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Allene Trifunctionalization *via* Amidyl Radical Cyclization and TEMPO Trapping

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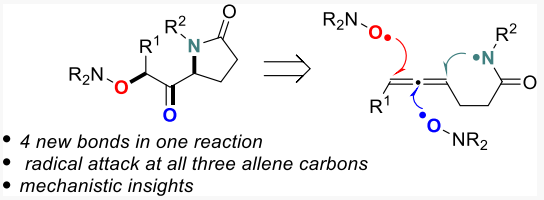
ABSTRACT: Radical-mediated trifunctionalizations of allenes are virtually unknown, in contrast to well-studied radical difunctionalizations of alkenes and alkynes. In this article, we describe a light-promoted reaction that transforms all three allene carbons to new carbon−heteroatom bonds in one pot with no expensive transition-metal catalyst. Formation of an electron donor-acceptor complex between an electron-deficient aryl and K_2CO_3, followed by photochemical generation of an amidyl radical and cyclization, yields a vinyl radical that can be trapped by TEMPO to ultimately furnish the product. Insights into the impact of the allene substitution pattern, radical source, and donor are presented, along with studies to unravel the mechanism of this unusual transformation.



INTRODUCTION

Methods for regiocontrolled additions of heteroatom radicals to alkenes and alkynes represent convenient strategies to form multiple new chemical bonds in one step.[1] While significant efforts have been devoted to radical additions to alkenes, analogous transformations of allenes are largely unexplored. This may be due to the challenge of balancing allene electronics with radical philicity,[2] as allenes differ from alkenes and alkynes in their possession of an electropositive central carbon that perturbs the typical reactivity pattern. Radical addition to the central allene carbon results in rearrangement to a planar allylic radical, while addition to a terminal sp^2-hybridized carbon yields a vinyl radical that rapidly interconverts between the *E* and *Z* configurations. In irreversible radical additions, regioselectivity is controlled by factors that include electronic bias, radical philicity, and reactivity/stability; however, stereoselectivity remains a largely unsolved problem.[3] Further insights to establish general reactivity principles to overcome these limitations are needed to develop new methods to efficiently functionalize all three allene carbons. This communication reports a rare example of a radical-mediated allene trifunctionalization and provides key insights into competing radical pathways.

One strategy for allene trifunctionalization (Scheme 1A) involves the addition of a reagent across the first π-bond, followed by a second addition to the remaining π-bond,[4a] as illustrated by Montgomery's sequential borylcuprations of monosubstituted allenes to furnish highly modifiable scaffolds.[4b] While this approach can form four new bonds and two sp^3 carbons, it is not particularly versatile for other allene substitution patterns. A second strategy (Scheme 1B) adds a heteroatom to the central allene carbon to generate a reactive intermediate that further engages either a radical acceptor or an electrophile to give the product. Possible reactive intermediates include enols,[5] enamines,[6] methyleneaziridines,[7] and imines.[8] For example, Zhai described the addition of a nitrogen nucleophile to an allene to give an enamine, which ultimately furnished fused bicyclic rings.[6a] Our group has reported allene trifunctionalization *via* bicyclic methyleneaziridine intermediates that give products with three continuous heteroatom-bearing stereocenters. For example, aziridination of a proximal allene double bond, followed by dihydroxylation and ring opening, furnishes 1-amino-3-hydroxy-2-ones (Scheme 1B).[7b] However, this approach requires an isolation step and utilizes two expensive metal catalysts. We envisaged an alternate strategy (Scheme 1C), where a N-centered radical adds to the proximal allene double bond to form a new C−N bond and a vinyl radical.[9] Trapping by an O-centered radical would generate a reactive enolate that might engage a second radical to ultimately furnish the product. Herein, we describe efforts to prepare N,O,O triads from allenes in one pot *via* a transition-metal-free, visible-light-mediated radical cyclization/TEMPO trapping sequence.

RESULTS AND DISCUSSION

In the mechanistic work on light-promoted regioselective intramolecular allene amidation, we observed small amounts of a byproduct **3a** (Table 1) in TEMPO trapping studies.[10] Interestingly, all three carbons of the allene were functionalized with a new carbon−heteroatom; this was unexpected, as enols

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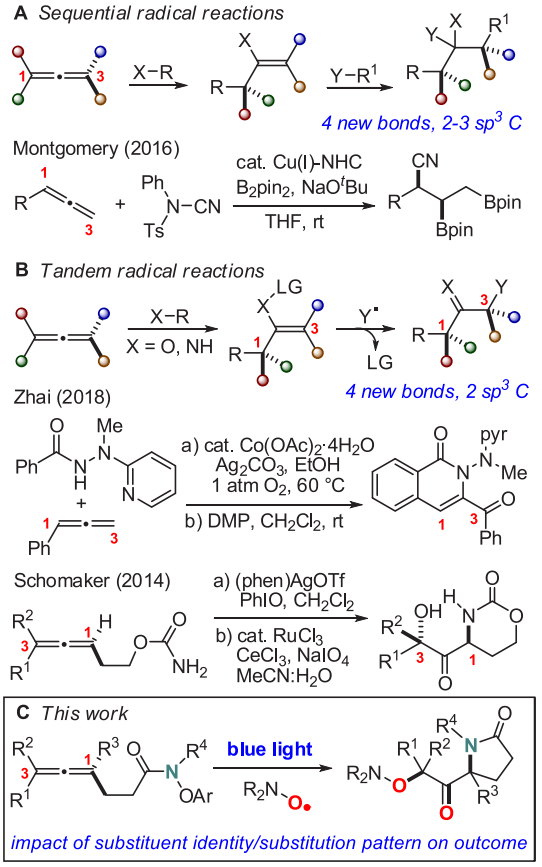
Scheme 1. Strategies for Allene Trifunctionalizations

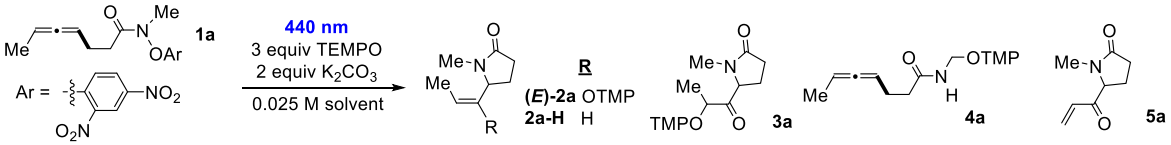


resulting from TEMPO addition to alkynes are not reported to engage in further reactions.[11] Efforts to optimize this reaction were carried out using allene **1a** containing an aryloxyamino moiety,[12] TEMPO, and a donor base in the presence of 440 nm light (Table 1). A 36% yield of the desired **3a** in *dr* 1.3:1 was noted in acetone, along with 14% of (*E*)-**2a** (entry 1); the reaction in the dark gave no conversion. In the absence of K_2CO_3, 19% of **3a** was noted (entry 2), indicating that TEMPO may also act as a donor. MeCN as the solvent gave a higher yield (44%) of **3a** and little (*E*)-**2a** (entry 3), although enone **5a** was observed. The reaction was not particularly air- or moisture-sensitive (entry 4), as taking no precautions gave comparable results. Reducing the amount of TEMPO gave a lower yield of **3a** in favor of the H-trapped product **2a−H** as a mixture of *E*/*Z* diastereomers (entry 5); increasing the equivalents of TEMPO gave no improvement (entry 6). Higher concentration was detrimental, perhaps due to poor light penetration (entry 7). Dilution (entry 8) gave longer reaction times and slightly eroded yields of **3a**, likely due to increased **2a−H**. Decreased K_2CO_3 increased the reaction time, with a slightly lower yield of **3a** (entry 9), but increasing the base had no effect (entry 10). K_2CO_3 could be replaced with Cs_2CO_3 (entry 11), but Et_3N was less effective (entry 12).

The performance of a variety of substituted TEMPO derivatives in the trifunctionalization of **1a** was also investigated (Table 2). Placing an -OH or -OMe group at the C4 position of the piperidine ring (entries 1−2) slightly improved the yield of **3aa** and **3ab** to ∼50%, as compared to 44% using TEMPO (Table 2). A -OBz group in the TEMPO derivative (entry 3) gave an increased yield of **3ac** of 65%, but ∼15% of an inseparable impurity was also present. Finally, a carbonyl group at the γ-position (entry 4) gave a yield comparable to TEMPO.

The moderate yields of **3a** in Table 1 required a better understanding of the mechanisms of byproduct formation, such as **5a** (entries 3, 4, and 6), in order to improve the scope. To provide further insights into the impact of the allene substitution pattern on the trifunctionalization event, diverse allenes were assessed under the optimized conditions shown in entry 3 of Table 1. As **5a** likely arises from TEMPO elimination from **2a** or **3a**, due to sensitivity toward hydrogen atom abstraction (HAA), other 1,3-disubstituted allenes were explored (Table 3). A C_5H_{11} hydrocarbon chain **1b** led to a lower yield (25%) of **3b**, presumably due to increased intramolecular [1,5]-HAA. To our delight, 1,3-disubstituted allenes bearing either an *i*Pr group (**1c**) or a *t*Bu group (**1d**) at

Table 1. Optimization of Reaction Conditions



entry[a]	solvent	**1a** (%)	**2a-H** (%)	**2a** (%)	**3a**[b] (%)	**4a** (%)	**5a** (%)
1[c]	acetone			14	36	20	
2[d]	acetone	37		8	19		
3	MeCN			4	44	14	14
4[e]	MeCN			5	42	11	13
5[f]	MeCN		7	7	33	5	11
6[g]	MeCN				42	14	7
7	MeCN (0.05 M)	16		11	29	18	
8	MeCN (0.01 M)		8	8	39	5	13
9[h]	MeCN			7	38	3	6
10[i]	MeCN			8	36	18	5
11[j]	MeCN			13	43	11	
12[k]	MeCN		5		24	9	

[a]^{1}H NMR yields with 1,3,5-trimethoxybenzene as the internal standard. [b]*dr* 1.3:1 to 1:1. [c]When performed in the dark, only **1a** was recovered. [d]No K_2CO_3. [e]No precautions taken. [f]2 equiv TEMPO. [g]4 equiv TEMPO. [h]0.5 equiv K_2CO_3. [i]4 equiv K_2CO_3. [j]Cs_2CO_3 for K_2CO_3. [k]NEt_3 for K_2CO_3.

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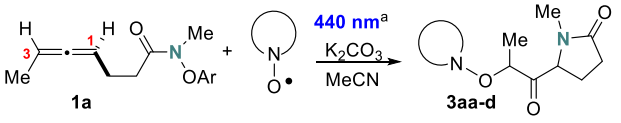
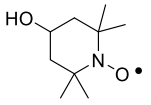
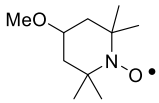
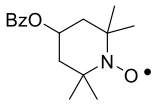
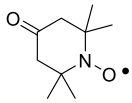
J. Org. Chem. 2021, 86, 8891−8899

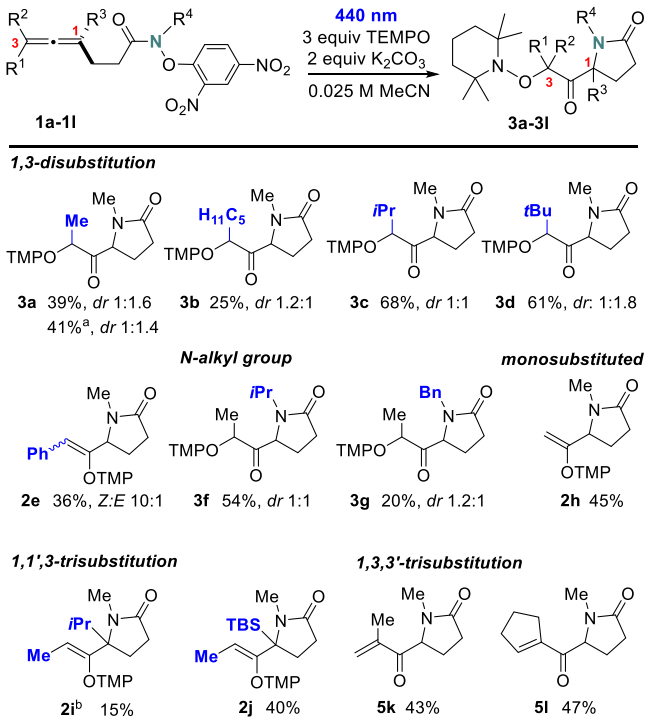
Table 2. Impact of TEMPO Derivatives on Trifunctionalization



entry	TEMPO derivative	product	yield (*dr*)
1		**3aa**	52%, *dr* 1:1.4
2		**3ab**	50%, *dr* 1:1
3		**3ac**	65%[b], *dr* 1:1
4		**3ad**	43%, *dr* 1:1.1

[a]Conditions: 1 equiv **1a**, 3 equiv TEMPO derivative, 2 equiv K_2CO_3, 0.025 M MeCN, and a 440 nm Kessel lamp. [b]~15% of an inseparable impurity.

Table 3. Effect of Allene Substitution on Trifunctionalization



[a]Reaction conducted on a 1.13 mmol scale. [b]Yield and *dr* determined *via* crude ^{1}H NMR yield using 1,3,5-trimethoxybenzene as the internal standard.

C1 gave 68 and 61% yields, respectively, of the triads **3c** and **3d**. Analysis of the crude ^{1}H NMR of the reactions employing substrates **1a**–**1d** indicated that only a single isomer of **2** was present, which was established as the (*E*)-isomer by nuclear Overhauser effect (NOE) experiments. The absence of the (*Z*)-isomer was attributed to the increased 1,5-*syn*-pentane interactions in this isomer, resulting in increased reactivity to give the triads **3a**–**3d**. Allene **1e**, which contains a phenyl ring in place of an alkyl group, gave no detectable **3e**. The major product was **2e** (36%) in an *Z*/*E* ratio of 10:1. The absence of **3e** may indicate that the phenyl ring is rotated out of conjugation with respect to the enol π-system to minimize 1,5-*syn*-pentane interactions and disfavor further reactions.

Substitution of the N–Me group in **1a** with an *i*Pr group in **1f** improved the yield of **3f** to 54% in 1:1.1 *dr* by decreasing the amount of the competing α-oxidation byproduct **4f**. As might be expected, installation of an *N*-Bn group in **1g**, bearing two activated benzylic C–H bonds, gave **3g** in only 20% yield, along with increased amounts of **4** or byproducts arising from it. Somewhat surprisingly, a less encumbered and presumably more reactive allene, the monosubstituted allene **1h**, furnished only **2h**. On closer examination, the result with **1h** supports the hypothesis that 1,5-*syn*-pentane interactions are the driving force behind the reaction of the intermediate 2,2,6,6-tetramethylpiperidine (TMP) enol ether with a second equivalent of TEMPO to give trifunctionalized products **3**. Increasing the steric hindrance in the 1,3,3′-trisubstituted allene **1i** hindered the addition of the N-centered radical to the allene, leading to a poor yield of **3i**.[13] Replacing the *i*Pr group of **1i** with a tert-butyldimethylsilyl (TBS) group gave a 40% isolated yield of **2j**, with no detectable **3j** in the crude ^{1}H NMR due to the bulk of the TBS substituent. Interestingly, only the *Z*-isomers of **2i** and **2j** were obtained using **1i** and **1j**, but sterics prevents further reactions with TEMPO (see the Supporting Information for details).

A 1,1,3-trisubstituted allene **1k** gave the enone **5k** in 43% yield, accompanied by a 30% yield of the TMP enol ether **2k**. The good mass balance in this reaction implies that the addition of the amidyl radical to the allene and trapping with TEMPO occur in good yield; however, the increased sterics of the enol ether results in competing elimination. This same trend was noted with the cyclopentyl-substituted allene **1l**, which delivered a similar ratio of **2l** (16%) to **5l** (47%), as compared to the acyclic analogue **1k**. This insight suggests that the future efforts should focus on these substrates in combination with TEMPO and a smaller radical for the final bond-forming event.

Unraveling the mechanism is key to improving the scope and stereoselectivity of radical-mediated allene trifunctionalizations in general. We propose that the first C–N bond-forming event is initiated upon the formation of an electron donor–acceptor (EDA) complex between the electron-poor aryl group on the acceptor and the donor K_2CO_3 (Scheme 2A).[14] Homolytic cleavage of the N–O bond under visible light irradiation produces an electrophilic amidyl radical (Scheme 2B), which engages the nucleophilic proximal allene carbon to yield a γ-lactam and a vinyl radical (Scheme 2B). The latter species can abstract a weak C–H bond to give **2a**–**H**, or it may react with TEMPO to furnish **2a**. Both the *E*- and *Z*-isomers are proposed to form; however, only the *E*-isomer was detected by ^{1}H NMR reaction monitoring in the case of **1a**. The greater *syn*-1,5-pentane interactions in the (*Z*)-isomer, where the OTMP group is *cis* to the Me group, as compared to the *cis* relationship between Me and the lactam ring in the (*E*)-isomer, may favor the rapid conversion of (*Z*)-**2a** to **3a**.

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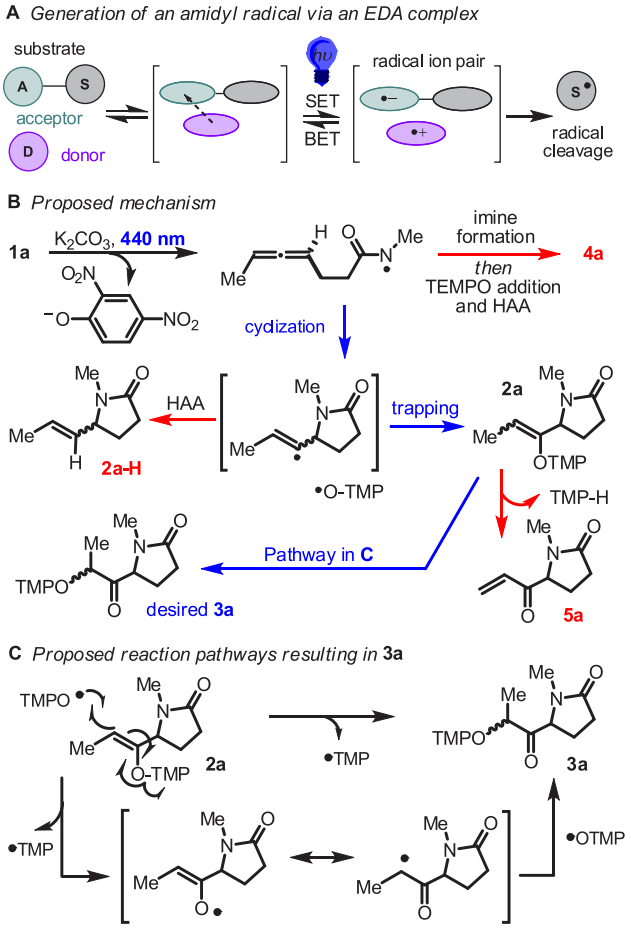
J. Org. Chem. 2021, 86, 8891–8899

Scheme 2. Proposed Mechanisms for the Desired Allene Trifunctionalization Product and Major Byproducts



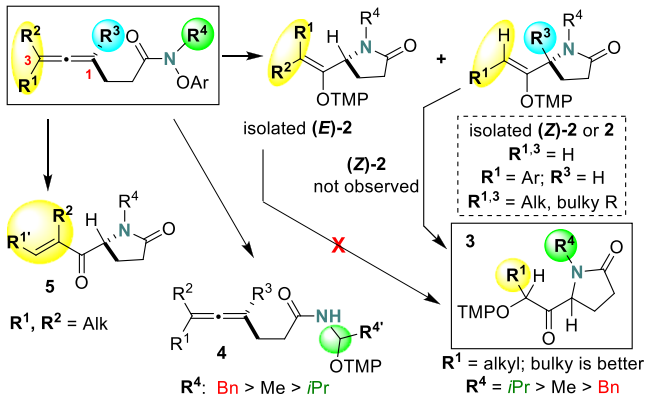
An alternative stepwise mechanism also hinges on the homolytic scission of the weak N−O bond in **2a** to form an α-keto radical, which combines with TEMPO to give **3** (Scheme 2C, bottom pathway). Depending on the substitution pattern of the allene, the last TEMPO addition could be reversible. A crossover experiment involving the treatment of **3a** with MeO-TEMPO was carried out, but no **3ab** was noted. However, we cannot rule out the possibility that in **1k** and **1l**, a stabilized tertiary radical may drive reversibility of TEMPO capture. This reversibility might be further favored by strain release in the sterically congested adducts **3k**−**3l**, favoring disproportionation with TEMPO to give enones **5k**−**5l** as the major products. In **1i**−**1j**, the proximity of the bulky substituent on the lactam may hinder the overlap of the N−O s* orbital with the p orbital of the alkene and slow down homolysis to furnish **2i**−**2j**. For **1h**, the lack of sufficient stability of a primary radical stops the reaction at **2h**. However, it should be noted that no byproducts *via* a 1,5-HAT reaction from the proposed α-keto radical intermediates were observed.

Byproducts arising from proposed intermediates in the reaction pathway are influenced by the judicious choice of substituents on the allene. While control experiments indicated that **3a** is sensitive to thermal degradation, and possibly photodegradation (see the Supporting Information for further details), re-exposing **3a** to the reaction conditions did not result in the formation of **5a**. This supports the likelihood that the enone **5a** arises from **2a**. Finally, byproduct **4a** is proposed to result from imine formation *via* the amidyl radical, followed by TEMPO addition and H-trapping (Scheme 2B).

CONCLUSIONS

In conclusion, a new mode of radical reactivity enables the trifunctionalization of all three unsaturated carbons of an allene in one pot. Four new bonds and two sp^3 asymmetric centers are formed to deliver latent 1,2-diketones, which can furnish imidazoles and 2-aminoimidazoles upon the reaction with amidines and guanidines. Our studies provide insights into several key factors that must be considered in future efforts directed toward developing other tandem radical-mediated allene oxidations (Scheme 3). For example, 1,3- and 1,1′,3-substituted allenes furnish the desired products if sufficient 1,5-*syn*-pentane interactions are present in the intermediate TMP enol ether (*Z*)-**2**. While 1,3,3′-substituted allenes currently favor enone formation, less bulky radicals may prove effective for expanding the scope. We hope to apply our insights into new reactions to secure useful scaffolds not readily accessible through traditional methods and expand on similar, nontraditional 1,5-*syn*-pentane interactions to promote unexpected reactivities.

Scheme 3. Summary of Reactivity Patterns in Allene Trifunctionalizations with Amidyl and TEMPO Radicals



EXPERIMENTAL SECTION

General. All glassware was oven-dried overnight at 130 °C or flame-dried under a stream of dry nitrogen prior to use. Unless otherwise specified, reagents were used as obtained from the vendor without further purification. Acetone was refluxed in $KMnO_4$, distilled from $CaSO_4$, and stored over 4 Å molecular sieves. Triethylamine was dried over CaH_2 and freshly distilled prior to use. All other solvents were purified in accordance with "Purification of Laboratory Chemicals".[15] Air- and moisture-sensitive reactions were performed using standard Schlenk techniques under an atmosphere of N_2. Analytical thin-layer chromatography (TLC) was performed utilizing precoated silica gel 60 F_{254} plates containing a fluorescent indicator, while preparative chromatography was performed using SilicaFlash P60 silica gel (230−400 mesh) *via* Still's method.[16] Unless otherwise stated, the mobile phases for column chromatography were mixtures of hexanes/ethyl acetate. Columns were typically run using a gradient method, beginning with 100% hexanes and gradually increasing the polarity using ethyl acetate. $KMnO_4$ stain was used to visualize reaction products. 440, 456, and 525 nm Kessil PR160 LED photoredox light were used as the light sources at the highest intensity setting. When irradiating under ambient conditions, the light source was placed 3 cm from the reaction vessel and no fan or cooling device was used unless noted. Reactions performed at room temperature (rt) to −40 °C were cooled in an isopropanol bath

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using a chiller. Dry acetonitrile, ether, dichloromethane, and tetrahydrofuran (THF) used for the synthesis of starting materials and products were purchased from Fisher Chemical and purified by an inert solvent purification system (PureSol MD 5) before use. TEMPO and derivatives were purchased from the following vendors and used as received: TEMPO (98%), and 4-hydroxy-TEMPO benzoate, free radical (97%) were purchased from Sigma-Aldrich. The 4-hydroxy-2,2,6,6-tetramethyl piperidinyloxy free radical (98%), 2,2,6,6-tetramethyl-4-piperidone 1-oxyl (96%), and 4-methoxy-TEMPO (98%) were purchased from Oakwood Chemical.

^{1}H NMR and ^{13}C NMR spectra were obtained using Bruker Avance III 500 and Bruker Avance III 400. For ^{1}H NMR, chemical shifts are reported relative to residual protiated solvent peaks (δ 7.26 and 7.15 for $CDCl_3$ and C_6D_6, respectively). ^{13}C NMR spectra were measured at either 125 or 100 MHz on the same instruments noted above for recording ^{1}H NMR spectra. Chemical shifts were again reported in accordance with residual protiated solvent peaks (δ 77.1 and 128.0 for $CDCl_3$ and C_6D_6, respectively). Accurate mass measurements were acquired at the University of Wisconsin, Madison, using a Micromass LCT (electrospray ionization, time-of-flight analyzer, or electron impact methods).

General Procedure for the Preparation of *N*-Methyl Hydroxamic Acids. To a flame-dried round-bottom flask under nitrogen was added the corresponding carboxylic acid, followed by anhydrous THF (0.3 M solution). Dimethyl formamide (DMF) (1 drop) was added, followed by dropwise addition of oxalyl chloride (1.3 equiv). The resulting solution was stirred until the reaction was deemed complete (as monitored by NMR aliquots). The resulting solution was cannula transferred into a conical flask (using anhydrous THF to rinse the flask) and concentrated *in vacuo*. Acid chloride was used without further purification.

N-methyl hydroxamic acid was synthesized according to the procedure described by Leonori.[17] A solution of *N*-methyl hydroxylamine hydrochloride (1.1 equiv) in THF (0.6 M) was cooled to 0 °C in a water-ice bath, treated with $NaHCO_3$ (2.2 equiv), and stirred for 15 min. A solution of acid chloride (1 equiv) in THF was cannula transferred dropwise, and the mixture was allowed to warm to rt and stirred overnight. The resulting mixture was diluted with H_2O and EtOAc. The aqueous layer was extracted three times with EtOAc, and the combined organic layers were washed with brine, dried over Na_2SO_4, and filtered and concentrated *in vacuo*. Purification by column chromatography on silica gel gave the corresponding *N*-methyl hydroxamic acid.

*N-Hydroxy-N-methylundeca-4,5-dienamide (**C-1b**).* Compound **C-1b** (500.0 mg, 2.74 mmol, 50% over two steps) was obtained from the corresponding homoallenic carboxylic acid (289.7 mg, 1.371 mmol) as a clear faint yellow oil after purification by column chromatography using ethyl acetate in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.47 (s, 1H), 5.20−5.12 (m, 2H), 3.35 (s, 3H), 2.57−2.28 (m, 4H), 2.00−1.94 (m, 2H), 1.43−1.36 (m, 2H), 1.30 (dq, J = 7.4, 3.4 Hz, 4H), and 0.89 (t, J = 7.2 Hz, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 203.7, 166.7, 92.7, 89.4, 35.6, 31.3, 30.0, 28.9, 28.8, 24.1, 22.5, and 14.1. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{12}H_{22}NO_2$, 212.1645; found, 212.1644.

*N-Hydroxy-N,7,7-trimethylocta-4,5-dienamide (**C-1d**).* Compound **C-1d** (311.8 mg, 1.580 mmol, 67% over two steps) was obtained from the corresponding homoallenic carboxylic acid (360 mg, 2.350 mmol) as a clear yellow oil after purification by column chromatography using ethyl acetate in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.52 (s, 1H), 5.27−5.22 (m, 1H), 5.20−5.13 (s, 1H), 3.35 (s, 3H), 2.55−2.27 (m, 4H), and 1.02 (s, 9H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 200.9, 166.8, 104.6, 91.2, 35.7, 31.7, 30.1, and 24.2. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{11}H_{20}NO_2$, 198.1487; found, 198.1488.

*N-Hydroxy-N,6-dimethylhepta-4,5-dienamide (**C-1k**).* Compound **C-1k** (144.2 mg, 1.663 mmol, 51% over two steps) was obtained from the corresponding homoallenic carboxylic acid (180.6 mg, 2.162 mmol) as a clear colorless oil after purification by column chromatography using ethyl acetate in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.54 (s, 1H), 5.06−5.00 (m, 1H), 3.36 (s, 3H), 2.62−2.24 (m, 4H), and 1.70−1.63 (m, 6H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 201.5, 166.9, 96.9, 87.5, 35.7, 30.0, 24.4, and 20.6. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_9H_{16}NO_2$, 170.1176; found, 170.1175.

General Procedure for the Preparation of *N*-Methyl Hydroxamic Acids Using 1,1′-Carbonyldiimidazole. The hydroxamic acids were prepared according to the literature procedure with slight modifications.[18] To a solution of carboxylic acid (1 equiv) in 15 mL DMF, 1,1′-carbonyldiimidazole (2 equiv) was added in one portion. The mixture was stirred for 30 min before *N*-methylhydroxylamine hydrochloric salt (3 equiv) was added. The reaction was stirred for 12 h at rt and then quenched with water. The mixture was extracted with EtOAc. The extracts were washed twice with water, combined, dried, and concentrated. Purification by column chromatography on silica gel (hexane/ethyl acetate gradient) furnished the corresponding *N*-methyl hydroxamic acid.

*5-Cyclopentylidene-N-hydroxy-N-methylpent-4-enamide (**C-1l**).* Compound **C-1l** (328.2 mg, 1.681 mmol, 70% over two steps) was obtained from the corresponding homoallenic carboxylic acid (400.0 mg, 2.410 mmol) as a white solid after purification by column chromatography using ethyl acetate in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.45 (s, 1H), 5.18−5.12 (m, 1H), 3.35 (s, 3H), 2.45−2.29 (m, 8H), and 1.69−1.63 (m, 4H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 196.9, 166.8, 105.6, 90.0, 35.5, 31.3, 30.0, 27.1, and 24.6. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{11}H_{18}NO_2$, 196.1332; found, 196.1331.

General Procedure for the Preparation of *N*-Methylaryloxy Carbamate. *N*-methylaryloxy carbamate precursors were synthesized according to the procedure described by Leonori.[17] To a solution of the allenic alcohol **D-1** (1 equiv) in THF (1 M) in a dry Schlenk flask equipped with a stir bar under N_2 was added carbonyldiimidazole. The reaction mixture was stirred until the complete consumption of the starting material was determined by TLC analysis. *N*-methylhydroxylamine (1.2 equiv) and Et_3N (1.2 equiv) were added, and the reaction mixture was stirred for 24 h at rt. The reaction mixture was diluted with water, and the resulting layers were separated. The aqueous layer was extracted three times with EtOAc, and the organic layers were combined. The resulting combined organic layers were washed with brine, dried over $MgSO_4$, and filtered and concentrated *in vacuo*. Purification by column chromatography on silica gel (hexanes/ethyl acetate gradient) furnished the corresponding *N*-methyl hydroxamic acid.

*Penta-2,3-dien-1-yl hydroxy(methyl)carbamate (**C-1m**).* Compound **C-1m** (172 mg, 2.945 mmol, 37% over two steps) was obtained from the corresponding homoallenic carboxylic acid (614.8 mg, 7.362 mmol) as a clear colorless oil after purification by column chromatography using ethyl acetate in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.72 (s, 1H), 5.32−5.16 (m, 2H), 4.62 (dd, J = 5.9, 3.2 Hz, 2H), 3.22 (s, 3H), and 1.68 (dd, J = 6.4, 3.9 Hz, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.2, 157.8, 87.8, 86.4, 64.7, 37.7, and 13.8. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_7H_{11}NO_3Na$, 180.0631; found, 180.0630.

General Procedure for the Preparation of *N*-Methylaryloxy Amides. Precursors were synthesized according to the procedure described by Leonori.[17] To a dry Schlenk flask equipped with a stir bar under nitrogen was added the corresponding *N*-methylhydroxamic acid (1 equiv) dissolved in anhydrous THF (0.2 M). The resulting solution was cooled to 0 °C and stirred for 15 min. NaH (1.1 equiv, 60% in mineral oil) was added, and the reaction mixture was stirred for 1 h at 0 °C. 1-Chloro-2,4-dinitrobenzene (1.1 equiv) was added in three portions, after which the reaction mixture was allowed to warm up to rt and stirred overnight. After the completion of the reaction, the mixture was diluted with H_2O and EtOAc and the resulting layers were separated. The aqueous phase was extracted three times with EtOAc, and the organic layers were combined. The resulting organic solution was washed with brine, dried over Na_2SO_4, and filtered and concentrated *in vacuo*. Purification by column chromatography on silica gel (hexanes/ether gradient) resulted in the corresponding allene precursor.

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J. Org. Chem. 2021, 86, 8891−8899

*N-(2,4-Dinitrophenoxy)-N-methylundeca-4,5-dienamide (**1b**).* Compound **1b** (468.8 mg, 1.242 mmol, 93%) was obtained from hydroxamic acid (282.4 mg, 1.336 mmol) as a clear yellow oil after purification by column chromatography using ether in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.90 (d, J = 2.6 Hz, 1H), 8.50 (dd, J = 9.3, 2.7 Hz, 1H), 7.57 (d, J = 9.2 Hz, 1H), 5.17−5.07 (m, 2H), 3.37 (s, 3H), 2.57−2.52 (m, 2H), 2.34−2.28 (m, 2H), 1.95−1.88 (m, 2H), 1.35−1.24 (m, 6H), and 0.88−0.84 (m, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 203.7, 177.0, 156.2, 142.3, 137.0, 129.7, 122.5, 115.1, 92.8, 89.3, 36.3, 32.0, 31.3, 28.8, 28.8, 22.9, 22.5, and 14.0. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{18}H_{23}N_3O_6Na$, 400.1479; found, 400.1476.

*N-(2,4-Dinitrophenoxy)-N,7,7-trimethylocta-4,5-dienamide (**1d**).* Compound **1d** (505.5 mg, 1.391 mmol, 96%) was obtained from hydroxamic acid (286.1 mg, 1.450 mmol) as a clear yellow oil after purification by column chromatography using ether in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.90 (d, J = 2.7 Hz, 1H), 8.50 (dd, J = 9.3, 2.7 Hz, 1H), 7.58 (d, J = 9.3 Hz, 1H), 5.22 (q, J = 6.0 Hz, 1H), 5.13−5.08 (m, 1H), 3.37 (s, 3H), 2.60−2.47 (m, 2H), 2.35−2.28 (m, 2H), and 0.95 (s, 9H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 200.9, 177.0, 156.2, 142.3, 137.0, 129.7, 122.6, 115.0, 104.7, 91.1, 36.3, 32.0, 31.7, 30.0, and 22.9. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{17}H_{21}N_3O_6Na$, 386.1323; found, 386.1322.

*N-(2,4-Dinitrophenoxy)-N,6-dimethylhepta-4,5-dienamide (**1k**).* Compound **1k** (165.1 mg, 492.4 mmol, 64%) was obtained from hydroxamic acid **C-1k** (129.7 mg, 0.766 mmol) as a clear yellow oil after purification by column chromatography using ether in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.90 (d, J = 2.7 Hz, 1H), 8.50 (dd, J = 9.3, 2.8 Hz, 1H), 7.57 (d, J = 9.3 Hz, 1H), 5.04−4.97 (m, 1H), 3.37 (s, 3H), 2.52 (t, J = 7.2 Hz, 2H), 2.28 (td, J = 7.1, 5.7 Hz, 2H), and 1.63 (d, J = 2.9 Hz, 6H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 201.5, 177.2, 156.2, 142.3, 137.0, 129.6, 122.5, 115.0, 96.9, 87.4, 36.3, 31.9, 23.1, and 20.6. HRMS (ESI) m/z calcd for $C_{15}H_{17}N_3O_6$ $[M + Na]^+$, 358.1010; found, 358.1007.

*5-Cyclopentylidene-N-(2,4-dinitrophenoxy)-N-methylpent-4-enamide (**1l**).* Compound **1l** (341.0 mg, 0.944 mmol, 92%) was obtained from hydroxamic acid (200.0 mg, 1.02 mmol) as a clear yellow oil after purification by column chromatography using ether in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.90 (d, J = 2.7 Hz, 1H), 8.49 (dd, J = 9.3, 2.7 Hz, 1H), 7.56 (d, J = 9.3 Hz, 1H), 5.15−5.07 (m, 1H), 3.37 (s, 3H), 2.53 (t, J = 7.2 Hz, 2H), 2.33−2.24 (m, 6H), and 1.68−1.60 (m, 4H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 196.9, 177.2, 156.2, 142.3, 137.0, 129.7, 122.5, 115.0, 105.6, 89.9, 36.3, 31.9, 31.2, 27.0, and 23.3. HRMS (ESI) m/z calculated for $C_{17}H_{19}N_3O_6$ $[M + Na]^+$, 384.1166; found, 384.1160.

*Penta-2,3-dien-1-yl (2,4-dinitrophenoxy) (methyl)carbamate (**1m**).* Compound **1m** [271.5 mg (0.840 mmol, 85%] was obtained from hydroxamic acid (155.7 mg, 990.6 mmol) as a clear yellow oil after purification by column chromatography using ether in hexanes as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.86 (d, J = 2.7 Hz, 1H), 8.44 (dd, J = 9.3, 2.7 Hz, 1H), 7.61 (d, J = 9.3 Hz, 1H), 5.28−5.14 (m, 2H), 4.64 (dd, J = 6.6, 2.3 Hz, 2H), 3.40 (s, 3H), and 1.65 (dd, J = 7.1, 3.1 Hz, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.5, 157.5, 157.2, 141.9, 136.7, 129.3, 122.2, 116.0, 88.2, 85.6, 65.8, 39.0, and 13.8. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{13}H_{13}N_3O_7Na$, 346.0646; found, 346.0644.

General Procedure for the Visible-Light-Mediated Amidation of Allenes and Optimization Studies. To a flame-dried 25 mL Schlenk tube equipped with a stir bar under nitrogen were added the substrate (1 equiv) and potassium carbonate (2 equiv). The tube was evacuated and purged with N_2 three times. TEMPO (3 equiv) followed by dry MeCN (0.025 M) was then added, and the resulting mixture was irradiated by a Kessel blue LED lamp (440 nm) until TLC showed the complete consumption of the starting material. The distance between the lamp and the tube was approximately 3 cm. After completion of the reaction (usually 4−5 h), the mixture was decanted into a conical flask and concentrated *in vacuo*. Internal standard 1,3,5-trimethoxybenzene was added, and the resulting crude ^{1}H NMR was obtained. Purification by column chromatography yielded the indicated products.

*1-Methyl-5-(2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-propanoyl)pyrrolidin-2-one (**3a**).* Following the general procedure, 33.5 mg (0.104 mmol) of **1a** was irradiated for 4.5 h to give 12.6 mg (0.041 mmol, 39%, *dr*: 1:1.6) of **3a** as a light-yellow oil after purification by column chromatography using dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.75−4.69 (m, 0.59H), 4.70−4.65 (m, 0.39H), 4.63−4.56 (m, 0.38H), 4.55−4.49 (m, 0.61H), 2.80 (s, 1.83H), 2.76 (s, 1.17H), 2.45−2.32 (m, 3.13H), 2.08−1.99 (m, 1.11H), 1.64−1.44 (m, 8H), 1.64−1.44 (d, J = 6.9 Hz, 1.55 H), 1.20 (s, 3H), 1.16 (s, 3H), and 1.22−1.07 (m, 6H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 208.8, 208.4, 175.4, 175.3, 85.5, 83.5, 65.2, 64.4, 40.3, 30.3, 29.7, 29.2, 29.1, 29.0, 28.8, 21.8, 21.6, 18.9, 17.2, 17.1, and 17.0. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{17}H_{31}N_2O_3$, 311.2329; found, 311.2323.

The general procedure was repeated on a 1.130 mmol scale of **1a** with a total reaction time of 4 h. Purification by column chromatography using ether in hexanes and then 2-propanol in ether resulted in (*E*)-**2a** as a clear yellow oil weighing 6.9 mg (0.023 mmol, 2%), a mixture of **3a**, and an unidentified impurity. Purification of the mixture of **3a** and the unidentified impurity by column chromatography using dichloromethane in ether resulted in **3a** as a clear yellow oil weighing 143.2 mg (0.461 mmol, 41%, *dr*: 1:1.4). **2a**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.52 (q, J = 7.3 Hz, 1H), 4.48 (dd, J = 8.3, 3.2 Hz, 1H), 2.78 (s, 3H), 2.73−2.60 (m, 1H), 2.43−2.32 (m, 1H), 2.23−2.10 (m, 2H), 1.68−1.59 (m, 4H), 1.54−1.46 (m, 4H), 1.39−1.31 (m, 1H), 1.13 (s, 3H), 1.05 (s, 3H), 1.02 (s, 3H), and 0.95 (s, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 175.4, 153.7, 97.7, 60.3, 60.0, 56.9, 39.9, 39.9, 32.4, 32.3, 30.8, 27.9, 22.5, 21.0, 20.7, 17.0, and 10.9. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{17}H_{31}N_2O_2$, 295.2380; found, 295.2375.

*1-Methyl-5-(2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-heptanoyl)pyrrolidin-2-one (**3b**) and (E)-5-(Hept-2-enoyl)-1-methylpyrrolidin-2-one (**5b**).* Following the general procedure, 43.5 mg (0.115 mmol) of **1b** was irradiated to give 10.6 mg (0.029 mmol, 25%, *dr*: 1.2:1) of **3b** as a light-yellow oil and 2.4 mg (0.011 mmol, 10%) of **5b** as a yellow-white solid after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. **2b-H** eluted with one of the diastereomers of **3b** resulted in a lower yield and different ratios of diastereomers than the crude material. **3b**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.63−4.57 (m, 0.55H), 4.54 (dd, J = 9.3, 4.0 Hz, 0.45H), 4.47 (dd, J = 8.2, 4.2 Hz, 0.45H), 4.40 (dd, J = 9.9, 4.1 Hz, 0.58H), 2.80 (s, 1.29H), 2.76 (s, 1.63H), 2.43−2.28 (m, 3.06H), 2.15−2.06 (m, 1.36H), 2.06−1.92 (m, 1.21H), 1.76 (d, J = 4.9 Hz, 0.65H), 1.47 (s, 6H), 1.35−1.27 (m, 6H), 1.21−1.14 (m, 6H), 1.12 (s, 6H), and 0.91−0.86 (m, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 207.8, 207.2, 175.5, 175.3, 88.0, 86.9, 65.5, 64.8, 40.5, 40.4, 31.9, 31.8, 31.6, 30.3, 30.1, 29.2, 29.2, 29.0, 28.8, 24.8, 24.4, 22.5, 22.5, 21.8, 21.0, 17.1, 17.0, 14.0, and 14.0. HRMS (ESI) m/z calcd for $C_{21}H_{38}N_2O_3$ $[M + Na]^+$, 389.2775; found, 389.2770. **5b**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.10−7.00 (m, 1H), 6.22−6.14 (m, 1H), 4.34−4.27 (m, 1H), 2.81 (s, 3H), 2.52−2.23 (m, 5H), 2.06−1.86 (m, 1H), 1.51−1.45 (m, 2H), 1.41−1.33 (m, 2H), and 0.93 (t, J = 7.3 Hz, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 197.0, 175.4, 151.1, 125.4, 66.4, 32.5, 30.1, 29.4, 29.0, 22.3, 22.2, and 13.8. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{12}H_{20}NO_2$, 210.1489; found, 210.1487.

*1-Methyl-5-(3-methyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-butanoyl)pyrrolidin-2-one (**3c**).* Following the general procedure, 38.6 mg (0.110 mmol) of substrate **1c** was irradiated to give 25.4 mg (0.075 mmol, 68%, *dr*: 1.2:1) of **3c** as a light-yellow oil after purification by column chromatography using dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.67−4.56 (m, 0.47H), 4.40 (d, J = 6.2 Hz, 0.52H), 4.35 (d, J = 6.2 Hz, 0.48H), 4.22 (dd, J = 10.5, 3.1 Hz, 0.54H), 2.89 (s, 1.41H), 2.81 (s, 1.53H), 2.77−2.64 (m, 0.65H), 2.42−2.29 (m, 3.13H), 2.28−2,15 (m, 1.40 H), 2.10−2.00 (m, 0.57H), 1.63−1.39 (m, 6H), 1.26−1.06 (m, 12H), and 1.05−0.90 (m, 6H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 207.2, 206.6, 174.2, 174.2, 86.9, 86.7, 67.5, 67.3, 30.6, 29.3, 28.6, 28.5, 28.1, 28.0, 27.9, 20.1, 18.8, 18.5, 17.7, 17.6, 16.9, 16.0, and 15.9. HRMS

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(ESI) m/z: $[M + H]^+$ calcd for $C_{19}H_{35}N_2O_3$, 339.2642; found, 339.2637.

*5-(3,3-Dimethyl-2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-butanoyl)-1-methylpyrrolidin-2-one (**3d**).* Following the general procedure, 41.6 mg (0.114 mmol) of **1d** was irradiated to give 24.8 mg (0.074 mmol, 61%, *dr*: 1:1.8) of **3d** as a light-yellow oil after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.63−4.58 (m, 0.65H), 4.44 (s, 0.34H), 4.42 (s, 0.65H), 4.14 (dd, J = 10.8, 2.8 Hz, 0.38H), 2.97 (s, 2H), 2.80 (s, 1H), 2.38−2.25 (m, 3H), 2.14−2.01 (m, 1H), 1.64−1.44 (m, 4H), 1.34−1.28 (m, 5H), 1.24−1.22 (m, 3H), 1.10 (s, 3H), 1.09−1.06 (m, 9H), 0.97 (s, 2H), and 0.90 (s, 1H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 208.3, 207.0, 175.4, 174.9, 87.3, 85.3, 70.9, 69.4, 62.1, 61.9, 60.3, 60.0, 41.3, 40.9, 40.8, 40.3, 36.9, 35.9, 34.8, 34.5, 34.2, 33.6, 30.3, 30.1, 29.2, 29.0, 28.8, 26.8, 26.5, 20.9, 20.7, 20.7, 20.5, 20.4, 18.0, 17.0, and 17.0. HRMS (ESI) m/z calcd for $C_{20}H_{36}N_2O_3$ $[M + Na]^+$, 375.2618; found, 375.2613.

*(Z)-1-Methyl-5-(2-phenyl-1-((2,2,6,6-tetramethylpiperidin-1-yl)-oxy)vinyl)pyrrolidin-2-one (**2e**).* Following the general procedure, 26.1 mg (0.068 mmol) of **1e** was irradiated to give 8.7 mg (0.024 mmol, 36%) of **2e** as a white solid with a diastereomer ratio of 10:1 after purification by column chromatography using ether in hexane as the mobile phase. (***E***)-**2e**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.88−7.82 (m, 2H), 7.34 (t, J = 7.7 Hz, 2H), 7.26−7.21 (m, 1H), 6.07 (s, 1H), 4.99−4.96 (m, 1H), 3.25 (s, 3H), 2.95−2.86 (m, 1H), 2.50 (dd, J = 17.9, 6.5 Hz, 1H), 2.16−2.10 (m, 1H), 1.81−1.72 (m, 1H), 1.65−1.58 (m, 1H), 1.55−1.45 (m, 4H), 1.40−1.35 (m, J = 11.9, 3.6 Hz, 1H), 1.14 (s, 3H), 1.07 (s, 3H), and 1.05−1.01 (m, 6H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 169.9, 142.5, 136.0, 129.4, 128.0, 126.5, 112.7, 72.0, 60.9, 59.1, 40.3, 40.1, 32.3, 31.8, 31.5, 27.8, 26.4, 20.7, 20.4, and 17.3. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{22}H_{33}N_2O_2$, 357.2536; found, 357.2530.

*1-Isopropyl-5-(2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy) propanoyl)pyrrolidin-2-one (**3f**).* Following the general procedure, 17.3 mg (0.0495 mmol) of **1f** was irradiated to give 9.1 mg (54%, 0.075 mmol, *dr*: 1:1.1) of **3f** as a clear yellow oil after purification by column chromatography using dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.94 (dd, J = 9.5, 1.7 Hz, 0.45H), 4.87 (dd, J = 9.5, 1.9 Hz, 0.54H), 4.66 (q, J = 6.9 Hz, 0.45H), 4.59 (q, J = 6.9 Hz, 0.55H), 4.31−4.22 (m, 1H), 2.54−2.17 (m, 3H), 2.09−1.97 (m, 1H), 1.71−1.64 (m, 1H) 1.54−1.45 (m, 7H), 1.41−1.33 (m, 1H), 1.24−1.11 (m, 15H), and 1.04 (dd, J = 9.1, 6.8 Hz, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 209.4, 209.1, 175.34, 175.2, 84.5, 83.2, 60.0, 58.5, 44.0, 43.9, 34.2, 30.3, 29.6, 29.6, 23.4, 23.1, 20.9, 20.8, 20.3, 20.3, 18.5, 17.2, 17.1, and 17.1. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{19}H_{35}N_2O_3$, 339.2642; found, 339.2637.

*1-Benzyl-5-(2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-propanoyl)pyrrolidin-2-one (**3g**) and 5-Acryloyl-1-benzylpyrrolidin-2-one (**5g**).* Following the general procedure, 43.4 mg (0.109 mmol) of **1g** was irradiated to give 8.3 mg (0.021 mmol, 20%, *dr*: 1.2:1) of **3g** as a light-yellow oil and 0.8 mg (0.003 mmol, 3%) of **5g** as a light-yellow oil after purification by column chromatography using ether in hexane and then dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.33−7.27 (m, 2H), 7.26−7.23 (m, 1H), 7.19−7.13 (m, 2H), 5.27−5.17 (m, 1H), 4.62−4.47 (m, 1.3H), 4.34 (q, J = 6.9 Hz, 0.7H), 3.80 (d, J = 14.8 Hz, 0.7H), 3.71 (d, J = 14.9 Hz, 0.3H), 2.49−2.38 (m, 2H), 2.37−2.25 (m, 1H), 2.10−1.97 (m, 1H), 1.53−1.24 (m, 9H), and 1.15−0.76 (m, 12H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 208.8, 208.5, 175.3, 175.2, 135.9, 135.9, 128.8, 128.7, 128.5, 128.5, 127.7, 85.0, 83.4, 62.0, 60.8, 45.3, 40.2, 29.4, 29.4, 21.9, 21.4, 18.9, 17.1, 17.0, and 16.9. HRMS (ESI) m/z calcd for $C_{23}H_{34}N_2O_3$ $[M + H]^+$, 387.2642; found, 387.2640. **5g**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.34−7.27 (m, 3H), 7.20−7.13 (m, 2H), 6.42−6.22 (m, 2H), 5.86 (dd, J = 10.3, 1.4 Hz, 1H), 5.16 (d, J = 14.8 Hz, 1H), 4.25 (dd, J = 9.7, 4.0 Hz, 1H), 3.86−3.76 (d, J = 15.3 Hz, 1H), 2.56−2.39 (m, 2H), 2.34−2.20 (m, 1H), and 1.95−1.87 (m, 1H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 197.3, 175.1, 135.9, 132.3, 130.7, 128.8, 128.6, 127.8, 62.5, 45.5, 29.5, and 22.1. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{14}H_{16}NO_2$, 230.1176; found, 230.1174.

*1-Methyl-5-(1-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)vinyl) pyrrolidin-2-one (**2h**).* Following the general procedure, 0.020 g (0.065 mmol) of **1h** was irradiated to give 8.3 mg (0.030 mmol, 45%) of **2h** as a light-yellow oil after purification by column chromatography using dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.80 (s, 1H), 4.07 (s, 1H), 3.93 (dd, J = 8.7, 2.7 Hz, 1H), 2.82 (s, 3H), 2.65−2.55 (m, 1H), 2.39−2.31 (m, 1H), 2.28−2.09 (m, 2H), 1.67−1.48 (m, 5H), 1.40−1.34 (m, 1H), 1.14 (s, 3H), 1.08 (s, 3H), 1.06 (s, 3H), and 1.01 (s, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 175.3, 161.6, 87.3, 63.2, 60.6, 39.8, 32.6, 32.4, 30.3, 28.1, 23.5, 20.8, 20.5, and 16.9. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{16}H_{29}N_2O_2$, 281.2224; found, 281.2220.

*(Z)-5-Isopropyl-1-methyl-5-(1-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)prop-1-en-1-yl)pyrrolidin-2-one (**3i**).* Following the general procedure, 41.8 mg (0.115 mmol) of **1i** was irradiated under the reaction conditions to give ^{1}H NMR yields of **3i**, (***Z***)-**2i**, and **5i** using 1,3,5-trimethoxybenzene as the internal standard. An analytical sample of (*Z*)-2i was obtained and an NOE was conducted to support the formation of the *Z*-isomer.

*(Z)-5-(tert-Butyldimethylsilyl)-1-methyl-5-(1-((2,2,6,6-tetramethyl-piperidin-1-yl)oxy)prop-1-en-1-yl)pyrrolidin-2-one (**2j**).* Following the general procedure, 37.5 mg (0.086 mmol) of **1j** was irradiated to give 14.2 mg (0.035 mmol, 40%) of (***Z***)-**2j** as a white solid after purification by column chromatography using dichloromethane in ether as the mobile phase. ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.70 (q, J = 7.0 Hz, 1H), 3.42 (s, 3H), 2.36−2.22 (m, 2H), 2.17−2.12 (m, 2H), 1.59−1.49 (m, 1H), 1.49−1.38 (m, 7H), 1.32−1.27 (m, 1H), 1.22 (s, 3H), 1.11 (s, 3H), 1.03 (s, 3H), 0.98 (s, 3H), 0.94 (s, 9H), 0.36 (s, 3H), and 0.14 (s, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 173.1, 149.1, 113.7, 81.6, 60.4, 59.0, 40.4, 40.1, 33.6, 32.4, 31.2, 31.0, 27.2, 25.1, 21.2, 21.2, 20.2, 18.1, 17.1, and −1.9, −3.6. HRMS (ESI) m/z: $[M + H]^+$ calcd for $C_{23}H_{45}N_2O_2Si$, 431.3064; found, 431.3057.

*1-Methyl-5-(2-methyl-1-((2,2,6,6-tetramethylpiperidin-1-yl) oxy)-prop-1-en-1-yl)pyrrolidin-2-one (**2k**) and 5-Methacryloyl-1-methylpyrrolidin-2-one (**5k**).* Following the general procedure, 36.5 mg (0.109 mmol) of **1k** was irradiated to give 9.4 mg (0.030 mmol, 28%) of **2k** as a light-yellow oil and 7.9 mg (0.047 mmol, 43%) of **5k** as a light-yellow oil after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. **2k**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.93 (dd, J = 6.5, 3.9 Hz, 1H), 3.13 (s, 3H), 2.46−2.37 (m, 1H), 2.20−2.07 (m, 2H), 2.07−1.98 (m, 1H), 1.84 (s, 3H), 1.67 (s, 3H), 1.58−1.49 (m, 1H), 1.48−1.34 (m, 4H), 1.35−1.27 (m, 1H), 1.18 (s, 3H), 1.06 (s, 6H), and 1.00 (s, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.7, 136.4, 122.1, 78.4, 60.1, 59.1, 40.3, 40.2, 36.4, 33.7, 33.4, 29.6, 26.8, 20.6, 20.4, 20.2, and 17.1. HRMS (ESI) m/z: calcd for $C_{18}H_{32}N_2O_2$ $[M + Na]^+$, 331.2356; found, 331.2351. **5k**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.99−5.92 (m, 2H), 4.87−4.80 (m, 1H), 2.78 (s, 3H), 2.44−2.33 (m, 3H), 1.96−1.93 (m, 3H), and 1.93−1.86 (m, 1H).^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 198.1, 175.3, 142.7, 126.0, 63.2, 29.2, 28.9, 23.3, and 17.8. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_9H_{13}NO_2Na$, 190.0839; found, 190.0837.

*5-(Cyclopentylidene((2,2,6,6-tetramethylpiperidin-1-yl-oxy) methyl)-1-methylpyrrolidin-2-one (**2l**) and 5-(Cyclopent-1-ene-1-carbonyl)-1-methylpyrrolidin-2-one (**5l**).* Following the general procedure, 36.5 mg (0.101 mmol) of **1l** was irradiated to give 5.3 mg (0.016 mmol, 16%) of **2l** as a light-yellow oil and 9.1 mg (0.047 mmol, 47%) of **5l** as a white solid after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. **2l**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.75 (t, J = 4.6 Hz, 1H), 3.15 (s, 3H), 2.75−2.66 (m, 1H), 2.57−2.48 (m, 1H), 2.35−2.19 (m, 4H), 2.15−2.07 (m, 1H), 1.95−1.87 (m, 1H), 1.88−1.74 (m, 2H), 1.61−1.44 (m, 6H), 1.31−1.27 (m, 2H), 1.19 (s, 3H), 1.09−1.02 (m, 6H), and 0.99 (s, 3H). ^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 171.5, 133.2, 130.5, 78.8, 65.9, 60.2, 59.0, 40.3, 40.2, 34.8, 31.5, 31.2, 29.0, 27.1, 26.3, 26.2, 20.3, 20.1, and 17.2. HRMS (ESI) m/z: $[M + Na]^+$ calcd for $C_{20}H_{34}N_2O_2Na$, 357.2513; found, 357.2508. **5l**: ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.86−6.80 (m, 1H),

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J. Org. Chem. 2021, 86, 8891−8899

4.80−4.64 (m, 1H), 2.78 (s, 3H), 2.69−2.52 (m, 4H), 2.50−2.31 (m, 3H), and 2.05−1.84 (m, 3H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 195.3, 175.4, 145.1, 143.4, 64.4, 34.4, 30.9, 29.4, 28.9, 23.3, and 22.4. HRMS (ESI) *m/z*: $[M + Na]^+$ calcd for $C_{11}H_{15}NO_2Na$, 216.0995; found, 216.0994.

*N-(((2,2,6,6-Tetramethylpiperidin-1-yl)oxy)methyl)octa-5,6-dienamide (**4m**).* Following the general procedure, 37.2 mg (0.111 mmol) of **1m** was irradiated to give 1.5 mg (0.0049 mmol, 4%) of **4m** as a white solid after purification by column chromatography using ether in hexane as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$): δ 6.09 (s, 1H), 5.11−5.00 (m, 2H), 4.89 (d, *J* = 7.2 Hz, 2H), 2.25 (t, *J* = 7.1 Hz, 2H), 2.07−2.00 (m, 2H), 1.81−1.75 (m, 2H), 1.65 (dd, *J* = 6.9, 3.3 Hz, 3H), 1.49−1.44 (m, 4H), 1.35−1.29 (m, 2H), 1.18 (s, 6H), and 1.08 (s, 6H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 205.0, 172.8, 89.4, 86.0, 75.5, 59.6, 39.7, 35.9, 33.3, 29.7, 28.2, 24.6, 20.1, 17.1, and 14.6. HRMS (ESI) *m/z*: calcd for $C_{18}H_{32}N_2O_2$ $[M + H]^+$, 309.2537; found, 309.2532.

*Penta-2,3-dien-1-yl (((2,2,6,6-tetramethylpiperidin-1-yl)oxy)methyl)carbamate (**4n**).* Following the general procedure, 27.5 mg (0.085 mmol) of **1n** was irradiated to give 6.5 mg (0.022 mmol, 26%) of **4n** as a white solid after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$): δ 5.50 (s, 1H), 5.28−5.17 (m, 2H), 4.83 (d, *J* = 7.5 Hz, 2H), 4.64−4.54 (m, 2H), 1.73−1.64 (m, 3H), 1.58−1.51 (m, 1H), 1.44 (dd, *J* = 9.8, 5.4 Hz, 4H), 1.48−1.39 (m, 1H), 1.17 (s, 6H), and 1.09 (s, 6H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 206.1, 155.8, 87.5, 86.6, 77.6, 63.4, 59.6, 39.7, 33.2, 20.1, 17.1, and 13.9. HRMS (ESI) *m/z*: $[M + H]^+$ calcd for $C_{16}H_{29}N_2O_3$, 297.2173; found, 297.2169.

*tert-Butyl 2-(2-((2,2,6,6-tetramethylpiperidin-1-yl)oxy)-propanoyl)pyrrolidine-1-carboxylate (**3o**).* Following the general procedure, 36.3 mg (0.0891 mmol) of **1o** was irradiated under the reaction conditions to result in a 22% ^1H NMR yield with a 2.14:1 ratio of diastereomers.

*5-(2-((4-Hydroxy-2,2,6,6-tetramethylpiperidin-1-yl)oxy)-propanoyl)-1-methylpyrrolidin-2-one (**3aa**).* Following the general procedure with the corresponding TEMPO derivative, 27.0 mg (0.084 mmol) of **1a** was irradiated to give 14.4 mg (0.0441 mmol, 52%) of **3aa** as a light-yellow oil as a mixture of diastereomers (*dr*: 1:1.4) after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$): δ 4.69−4.62 (m, 1H), 4.60 (q, *J* = 6.9 Hz, 0.46H), 4.53 (q, *J* = 7.0 Hz, 0.54H), 3.99 (m, 1.06H), 2.79 (s, 1.7H), 2.76 (s, 1.2H), 2.42−2.32 (m, 3.8H), 2.09−1.96 (m, 1.4H), 1.90−1.78 (m 2.6H), 1.54−1.39 (m, 6H), and 1.27−1.12 (m, 12H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 208.3, 208.0, 175.4, 175.3, 85.3, 30.3, 29.7, 29.1, 29.1, 29.1, 29.0, 29.0, 28.8, 21.8, 21.6, 18.7, and 17.2. HRMS (ESI) *m/z*: $[M + Na]^+$ calcd for $C_{17}H_{30}N_2O_4Na$, 349.2098; found, 349.2093.

*5-(2-((4-Methoxy-2,2,6,6-tetramethylpiperidin-1-yl)oxy)-propanoyl)-1-methylpyrrolidin-2-one (**3ab**).* Following the general procedure with the corresponding TEMPO derivative, 35.7 mg (0.111 mmol) of **1a** was irradiated to give 18.8 mg (0.0552 mmol, 50%) of **3aa** as a light-yellow oil as a mixture of diastereomers (*dr*: 1:1) after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$): δ 4.69−4.62 (m, 1H), 4.60 (q, *J* = 6.9 Hz, 0.5H), 4.53 (q, *J* = 7.0 Hz, 0.5H), 3.49−3.41 (m, 1H), 3.33 (s, 3H), 2.79 (s, 1.46H), 2.76 (s, 1.43H), 2.44−2.29 (m, 3H), 2.09−1.96 (m, 1H), 1.96−1.80 (m, 2H), 1.71−1.62 (m, 1H), 1.46 (d, *J* = 7.1 Hz, 1.77H), 1.42 (d, *J* = 6.9 Hz, 2.07H), 1.25 (s, 1.5H), 1.24 (s, 1.5H), 1.23−1.19 (m, 3H), 1.19−1.16 (m, 4.5H), and 1.14 (s, 1.5H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 208.3, 208.1, 175.4, 175.3, 85.3, 83.5, 65.1, 64.5, 55.8, 30.3, 29.7, 29.1, 29.1, 28.9, 28.8, 21.8, 21.6, 18.7, and 17.2. HRMS (ESI) *m/z*: $[M + H]^+$ calcd for $C_{18}H_{32}N_2O_4Na$, 363.2254; found, 363.2252.

*2,2,6,6-Tetramethyl-1-((1-(1-methyl-5-oxopyrrolidin-2-yl)-1-oxopropan-2-yl)oxy)piperidin-4-yl benzoate (**3ac**).* Following the general procedure with the corresponding TEMPO derivative, 33.0 mg (0.102 mmol) of **1ac** was irradiated to give 27.7 mg (0.065 mmol, 65%) of **3ac** as a light-yellow oil as a mixture of diastereomers (*dr*: 1:1) after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. An unidentified impurity was obtained along with **3ac**. ^1H NMR (500 MHz, $CDCl_3$): δ 8.03−7.99 (m, 2H), 7.56 (t, *J* = 7.3 Hz, 1H), 7.44 (t, *J* = 7.8 Hz, 2H), 5.36−5.24 (m, 1H), 4.70−4.65 (m, 1.34H), 4.65−4.60 (m, 0.49H), 4.56 (q, *J* = 7.0 Hz, 0.51H), 2.80 (s, 1.53H), 2.77 (s, 1.37H), 2.46−2.31 (m, 3.30H), 2.09−1.97 (m, 3.23H), 1.81−1.68 (m, 1.92H), 1.48 (d, *J* = 7.0 Hz, 1.60H), 1.45 (d, *J* = 6.9 Hz, 1.45H), 1.38−1.27 (m, 9H), and 1.24−1.17 (m, 3H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$:) δ 208.2, 207.9, 175.4, 175.2, 166.1, 133.0, 132.8, 130.4, 129.5, 128.4, 128.3, 85.4, 83.6, 65.1, 64.5, 60.1, 29.1, 29.1, 29.0, 28.8, 21.8, 21.6, 18.7, and 17.1. HRMS (ESI) *m/z*: $[M + H]^+$ calcd for $C_{24}H_{35}N_2O_5$, 431.2541; found, 431.2536.

*2,2,6,6-Tetramethyl-1-((1-(1-methyl-5-oxopyrrolidin-2-yl)-1-oxopropan-2-yl)oxy)piperidin-4-one (**3ad**).* Following the general procedure with the corresponding TEMPO derivative, 30.1 mg (0.0937 mmol) of **1ad** was irradiated under the reaction conditions to give 13.2 mg (0.0407 mmol, 43%) of **3ad** as a light-yellow oil as a mixture of diastereomers (*dr*: 1:1.1) after purification by column chromatography using ether in hexane and then 2-propanol in ether as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$): δ 4.73−4.59 (m, 2H), 2.81−2.75 (m, 3H), 2.68−2.52 (m, 2H), 2.44−2.33 (m, 3H), 2.33−2.18 (m, 2H), 2.10−1.94 (m, 1H), 1.54−1.46 (m, 3H), 1.38−1.27 (m, 6H), and 1.24−1.15 (m 6H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 207.6, 207.4, 207.0, 175.3, 175.1, 85.3, 83.7, 65.1, 64.5, 53.6, 29.7, 29.0, 29.0, 28.9, 28.8, 21.7, 21.6, 18.5, and 17.1. HRMS (ESI) *m/z*: $[M + H]^+$ calcd for $C_{17}H_{29}N_2O_4$, 325.2122; found, 325.2119.

*N-(((2,2,6,6-Tetramethylpiperidin-1-yl)oxy)methyl)acetamide (**4′**).* Following the general procedure, 20.0 mg (0.078 mmol) of substrate 1′ was irradiated under the reaction conditions to result in 4.9 mg (0.021 mmol, 65%) of **4′** as a light-yellow oil solid after purification by column chromatography using ethyl acetate in hexane as the mobile phase. ^1H NMR (500 MHz, $CDCl_3$, rotamers): δ 6.15 (s, 1H), 4.94−4.71 (m, 2H), 2.14 (s, 0.35H), 2.02 (s, 2.63H), 1.58−1.52 (m, 1H), 1.49−1.42 (m, 4H), 1.36−1.30 (m, 1H), 1.18 (s, 5.31H), 1.14 (s, 1.12H), and 1.08 (s, 6.13H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$, rotamers): δ 170.0, 79.5, 75.6, 59.7, 59.6, 39.7, 39.6, 33.4, 33.3, 29.7, 23.6, 20.1, 20.1, 17.1, and 17.1. HRMS (ESI) *m/z*: $[M + H]^+$ calcd for $C_{12}H_{25}N_2O_2$, 229.1910; found, 229.1910.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.joc.1c00675.

Substrates utilized in TEMPO screening, pictures of a large-scale reaction setup, solvent screening and control reactions, temperature screening, donor screening, concentration screening, equivalents of TEMPO screening, light source screening, mechanistic experiments, and NMR spectral data (PDF)

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Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

Notes

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