 43 (89). HRMS-EI calcd. for $C_{12}H_{21}NO_4$ [M]$^+$: 243.1471; found 243.1470. $C_{12}H_{21}NO_4$ (243.15): calcd. C 59.24, H 8.70, N 5.76; found C 59.27, H 8.74, N 5.79.

(*E*)-Butyl 3-(2-Oxopyrrolidin-1-yl)acrylate (*E*-5a): Pale yellow oil; R_f = 0.2, hexane/EtOAc (1:1). IR: $\tilde{\nu}_{max}$ = 1726, 1698, 1623, 1203, 1147 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.09 (d, $^3J_{H,H}$ = 14.2 Hz, 1 H, =CHN), 5.20 (d, $^3J_{H,H}$ = 14.2 Hz, 1 H, =CH), 4.14 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.54 (t, $^3J_{HH}$ = 8.0 Hz, 2 H, CH_2N), 2.53 (t, $^3J_{H,H}$ = 8.0 Hz, 2 H, CH_2CO), 2.20–2.13 (m, 2 H, CH_2), 1.65–1.58 (m, 2 H, CH_2), 1.49–1.29 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 174.2, 167.2, 137.1, 100.6, 64.0, 44.9, 30.9, 30.8, 19.1, 17.4, 13.7 ppm. MS (EI): *m*/*z* (%) = 211 (30) [M$^+$], 155 (56), 138 (100), 110 (71). HRMS-ESI $C_{10}H_{18}NO_3$ [MH]$^+$: 212.1287; found 212.1293. $C_{11}H_{17}NO_3$ (211.13): calcd. C 62.54, H 8.11, N 6.63; found C 62.61, H 8.08, N 6.62.

(*E*)-Butyl 3-(2-Oxooxazolidin-3-yl)acrylate (*E*-5b): White solid; m.p. 61–62 °C; R_f = 0.35, hexane/EtOAc (1:2). IR: $\tilde{\nu}_{max}$ = 1769, 1702, 1633, 1197, 1161 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.94 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CHN), 5.15 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 4.53 (t, $^3J_{H,H}$ = 7.9 Hz, 2 H, CH_2O), 4.15 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.85–3.71 (t, $^3J_{H,H}$ = 7.9 Hz, 2 H, CH_2N), 1.68–1.61 (m, 2 H, CH_2), 1.44–1.35 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 166.6, 154.6, 138.0, 100.6, 64.2, 64.5, 42.2, 30.7, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 213 (36) [M$^+$], 140 (100), 113 (47), 95 (56). HRMS-ESI calcd. for $C_{10}H_{16}NO_4$ [MH]$^+$: 214.1079; found 214.1076. $C_{10}H_{15}NO_4$ (213.11): calcd. C 56.33, H 7.09, N 6.57; found C 56.33, H 7.16, N 6.62.

(*E*)-Butyl 3-(2-Oxoimidazolidin-1-yl)acrylate (*E*-5c, monosubstitution product): White solid; m.p. 80–82 °C; R_f = 0.3, hexane/EtOAc (1:5). IR: $\tilde{\nu}_{max}$ = 3241, 1729, 1699, 1619, 1265, 1169 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.01 (d, $^3J_{H,H}$ = 14.0 Hz, 1 H, =CHN), 6.20 (br. s, 1 H, NH), 4.96 (d, $^3J_{H,H}$ = 14.0 Hz, 1 H, =CH), 4.11 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.76–3.50 (m, 4 H, CH_2), 1.67–1.59 (m, 2 H, CH_2), 1.45–1.35 (m, 2 H, CH_2), 0.97 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 167.7, 157.5, 138.7, 96.4, 63.9, 42.1, 37.5, 30.9, 19.2, 13.8 ppm. MS (EI): *m*/*z* (%) = 212 (41) [M$^+$], 156 (60), 139 (100). HRMS-ESI calcd. for $C_{10}H_{18}N_2O_3$ [MH]$^+$: 213.1239; found 213.1233. $C_{10}H_{17}N_2O_3$ (212.12): calcd. C 56.59, H 7.60, N 13.20; found C 56.59, H 7.75, N 13.02.

(2*E*,2′*E*)-Dibutyl 3,3′-(2-Oxoimidazolidine-1,3-diyl)diacrylate (*E*,*E*-5c′, disubstitution product): Colourless solid; m.p. 140–142 °C; R_f = 0.75, hexane/EtOAc (1:5). IR: $\tilde{\nu}_{max}$ = 1734, 1698, 1629, 1221, 1158, 907, 729 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.03 (d, $^3J_{H,H}$ = 14.1 Hz, 2 H, =CHN), 5.13 (d, $^3J_{H,H}$ = 14.1 Hz, 2 H, =CH), 4.13 (t, $^3J_{H,H}$ = 6.7 Hz, 4 H, OCH_2), 3.74 (s, 4 H, CH_2), 1.66–1.59 (m, 4 H, CH_2), 1.48–1.20 (m, 4 H, CH_2), 0.92 (t, $^3J_{H,H}$ = 7.4 Hz, 6 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 166.8, 151.9, 137.7, 99.4, 64.2, 39.7, 30.4, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 338 (41) [M$^+$], 256 (100), 226 (48), 206 (51). HRMS-ESI calcd. for $C_{17}H_{27}N_2O_5$ [MH]$^+$: 339.1920; found 339.1917. $C_{17}H_{26}N_2O_5$ (338.19): calcd. C 60.34, H 7.74, N 8.28; found C 60.44, H 7.63, N 8.25.

(*E*)-Butyl 3-(2-Oxopiperidin-1-yl)acrylate (*E*-5d): Yellow oil; R_f = 0.2, hexane/EtOAc (2:1). IR: $\tilde{\nu}_{max}$ = 1707, 1682, 1619, 1250, 1146 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.61 (d, $^3J_{H,H}$ = 14.5 Hz, 1 H, =CHN), 5.27 (d, $^3J_{H,H}$ = 14.5 Hz, 1 H, =CH), 4.15 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.44 (t, $^3J_{H,H}$ = 6.2 Hz, 2 H, CH_2), 2.57 (t, $^3J_{H,H}$ = 6.6 Hz, 2 H, CH_2), 1.96–1.92 (m, 2 H, CH_2) 1.87–1.82 (m, 2 H, CH_2), 1.68–1.61 (m, 2 H, CH_2), 1.44–1.35 (m, 2 H, CH_2), 0.92 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.3, 167.5, 140.7, 100.0, 64.0, 45.6, 33.1, 30.8, 22.4, 22.2, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 225 (6) [M$^+$], 152 (20), 124 (100). HRMS-ESI calcd. for $C_{12}H_{20}NO_3$ [MH]$^+$: 226.1443; found 226.1447. $C_{12}H_{19}NO_3$ (225.14): calcd. C 63.98, H 8.50, N 6.22; found C 63.99, H 8.49, N 6.15.

Experimental Procedure for the Hydrogenation of 1a: A two-neck 10 mL round bottomed flask was charged with a magnetic stir bar, Pd/C (5% on carbon, 0.025 mmol, 0.1 equiv.), a mixture of *E*- and *Z*-enamide **1a** (1:1, 1 mmol, 1 equiv.) and EtOH (2.5 mL). The flask was then purged and filled with H_2, and left to stir under the H_2 atmosphere for 3 h. The reaction mixture was filtered through a short silica gel pad, and evaporated to afford analytically pure **7** quantitatively.

Butyl 3-(Benzamido)propanoate (7):[5] Colourless oil. IR: $\tilde{\nu}_{max}$ = 3328, 1732, 1640, 1536, 1181 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.80–7.71 (m, 2 H, Ar), 7.52–7.45 (m, 1 H, Ar), 7.44–7.41 (m, 2 H, Ar), 6.89 (br. s, 1 H, NH), 4.11 (t, $^3J_{H,H}$ = 6.7 Hz, 2 H, OCH_2), 3.72 (dd, $^3J_{H,H}$ = 6.0, 11.8 Hz, 2 H, CH_2), 2.64 (t, $^3J_{H,H}$ = 6.0 Hz, 2 H, CH_2), 1.66–1.55 (m, 2 H, CH_2), 1.42–1.30 (m, 2 H, CH_2), 0.92 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 173.1, 167.3, 131.6, 128.6, 126.9, 64.8, 35.3, 33.9, 30.6, 19.2, 13.7 ppm. MS (EI): *m*/*z* (%) = 249 (25) [M^+], 144 (56), 105 (100), 77 (43).

(*E*)-*tert*-Butyl 3-(Benzamido)acrylate (*E*-8a): White solid; m.p. 133–134 °C; R_f = 0.1, hexane/EtOAc (5:1). IR: $\tilde{\nu}_{max}$ = 3307, 1672, 1632, 1277, 1134, 704 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 8.63 (br. d, $^3J_{H,H}$ = 11.6 Hz, 1 H, NH), 8.12 (dd, $^3J_{H,H}$ = 11.6, 14.1 Hz, 1 H, =CHN), 7.85–7.83 (m, 2 H, Ar), 7.57–7.54 (m, 1 H, Ar), 7.47–7.43 (m, 2 H, Ar), 5.55 (d, $^3J_{H,H}$ = 14.1 Hz, 1 H, =CH), 1.48 (s, 9 H, *t*Bu) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 166.8, 165.1, 137.2, 132.8, 132.5, 128.9, 127.5, 104.5, 80.4, 28.3 ppm. MS (EI): *m*/*z* (%) = 247 (7) [M^+], 191 (39), 105 (100), 77 (42). HRMS-EI calcd. for $C_{14}H_{17}NO_3$ [$M]^+$: 247.1208; found 247.1208. $C_{14}H_{17}NO_3$ (247.12): calcd. C 68.00, H 6.93, N 5.66; found C 68.002, H 6.95, N 5.69.

(*Z*)-*tert*-Butyl 3-Benzamidoacrylate (*Z*-8a): White solid; m.p. 66–67 °C; R_f = 0.35, hexane/EtOAc (5:1). IR: $\tilde{\nu}_{max}$ = 3331, 1694, 1671, 1522, 1367, 1224, 1148, 694 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.51 (br. d, $^3J_{H,H}$ = 10.9 Hz, 1 H, NH), 7.96–7.94 (m, 2 H, Ar), 7.67 (dd, $^3J_{H,H}$ = 10.9, 8.9 Hz, 1 H, =CHN), 7.60–7.56 (m, 1 H, Ar), 7.52–7.49 (m, 2 H, Ar), 5.17 (d, $^3J_{H,H}$ = 10.9 Hz, 1 H, =CH), 1.52 (s, 9 H, *t*Bu) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.1, 164.6, 137.8, 132.7, 132.4, 128.9, 127.7, 99.17, 80.9, 28.3 ppm. MS (EI): *m*/*z* (%) = 247 (14) [M^+], 191 (45), 105 (100), 77 (36). HRMS-EI calcd. for $C_{14}H_{17}NO_3$ [$M]^+$: 247.1208; found 247.1209. $C_{14}H_{17}NO_3$ (247.12): calcd. C 68.00, H 6.93, N 5.66; found C 68.09, H 6.90, N 5.71.

***N*-[*N*′,*N*′-Dimethylamino-(*Z*)-propenoyl]benzamide (*Z*-8b):** White solid; m.p. 49–50 °C (lit.[7] 55–57 °C); R_f = 0.15, hexane/EtOAc (2:1). IR: $\tilde{\nu}_{max}$ = 3208, 1682, 1632, 1595, 1452, 1382, 1255, 1140, 785 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 12.59 (d, $^3J_{H,H}$ = 10.2 Hz, 1 H, NH), 7.98–7.96 (m, 2 H, Ar), 7.66 (dd, $^3J_{H,H}$ = 10.2, 8.9 Hz, 1 H, =CHN), 7.57–7.53 (m, 1 H, Ar), 7.49–7.45 (m, 2 H, Ar), 5.51 (d, $^3J_{H,H}$ = 8.9 Hz, 1 H, =CH), 3.07 (s, 6 H, NMe_2) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 169.2, 164.7, 136.7, 132.6, 128.7, 127.8, 95.6, 37.6, 35.4 ppm. MS (EI): *m*/*z* (%) = 218 (37) [M^+], 174 (35), 105 (100), 77 (62).

(*E*)-*N*,*N*-Dimethyl-3-(2-oxooxazolidin-3-yl)acrylamide (*E*-9a): White solid; m.p. 231–232 °C; R_f = 0.35, hexane/EtOAc/MeOH (2:2:1). IR: $\tilde{\nu}_{max}$ = 1751, 1659, 1594, 1402, 1218, 753 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.92 (d, $^3J_{H,H}$ = 13.5 Hz, 1 H, =CHN), 5.58 (d, $^3J_{H,H}$ = 13.5 Hz, 1 H, =CH), 4.50 (t, $^3J_{H,H}$ = 8.0 Hz, 2 H, CH_2O), 3.79 (t, $^3J_{H,H}$ = 8.0 Hz, 2 H, CH_2N), 3.03 (br. s, 6 H, NMe_2) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 166.1, 154.7, 136.7, 99.8, 62.3, 42.6, 37.3, 35.7 ppm. MS (EI): *m*/*z* (%) = 184 (20) [M^+], 140 (100), 96 (56), 43 (58). HRMS-EI calcd. for $C_8H_{12}N_2O_3$ [$M]^+$: 184.0848; found 184.0851. $C_8H_{12}N_2O_3$ (184.08): calcd. C 52.17, H 6.57, N 15.21; found C 52.23, H 6.64, N 15.19.

(*E*)-3-(2-Oxooxazolidin-3-yl)acrylonitrile (*E*-9b): White solid; m.p. 177–179 °C; R_f = 0.15, CH_2Cl_2/EtOAc (1:1). IR: $\tilde{\nu}_{max}$ = 2215, 1761, 1637, 1413, 1217, 750 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 7.61 (d, $^3J_{H,H}$ = 14.6 Hz, 1 H, =CHN), 4.57 (d, $^3J_{H,H}$ = 14.6 Hz, 1 H, =CH), 4.56 (t, $^3J_{H,H}$ = 8.0 Hz, 2 H, CH_2O), 3.77 (t, $^3J_{H,H}$ = 8.0 Hz, 2 H, CH_2N) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 153.7, 141.9, 117.0, 77.9, 62.5, 41.7 ppm. MS (EI): *m*/*z* (%) = 138 (87) [M^+], 83 (52), 79 (100), 52 (76), 42 (52). HRMS-EI calcd. for $C_6H_6N_2O_2$ [$M]^+$: 138.0429; found 138.0429. $C_6H_6N_2O_2$ (138.04): calcd. C 52.17, H 4.38, N 20.28; found C 52.33, H 4.29, N 20.37.

(*Z*)-Methyl 3-(Dimethylamino)-3-oxoprop-1-enylcarbamate (*Z*-10): Off white solid; m.p. 91–92 °C (lit.[12] 93–94 °C); R_f = 0.5, hexane/EtOAc (1:2). IR: $\tilde{\nu}_{max}$ = 3233, 1741, 1641, 1589, 1472, 1387, 1366, 1272, 1206, 1047, 795 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 10.73 (br. s, 1 H, NH), 7.14 (dd, $^3J_{H,H}$ = 9.9, 8.9 Hz, 1 H, =CHN), 5.28 (d, $^3J_{H,H}$ = 8.9 Hz, 1 H, =CH), 3.73 (s, 3 H, OMe), 3.01 (s, 3 H, NMe), 2.94 (s, 3 H, NMe) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 168.8, 154.5, 137.9, 93.4, 52.8, 37.4, 35.1 ppm. MS (EI): *m*/*z* (%) = 172 (56) [M^+], 128 (50), 96 (100), 44 (56).

(*Z*)-3-(2-Oxooxazolidin-3-yl)acrylonitrile (*Z*-11): Yellow oil; R_f = 0.4, hexane/EtOAc (1:2). IR: $\tilde{\nu}_{max}$ = 3264, 1699, 1637, 1596, 1390, 1148, 789 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$, 22 °C): δ = 11.44 (br. s, 1 H, NH), 7.40 (t, $^3J_{H,H}$ = 9.1 Hz, 1 H, =CHN), 5.35 (d, $^3J_{H,H}$ = 9.1 Hz, 1 H, =CH), 3.04 (s, 3 H, NMe), 2.97 (s, 3 H, NMe), 2.29 (t, $^3J_{H,H}$ = 7.5 Hz, 2 H, CH_2), 1.73–1.64 (m, 2 H, CH_2), 0.94 (t, $^3J_{H,H}$ = 7.4 Hz, 3 H, CH_3) ppm. ^{13}C NMR (100.6 MHz, $CDCl_3$, 22 °C): δ = 171.6, 169.0, 136.0, 94.6, 38.8, 37.5, 35.2, 18.6, 13.7 ppm. MS (EI): *m*/*z* (%) = 184 (53) [M^+], 131 (39), 70 (100), 43 (39). HRMS-EI calcd. for $C_9H_{16}N_2O_2$ [$M]^+$: 184.1212; found 184.1210. $C_9H_{16}N_2O_2$ (184.12): calcd. C 58.67, H 8.75, N 15.21; found C 58.71, H 8.77, N 15.23.

Supporting Information (see also the footnote on the first page of this article): ^1H and ^{13}C NMR spectra of isolated products.

Acknowledgments

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