JOC The Journal of Organic Chemistry

Article

pubs.acs.org/joc

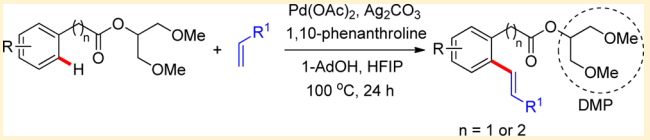
Palladium-Catalyzed *ortho*-Olefination of Phenyl Acetic and Phenyl Propylacetic Esters via C−H Bond Activation

Jundie Hu, Mingyu Guan, Jian Han, Zhi-Bin Huang, Da-Qing Shi,* and Yingsheng Zhao*

Key Laboratory of Organic Synthesis of Jiangsu Province, College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou 215123, China

Supporting Information

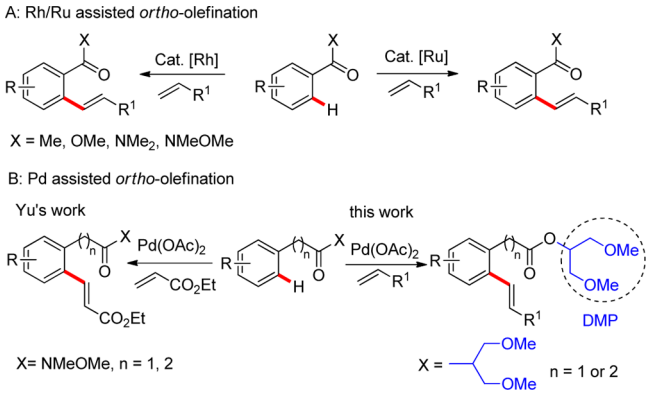
ABSTRACT: A highly regioselective palladium-catalyzed ester-directed *ortho*-olefination of phenyl acetic and propionic esters with olefins via C−H bond activation has been developed. A wide variety of phenyl acetic and propionic esters were tolerated in this transformation, affording the corresponding olefinated aromatic compounds. The *ortho*-olefination of heterocyclic acetic and propionic esters also took place smoothly giving the products in good yields, thus proving the potential utility of this protocol in synthetic chemistry.



INTRODUCTION

Directing group-assisted C−H functionalization has emerged as a powerful method of synthesis in organic chemistry, with wide application in total synthesis, medicinal chemistry, and material chemistry.[1] From literature, highly regioselective Pd-catalyzed C−H transformation has been accomplished via cyclopalladation using amides,[2] acids,[3] oximes,[4] and hydroxyls[5] as directing groups. Although a variety of directing groups have been developed,[6−9] the ester-assisted oxidative Heck reaction is not well explored (Scheme 1A).[10] In a ground-breaking research, Chang and co-workers first reported that the ester unit can be employed as directing group in the Rh (III)-catalyzed olefination of benzoates.[11] In 2012, Ackermann and co-workers also reported a ruthenium(II) complex catalyzed oxidative olefination of arenes using weakly coordinated esters as directing groups.[12] Very recently, Yu and co-workers[13] described the use of Weinreb amides/esters as effective directing groups and monoprotected amino acid as ligand in the Pd-catalyzed directed *ortho*-C−H olefination of phenylacetic acids derivatives. In spite of these significant progresses, developing an ester as directing group in assisted *ortho*-C−H transformation of phenylpropionic acid is still desirable. As functional group/directing group, esters are widely available and can be readily converted to amides, alcohols, or carbonyl compounds.[14,15] These advantages make them better than other reported amide types of directing group which usually need to go through introduction and removal processes.[16,17] Herein, we report a palladium-catalyzed ester-directed C−H olefination reaction of synthetically useful phenyl acetic[18] and propionic[19] acid derivatives employing 1,10-phenanthroline as ligand (Scheme 1B). Notably, heterocyclic acetic and propionic acids reacted well under mild conditions giving corresponding products in good yields.

Scheme 1. Weakly Coordinated Directing Group-Assisted C−H Transformation



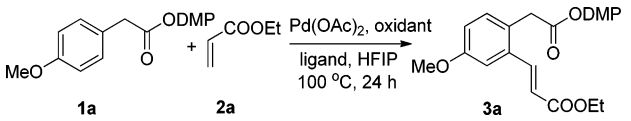
RESULTS AND DISCUSSION

We commenced our studies by exploring the effects of solvents (for detailed information see Supporting Information), ligands, oxidants, and additives on the palladium-catalyzed regioselective oxidative olefination of phenylacetic ester **1a** with acrylate **2a**. Initially, starting materials **1a** and **2a** were reacted in the presence of $Pd(OAc)_2$ (10 mol %) and Ag_2CO_3 (2 equiv) in hexafluoroisopropanol (HFIP) at 100 °C for 24 h. The isolated yield of the desired *ortho*-olefinated product **3a** was 11%. The addition of different additives, such as PivOH, 1-AdOH (1-Adamantane carboxylic acid), PPh_3, pyridine, all gave unsatisfactory yields (Table 1, entries 1−5). Expectedly, the addition of Ac-Gly-OH, which is well-known to improve the reactivity of the palladium center in weakly coordinated functional group[20] assisted C−H functionalization, greatly improved the yield of product (entry 6). Other bidentate ligands were also screened, and 1,10-phenanthroline exhibited

Received: April 8, 2015
Published: July 21, 2015

DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

Table 1. Optimization Reaction Conditions[a]



1a 2a 3a

entry	oxidant	additive	yield[b] (%)
1	Ag_2CO_3	–	11
2	Ag_2CO_3	PivOH	33
3	Ag_2CO_3	1-AdOH	45
4	Ag_2CO_3	Ph_3P	21
5	Ag_2CO_3	pyridine	4
6	Ag_2CO_3	Ac-Gly-OH	59
7	Ag_2CO_3	1,10-phenanthroline	73
8	AgOAc	1,10-phenanthroline	50
9	Ag_2O	1,10-phenanthroline	47
10	O_2/BQ	1,10-phenanthroline	9
11	O_2/$Cu(OAc)_2$	1,10-phenanthroline	34
12	$K_2S_2O_8$	1,10-phenanthroline	11
13[c]	Ag_2CO_3	1,10-phenanthroline PivOH	79
14[c]	Ag_2CO_3	1,10-phenanthroline 1-AdOH	86 (82)[d]
15[c]	Ag_2CO_3	1,10-phenanthroline AcOH	75
16[c,e]	Ag_2CO_3	1,10-phenanthroline 1-AdOH	0

[a]Reaction conditions: **1a** (0.1 mmol), **2a** (0.2 mmol), $Pd(OAc)_2$ (10 mol %), ligand (10 mol %), oxidant (0.2 mmol), HFIP (0.3 mL), 100 °C, 24 h. [b]LC yield determined using acetophenone as internal standard. [c]With ligands (10 mol %) respectively. [d]Isolated yield. [e]Without $Pd(OAc)_2$. Ac = acetyl, Gly = glycine, BQ = 1,4-benzoquinone.

the best promoting effect, thus affording the highly regioselective product **3a** in 73% yield (entry 7). Also, oxidants such as AgOAc, Ag_2O, O_2/$Cu(OAc)_2$, O_2/BQ, $K_2S_2O_8$ were all tested, but still silver carbonate turned out to be the best (entries 8−12). Interestingly, further improvement could be observed when 1-AdOH and 1,10-phenanthroline were both employed in the reaction (entries 13−15). Experiment also showed that no reaction could take place in the absence of palladium catalyst. It is worthy to note that a variety of phenylacetic esters, such as methyl (**1b**), ethyl (**1c**), isopropyl esters (**1d**) and ethyl acrylate **2a** were tested under the optimal reaction condition with all affording the corresponding oxidative Heck-type products (Scheme 2). However, the yields of olefinated compounds obtained from these esters are lower compared with that of substrate **1a**. In addition, better regioselectivity was achieved with ester **1a** as against substrates **1b−c**, which were identified by proton NMR spectrum (for detailed information, see Supporting Information). We speculated that the coordinating ability of the carbonyl group was enhanced by electron rich 1,3-dimethoxypropan-2-ol. Thus, the palladium intermediate could be trapped in the coordination center thereby avoiding the competitive poorly regioselective oxidative Heck reaction.

With an optimized catalytic system in hand, we next explored the scope of palladium-catalyzed ester-directed *ortho*-olefination of phenylacetic esters (Table 2). Various phenylacetic acid esters substituted with electron withdrawing or donating functional groups were tolerated under slightly modified reaction conditions, giving products in good yield (**3a** and **3f−l**). Interestingly, the substrate bearing sterically hindered 3,4,5-trimethoxy group **1m** underwent the reaction, affording mono-olefinated product **3m** in good yield. Also the presence of strong electron-withdrawing group of trifluoromethyl (**3k**) and bromide (**3i**) reduced reactivity; acceptable yields could be obtained by increasing reaction temperature and time to 110 °C and 48 h, respectively. Delightfully, heterocyclic acetic esters also gave mono-olefinated products (**3n**, **3o**) in acceptable synthetic yields. The ester of cyclohexeneacetic acid (**1p**) required a longer period of time to furnish the olefinated product in good yield. To further expand the substrate scope, the unsubstituted ester of phenylacetic acid was tested, and rather disappointingly a mixture of oxidative Heck type mono-olefinated products **3q** (*ortho*/others: 3:2) were generated, thereby limiting the substrate scope of this protocol. We speculated that the optimal reaction condition is propitious to an undirected palladium-catalyzed oxidative olefination, resulting in mixture of olefinated products (see Supporting Information). However, the presence of a *para*-substituent in arene would inhibit oxidative olefination reaction, thereby favoring the highly regioselective *ortho*-olefination reaction via the assistance of weakly coordinated directing group of ester.[21]

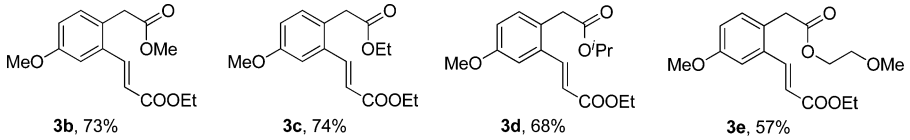
A series of olefins were also tested and representative data are listed in Table 3. For example, acrylic esters, acrylic amides, acrylic ketone, all afforded the corresponding Heck-type olefinated products, and the yields were in the range of 56 to 77%. When acrylonitrile was used as a counterpart, the *ortho*-olefinated product (**3w**) was obtained in 66% yield, proving its potential utilization in the construction of useful synthon.

To our delight, our newly developed protocol was also applicable to phenylpropionic acid derivatives (Table 4). Under modified reaction conditions, several *para*-substituted phenylpropionic acids were tested, affording the products in good to excellent yields (**5a−d**). It is worth noting that the diolefinated products were observed in less than 5% yields. We reasoned that the olefinated products would stabilize the palladium catalyst, inhibiting further C−H transformation. The olefination reaction of 3-(2-furyl) propionic acid and 2-thiophenepropionic acid occurred regioselectively at the 3-position, giving mono-olefinated products in 72% and 69% yields respectively (**5e−f**).

The substrate scope of ester directed *ortho*-olefination reaction could be further extended to benzoic acid derivates.[22] For example, substrate **6a** and **6b** was transformed into the corresponding mono-olefinated products in good yield under standard reaction condition (Scheme 3).

To fulfill synthetic requirements, the newly developed protocol should be easily scaled up in the lab. Indeed, the gram-scale reaction was carried out with 5 mol % $Pd(OAc)_2$ under an extended period of time (48 h) to give the product in 74% yield (Scheme 4).

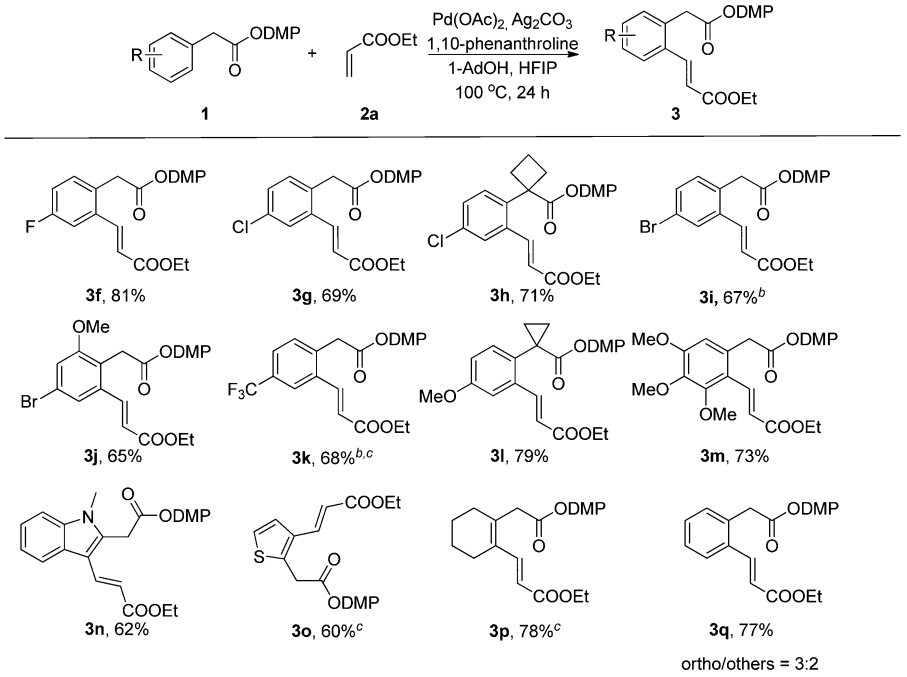
Scheme 2. Directing Group Optimization Studies



3b, 73% **3c**, 74% **3d**, 68% **3e**, 57%

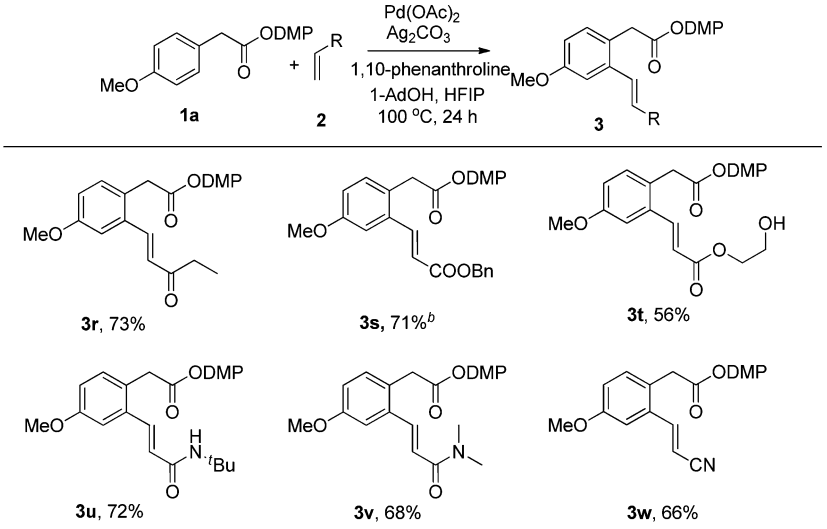
DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

Table 2. Scope of Phenylacetyl Esters[a]



[a]Reaction conditions: **1** (0.2 mmol), **2a** (0.3 mmol), $Pd(OAc)_2$ (10 mol %), Ag_2CO_3 (0.4 mmol), 1,10-phenanthroline (10 mol %), 1-AdOH (10 mol %), HFIP (0.5 mL), 100 °C, 24 h. [b]110 °C. [c]48 h.

Table 3. Scope of Olefins[a]



[a]Reaction conditions: **1a** (0.2 mmol), **2** (0.3 mmol), $Pd(OAc)_2$ (10 mol %), Ag_2CO_3 (0.4 mmol), 1,10-phenanthroline (10 mol %), 1-AdOH (10 mol %), HFIP (0.5 mL), 100 °C, 24 h. [b]80 °C.

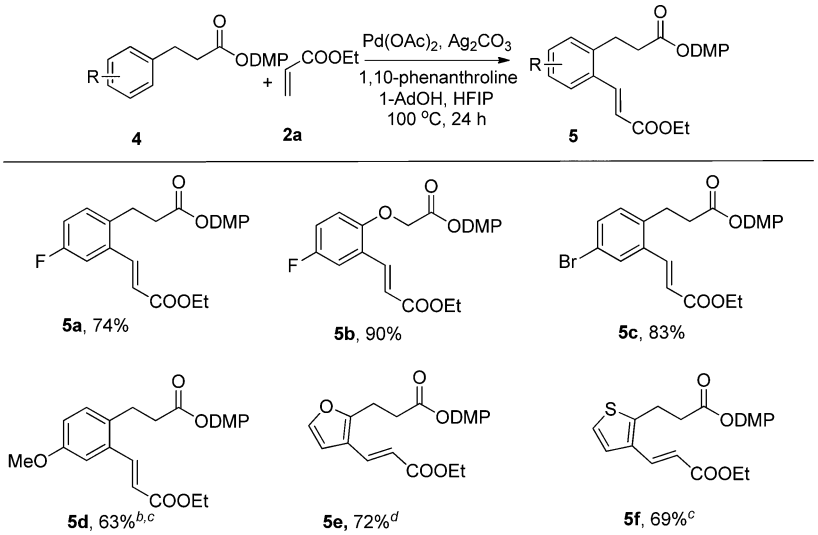
In an attempt to gain a deep understanding of the role of phenanthroline in this ester directed C−H transformation, **1a** and 20 equiv of AcOD were treated with and without 1,10-phenanthroline (10 mol %) in the presence of $Pd(OAc)_2$ (10 mol %) at 100 °C for 30 h. It turned out that 77% (Scheme 5B) deuteration incorporation occurred with phenanthroline compared with 11% deuteration incorporation (Scheme 5A) without phenanthroline. We hypothesized that phenanthroline could increase the rate of C−H activation or stabilize the palladium intermediate during the catalytic cycle. Although the mechanistic details are still unclear, a plausible mechanism for this reaction based on above data and pioneering reports[23] is proposed in Scheme 6. It is postulated that palladium intermediate **A** is possibly formed through a concerted metalation−deprotonation (CMD) pathway. The subsequent migratory insertion of olefin **2** might generate intermediate **B**, which undergoes *β*-hydride elimination to give olefin products **3**.

CONCLUSION

In conclusion, we have developed a regioselective palladium−catalyzed ester directed *ortho*-olefination of phenyl acetic and propionic esters with olefins. The new method provides an efficient, economical and practical way to modify aromatic-containing alipatic acids under mild condition. Olefinated heterocyclic acetic and propionic acid esters were also obtained

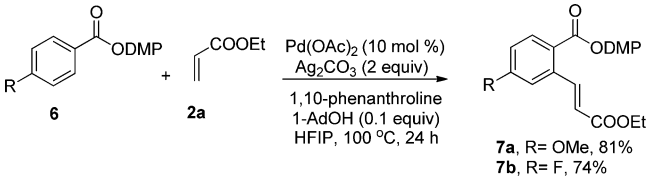
DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

Table 4. Scope of Phenylpropionic Acid Derivatives[a]

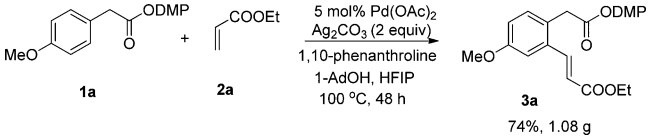


[a]Reaction conditions: **4** (0.2 mmol), **2a** (0.3 mmol), $Pd(OAc)_2$ (10 mol %), Ag_2CO_3 (0.4 mmol), 1,10-phenanthroline (10 mol %), 1-AdOH (10 mol %), HFIP (0.5 mL), 100 °C, 24 h. [b]110 °C. [c]48 h. [d]Dark operation.

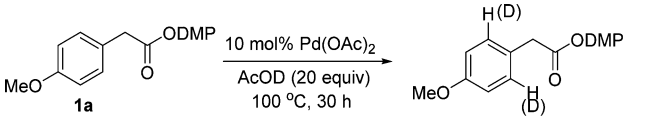
Scheme 3. Scope of Benzoates



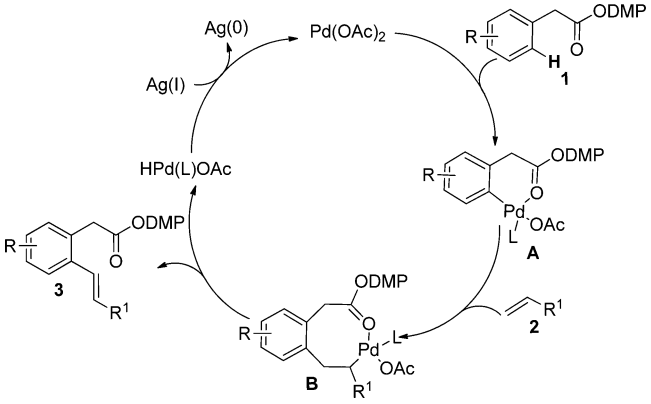
Scheme 4. Gram Scale of Reaction



Scheme 5. Deuterium Experiments



Scheme 6. Plausible Mechanism



in good yields. The use of ester directing group could find potential application in other C−H transformations, and the study is being undertaken presently in our laboratory.

EXPERIMENTAL SECTION

Preparation of Directing Group (1b−1e). To a solution of 2-(4-methoxyphenyl) acetic acid (1.7 g, 10 mmol, 1.0 equiv) in DCM (50 mL) at 0 °C was added $SOCl_2$ (2.4 g, 20 mmol, 2.0 equiv) dropwise and stirred for 15 min. To the mixture was added slowly the alcohol (30 mmol, 3.0 equiv), and the mixture was further stirred for 2 h at 0 °C. Et_3N (4.4 g, 40 mmol, 4.0 equiv) was then added to the resulting suspension and allowed to stir while slowly warming to room temperature over 8 h.[24] The resultant was concentrated, washed with ether, and filtered through Celite, washed again with aqueous NaOH (50 mL), and saturated aqueous NH_4Cl (50 mL), dried over sodium sulfate, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the oily products.

*Methyl-2-(4-methoxyphenyl)acetate (**1b**).* Colorless oil, 3.02 g, yield 84%, PE/EA= 10:1 (PE = petroleum ether, EA = ethyl acetate). ^1H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, J = 8.8 Hz, 2H), 6.87 (d, J = 8.8 Hz, 2H), 3.78 (s, 3H), 3.68 (s, 3H), 3.57 (s, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.9, 158.3, 129.8, 125.6, 113.5, 54.7, 51.5, 39.8; HRMS (ESI-TOF) m/z Calcd for $C_{10}H_{13}O_3$ $[M + H]^+$ 181.0865, found 181.0866.

*Ethyl-2-(4-methoxyphenyl)acetate (**1c**).* Colorless oil, 3.34 g, yield 86%, PE/EA= 10:1. ^1H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, J = 8.8 Hz, 2H), 6.86 (d, J = 8.8 Hz, 2H), 4.14 (q, J = 7.2 Hz, 2H), 3.79 (s, 3H), 3.55 (s, 2H), 1.25 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.1, 158.8, 130.4, 126.4, 114.1, 60.9, 55.4, 40.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{11}H_{14}O_3Na[M + Na]^+$ 217.0841, found 217.0841.

*Isopropyl 2-(4-methoxyphenyl)acetate (**1d**).* Colorless oil, 3.33 g, yield 80%, PE/EA= 10:1. ^1H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, J = 8.8 Hz, 2H), 6.86 (d, J = 8.8 Hz, 2H), 5.04−4.97 (m, 1H), 3.79 (s, 3H), 3.52 (s, 2H), 1.22 (d, J = 6.4 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.0, 158.1, 129.7, 125.9, 113.5, 67.6, 54.8, 40.3, 21.3; HRMS (ESI-TOF) m/z Calcd for $C_{12}H_{16}O_3Na[M + Na]^+$ 231.0997, found 231.0986.

*2-Methoxyethyl 2-(4-methoxyphenyl)acetate (**1e**).* Colorless oil, 3.72 g, yield 83%, PE/EA= 10:1. ^1H NMR (400 MHz, $CDCl_3$) δ 7.19 (d, J = 8.8 Hz, 2H), 6.84 (d, J = 8.8 Hz, 2H), 4.23−4.21 (m, 2H), 3.76 (s, 3H), 3.58 (s, 2H), 3.57−3.55 (m, 2H), 3.34 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.0, 158.8, 130.4, 126.1, 114.0, 70.4, 63.9,

DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

59.0, 55.3, 40.2; HRMS (ESI-TOF) m/z Calcd for $C_{12}H_{16}O_4Na[M + Na]^+$ 247.0946, found 247.0940.

Preparation of Substrates (1a, 1f−1p, 4a−4f, 6a and 6b)..[25,26] To a solution of DCC (2.1 g, 10 mmol, 1.0 equiv) in DCM (50 mL) at 0 °C was added DMAP (1.5 g, 12 mmol, 1.2 equiv) and 2-(4-methoxyphenyl) acetic acid (1.7 g, 10 mmol, 1.0 equiv). To the resulting suspension was then added 1,3-dimethoxy-2-propanol (1.8 g, 15 mmol, 1.5 equiv). The reaction mixture was allowed to stir while slowly warming to room temperature over 15 h. The reaction was concentrated in vacuo, washed with ether, filtered through Celite, washed again with NaOH (aq, 50 mL), washed with saturated NH_4Cl (aq, 50 mL), dried over sodium sulfate, and concentrated in vacuo. The crude mixture was purified by column chromatography on silica gel to give the corresponding products.

1,3-Dimethoxypropan-2-yl 2-(4-methoxyphenyl)acetate (**1a**). Colorless oil, 2.09 g, yield 83%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19 (d, J = 8.8 Hz, 2H), 6.84 (d, J = 8.4 Hz, 2H), 5.16−5.11 (m, 1H), 3.77 (s, 3H), 3.59 (s, 2H), 3.51 (d, J = 5.2 Hz, 4H), 3.31 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.5, 158.7, 130.3, 126.0, 113.9, 71.6, 71.1, 59.2, 55.2, 40.4; HRMS (ESI-TOF) m/z Calcd for $C_{14}H_{20}O_5Na[M + Na]^+$ 291.1208, found 291.1208.

1,3-Dimethoxypropan-2-yl 2-(4-fluorophenyl)acetate (**1f**). Colorless oil, 2.11 g, yield 88%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30−7.25 (m, 2H), 7.02 (t, J = 8.8 Hz, 2H), 5.19−5.14 (m, 1H), 3.66 (s, 2H), 3.54 (d, J = 4.8 Hz, 4H), 3.34 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.0, 162.0 (d, J_{C-F} = 244 Hz), 130.8 (d, J_{C-F} = 8.0 Hz), 129.7 (d, J_{C-F} = 3.3 Hz), 115.3 (d, J_{C-F} = 21 Hz), 71.8, 71.1, 59.2, 40.4; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{17}FO_4Na[M + Na]^+$ 279.1009, found 279.1009.

1,3-Dimethoxypropan-2-yl 2-(4-chlorophenyl)acetate (**1g**). Colorless oil, 1.99 g, yield 78%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30−7.27 (m, 2H), 7.23 (d, J = 8.8 Hz, 2H), 5.18−5.13 (m, 1H), 3.64 (s, 2H), 3.52 (d, J = 5.2 Hz, 4H), 3.33 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.8, 133.0, 132.4, 130.6, 128.6, 71.8, 71.1, 59.2, 40.6; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{17}ClO_4Na[M + Na]^+$ 295.0713, found 295.0707.

1,3-Dimethoxypropan-2-yl 1-(4-chlorophenyl)-cyclobutanecarboxylate (**1h**). Colorless oil, 2.53 g, yield 81%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 (s, 4H), 5.12−5.07 (m, 1H), 3.41 (d, J = 5.2 Hz, 4H), 3.21 (s, 6H), 2.86−2.80 (m, 2H), 2.48−2.41 (m, 2H), 2.07−2.00 (m, 1H), 1.89−1.82 (m, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.8, 142.1, 132.3, 128.2, 127.8, 71.8, 71.1, 59.1, 52.1, 32.2, 16.5; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{21}ClO_4Na[M + Na]^+$ 335.1026, found 335.1025.

1,3-Dimethoxypropan-2-yl 2-(4-bromophenyl)acetate (**1i**). Colorless oil, 2.49 g, yield 83%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, J = 8.4 Hz, 2H), 7.21 (d, J = 8.4 Hz, 2H), 5.23−5.18 (m, 1H), 3.67 (s, 2H), 3.57 (d, J = 5.2 Hz, 4H), 3.37 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.6, 132.9, 131.6, 131.0, 121.1, 71.8, 71.1, 59.2, 40.6; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{17}BrO_4Na[M + Na]^+$ 339.0208, found 339.0215.

1,3-Dimethoxypropan-2-yl 2-(4-bromo-2-methoxyphenyl)-acetate (**1j**). Colorless oil, 2.51 g, yield 76%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00−6.93 (m, 2H), 6.93 (s, 1H), 5.12−5.07 (m, 1H), 3.72 (s, 3H), 3.55 (s, 2H), 3.47 (d, J = 5.2 Hz, 4H), 3.28 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.8, 158.1, 131.9, 123.4, 122.2, 121.6, 114.0, 71.6, 71.1, 59.1, 55.6, 35.5; HRMS (ESI-TOF) m/z Calcd for $C_{14}H_{19}BrO_5Na[M + Na]^+$ 369.0314, found 369.0323.

1,3-Dimethoxypropan-2-yl 2-(4-(trifluoromethyl)phenyl)acetate (**1k**). Colorless oil, 2.29 g, yield 79%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (d, J = 8.0 Hz, 2H), 7.40 (d, J = 8.0 Hz, 2H), 5.18−5.13 (m, 1H), 3.71 (s, 2H), 3.50 (d, J = 5.2 Hz, 4H), 3.30 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.9, 137.5, 129.2, 125.0, 124.9, 124.9, 122.3, 71.5, 70.6, 58.6, 40.5; HRMS (ESI-TOF) m/z Calcd for $C_{14}H_{17}F_3O_4Na[M + Na]^+$ 329.0977, found 329.0980.

1,3-Dimethoxypropan-2-yl 1-(4-methoxyphenyl)-cyclopropanecarboxylate (**1l**). Colorless oil, 2.53 g, yield 86%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26 (d, J = 8.8 Hz, 2H), 6.82 (d, J = 8.4 Hz, 2H), 5.09−5.04 (m, 1H), 3.79 (s, 3H), 3.45 (d, J = 5.2 Hz, 4H), 3.29 (s, 6H), 1.60 (q, J = 4.0 Hz, 2H), 1.16 (q, J = 4.0 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.3, 158.6, 131.7, 131.5, 113.4, 71.9, 71.2, 59.2, 55.3, 28.4, 16.6; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{22}O_5Na[M + Na]^+$ 317.1365, found 317.1360.

1,3-Dimethoxypropan-2-yl 2-(3,4,5-trimethoxyphenyl)acetate (**1m**). Colorless oil, 2.43 g, yield 74%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.51 (s, 2H), 5.18−5.13 (m, 1H), 3.84 (s, 6H), 3.81 (s, 3H), 3.59 (s, 2H), 3.53 (d, J = 5.6 Hz, 4H), 3.32 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.6, 152.7, 136.6, 129.0, 105.8, 73.3, 71.3, 70.6, 60.3, 58.7, 55.6, 41.1; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{24}O_7Na[M + Na]^+$ 351.1420, found 351.1414.

1,3-Dimethoxypropan-2-yl 2-(1-methyl-1H-indol-2-yl)acetate (**1n**). Colorless oil, 2.44 g, yield 84%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, J = 8.0 Hz, 1H), 7.32 (d, J = 8.0 Hz, 1H), 7.29−7.25 (m, 1H), 7.17 (t, J = 8.0 Hz, 1H), 7.09 (s, 1H), 5.27−5.22 (m, 1H), 3.87 (s, 2H), 3.74 (s, 3H), 3.60 (d, J = 5.6 Hz, 4H), 3.38 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.7, 137.0, 127.9, 127.8, 121.7, 119.1, 119.0, 109.3, 106.7, 71.6, 71.2, 59.2, 32.6, 31.3; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{21}NO_4Na[M + Na]^+$ 314.1368, found 314.1360.

1,3-Dimethoxypropan-2-yl 2-(thiophen-2-yl)acetate (**1o**). Colorless oil, 1.78 g, yield 73%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20−7.19 (m, 1H), 6.94 (s, 2H), 5.19−5.13 (m, 1H), 3.87 (s, 2H), 3.53 (d, J = 5.2 Hz, 4H), 3.33 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.5, 134.5, 126.4, 126.3, 124.5, 71.6, 70.5, 58.7, 34.9; HRMS (ESI-TOF) m/z Calcd for $C_{11}H_{16}SO_4Na[M + Na]^+$ 267.0667, found 267.0667.

1,3-Dimethoxypropan-2-yl 2-(cyclohex-1-en-1-yl)acetate (**1p**). Colorless oil, 2.15 g, yield 89%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.55 (s, 1H), 5.14−5.09 (m, 1H), 3.51 (d, J = 4.8 Hz, 4H), 3.33 (s, 6H), 2.96 (s, 2H), 1.98 (s, 4H), 1.62−1.60 (m, 2H), 1.55−1.51 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.5, 131.0, 125.7, 71.2, 71.2, 59.2, 43.6, 28.3, 25.3, 22.7, 22.0; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{22}O_4Na[M + Na]^+$ 265.1416, found 265.1408.

1,3-Dimethoxypropan-2-yl 3-(4-fluorophenyl)propanoate (**4a**). Colorless oil, 4.06 g, yield 80%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.12−7.08 (m, 2H), 6.91−6.87 (m, 2H), 5.12−5.07 (m, 1H), 3.43 (d, J = 4.8 Hz, 4H), 3.27 (s, 6H), 2.87 (t, J = 7.6 Hz, 2H), 2.59 (t, J = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.1, 161.4 (d, J_{C-F} = 243 Hz), 136.1 (d, J_{C-F} = 3.2 Hz), 129.7 (d, J_{C-F} = 7.8 Hz), 115.1 (d, J_{C-F} = 21 Hz), 71.2 (d, J_{C-F} = 12.6 Hz), 59.0, 35.9, 30.0; HRMS (ESI-TOF) m/z Calcd for $C_{14}H_{19}FO_4Na[M + Na]^+$ 293.1165, found 293.1158.

1,3-Dimethoxypropan-2-yl 2-(4-fluorophenoxy)acetate (**4b**). Colorless oil, 4.45 g, yield 87%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.96−6.91 (m, 2H), 6.85−6.81 (m, 2H), 5.26−5.23 (m, 1H), 4.60 (d, J = 4.0 Hz, 2H), 3.52 (d, J = 3.6 Hz, 4H), 3.31 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.0, 157.3 (d, J_{C-F} = 238 Hz), 153.5 (d, J_{C-F} = 2.2 Hz), 115.5 (d, J_{C-F} = 2.0 Hz), 115.3 (d, J_{C-F} = 13.0 Hz), 71.7, 70.5, 65.4, 58.7; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{17}FO_5Na[M + Na]^+$ 295.0958, found 295.0963.

1,3-Dimethoxypropan-2-yl 3-(4-bromophenyl)propanoate (**4c**). Colorless oil, 4.96 g, yield 79%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, J = 8.4 Hz, 2H), 7.03 (d, J = 8.4 Hz, 2H), 5.12−5.07 (m, 1H), 3.44 (d, J = 5.6 Hz, 4H), 3.28 (s, 6H), 2.86 (t, J = 7.6 Hz, 2H), 2.60 (t, J = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.0, 139.4, 131.4, 130.1, 120.0, 71.3, 71.1, 59.1, 35.5, 30.3; HRMS (ESI-TOF) m/z Calcd for $C_{14}H_{19}BrO_4Na$ $[M + Na]^+$ 353.0364, found 353.0352.

1,3-Dimethoxypropan-2-yl 3-(4-methoxyphenyl)propanoate (**4d**). Colorless oil, 4.31 g, yield 81%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.12 (d, J = 8.8 Hz, 2H), 6.82 (d, J = 8.4 Hz, 2H), 5.16−5.11 (m 1H), 3.78 (s, 3H), 3.50 (d, J = 5.2 Hz, 4H), 3.34 (s, 6H), 2.90 (t, J = 7.6 Hz, 2H), 2.64 (t, J = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.5, 158.1, 132.5, 129.3, 113.9, 71.2, 59.2, 55.3, 36.2, 30.1; HRMS (ESI-TOF) m/z Calcd for $C_{15}H_{22}O_5Na[M + Na]^+$ 305.1365, found 305.1362.

1,3-Dimethoxypropan-2-yl 3-(furan-2-yl)propanoate (**4e**). Colorless oil, 3.96 g, yield 82%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (s, 1H), 6.28−6.26 (m, 1H), 6.03 (d, J = 3.2 Hz, 1H), 5.19−5.14 (m, 1H), 3.53 (d, J = 4.8 Hz, 4H), 3.35 (s, 6H), 2.98 (t, J = 7.6

DOI: 10.1021/acs.joc.5b00775
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Hz, 2H), 2.71 (t, J = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.0, 154.1, 141.2, 110.2, 105.3, 71.3, 71.1, 59.2, 32.7, 23.4; HRMS (ESI-TOF) m/z Calcd for $C_{12}H_{18}O_5Na[M + Na]^+$ 265.1052, found 265.1043.

*1,3-Dimethoxypropan-2-yl 3-(thiophen-2-yl)propanoate (**4f**).* Colorless oil, 4.39 g, yield 85%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.09 (d, J = 5.2 Hz, 1H), 6.89−6.87 (m, 1H), 6.80 (d, J = 3.2 Hz, 1H), 5.17−5.12(m, 1H), 3.50 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 3.15 (t, J = 7.6 Hz, 2H), 2.71 (t, J = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.9, 143.0, 126.8, 124.7, 123.5, 71.4, 71.1, 59.2, 36.1, 25.2; HRMS (ESI-TOF) m/z Calcd for $C_{12}H_{18}SO_4Na[M + Na]^+$ 281.0823, found 281.0832.

*1,3-Dimethoxypropan-2-yl 4-methoxybenzoate (**6a**).* Colorless oil, 4.00 g, yield 84%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.98 (d, J = 8.8 Hz, 2H), 6.87 (d, J = 8.8 Hz, 2H), 5.34−5.29 (m, 1H), 3.80 (s, 3H), 3.62 (d, J = 5.2 Hz, 4H), 3.35 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 165.8, 163.4, 131.8, 122.5, 113.5, 71.6, 71.3, 59.2, 55.4; HRMS (ESI-TOF) m/z Calcd for $C_{13}H_{18}O_5Na[M + Na]^+$ 277.1052, found 277.1045.

*1,3-Dimethoxypropan-2-yl 4-fluorobenzoate (**6b**).* Colorless oil, 3.75 g, yield 83%, PE/EA= 8:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01−8.05 (m, 2H), 7.09 (t, J = 8.8 Hz, 2H), 5.38−3.33 (m, 1H), 3.65 (d, J = 5.6 Hz, 4H), 3.38 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 165.8 (d, J_{C-F} = 252 Hz), 165.1, 132.4 (d, J_{C-F} = 9.3 Hz), 132.1 (d, J_{C-F} = 9.3 Hz), 126.4 (d, J_{C-F} = 3.0 Hz), 115.5 (d, J_{C-F} = 22.0 Hz), 72.1, 71.3, 59.3; HRMS (ESI-TOF) m/z Calcd for $C_{12}H_{15}FO_4Na[M + Na]^+$ 265.0852, found 265.0835.

General Procedure for the Synthesis of Products (3a−3w, 5a−5f, 7a and 7b). A mixture of phenylacetate (0.2 mmol, 1.0 equiv), **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (4.4 mg, 0.1 equiv), Ag_2CO_3 (547.6 mg, 2.0 equiv), 1,10-phenanthroline (3.6 mg, 0.1 equiv), adamantine carboxylic acid (3.6 mg, 0.1 equiv) and HFIP (0.5 mL) in a 15 mL glass vial (sealed with PTFE cap) was heated at 100 °C for 24 h. The reaction mixture was cooled to rt and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding products. Reactions involving **3i**, **3k**, **5d** and **5e** were heated at 110 °C, while **3k**, **3o**, **5d** were reacted for 48 h, and **5f** took place under darkness.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-5-methoxyphenyl)acrylate (**3a**).* Colorless oil, 60.0 mg, yield 82%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 16.0 Hz, 1H), 7.41 (s, 1H), 7.23 (d, J = 8.4 Hz, 1H), 6.83 (d, J = 8.4 Hz, 1H), 6.49 (d, J = 16.4 Hz, 1H), 5.15−5.10 (m, 1H), 4.22 (q, J = 6.8 Hz, 2H), 3.83 (s, 3H), 3.58 (s, 2H), 3.50 (d, J = 4.8 Hz, 4H), 3.30 (s, 6H), 1.29 (t, J = 6.8 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 167.4, 157.4, 139.7, 132.2, 129.7, 126.1, 123.4, 119.0, 111.3, 71.8, 71.1, 60.3, 59.2, 55.6, 40.3, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{26}O_7Na[M + Na]^+$ 389.1576, found 389.1577.

*Ethyl-3-(5-methoxy-2-(2-methoxy-2-oxoethyl)phenyl)acrylate (**3b**).* Colorless oil, 40.6 mg, yield 73%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, J = 16.4 Hz, 1H), 7.45 (d, J = 2.0 Hz, 1H), 7.31−7.28 (m, 1H), 6.91 (d, J = 7.6 Hz, 1H), 6.57 (d, J = 16.0 Hz, 1H), 6.40 (d, J = 15.6 Hz, 0.07H), 4.30 (q, J = 7.2 Hz, 2H), 3.91 (s, 3H), 3.73 (s, 3H), 3.61 (s, 2H), 1.37 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.6, 167.0, 157.0, 139.2, 131.7, 129.3, 125.7, 123.0, 118.6, 110.8, 76.9, 76.6, 76.3, 59.9, 55.1, 51.6, 39.6, 38.1, 35.9, 27.4, 13.9; HRMS (ESI-TOF) m/z Calcd for $C_{15}H_{18}O_5Na[M + Na]^+$ 301.1052, found 301.1050.

*Ethyl-3-(2-(2-ethoxy-2-oxoethyl)-5-methoxyphenyl)acrylate (**3c**).* Colorless oil, 43.2 mg, yield 74%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, J = 16.0 Hz, 1H), 7.45 (d, J = 2.4 Hz, 1H), 7.31−7.29 (m, 1H), 6.91 (d, J = 8.8 Hz, 1H), 6.57 (d, J = 16.0 Hz, 1H), 6.40 (d, J = 15.6 Hz, 0.11H), 4.30 (q, J = 7.2 Hz, 2H), 4.19 (q, J = 7.2 Hz, 2H), 3.91 (s, 3H), 3.59 (s, 2H), 1.37 (t, J = 7.2 Hz, 3H), 1.29 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.1, 167.0, 157.0, 139.3, 131.7, 129.2, 125.8, 123.0, 118.6, 110.8, 60.4, 59.9, 55.1, 39.9, 13.8, 13.7; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{20}O_5Na[M + Na]^+$ 315.1208, found 315.1213.

*Ethyl-3-(2-(2-isopropoxy-2-oxoethyl)-5-methoxyphenyl)acrylate (**3d**).* Colorless oil, 41.6 mg, yield 68%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, J = 16.4 Hz, 1H), 7.46 (d, J = 2.4 Hz, 1H), 7.32−7.29 (m, 1H), 6.91 (d, J = 8.6 Hz, 1H), 6.57 (d, J = 16.4 Hz, 1H), 6.40 (d, J = 16.0 Hz, 0.1H), 5.08−5.02 (m, 1H), 4.30 (q, J = 7.2 Hz, 2H), 3.92 (s, 3H), 3.56 (s, 2H), 1.38 (t, J = 7.2 Hz, 3H), 1.27 (d, J = 6.4 Hz, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.7, 167.0, 156.9, 139.3, 131.6, 129.2, 126.0, 122.9, 118.5, 110.8, 67.8, 59.9, 55.1, 40.2, 21.3, 13.9; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{22}O_5Na[M + Na]^+$ 329.1365, found 329.1359.

*Ethyl-3-(5-methoxy-2-(2-(2-methoxyethoxy)-2-oxoethyl)phenyl)-acrylate (**3e**).* Colorless oil, 36.7 mg, yield 57%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, J = 16.0 Hz, 1H), 7.43 (d, J = 2.0 Hz, 1H), 7.27−7.25 (m, 1H), 6.87 (d, J = 8.4 Hz, 1H), 6.52 (d, J = 16.4 Hz, 1H), 6.35 (d, J = 15.6 Hz, 0.05H), 4.28−4.22 (m, 4H), 3.87 (s, 3H), 3.60−3.58 (m, 4H), 3.37 (s, 3H), 1.33 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 167.0, 157.0, 139.2, 131.7, 129.3, 125.6, 123.0, 118.6, 110.8, 69.9, 63.5, 59.9, 58.5, 55.1, 39.6, 13.9; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{22}O_6Na[M + Na]^+$ 345.1314, found 345.1314.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-5-fluorophenyl)acrylate (**3f**).* Colorless oil, 57.3 mg, yield 81%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, J = 16.0 Hz, 1H), 7.47 (d, J = 7.2 Hz, 1H), 7.27 (s, 1H), 7.05 (d, J = 8.4 Hz, 1H), 6.52 (d, J = 16.0 Hz, 1H), 5.18−5.13 (m, 1H), 4.25 (q, J = 7.2 Hz, 2H), 3.64 (s, 2H), 3.52 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 1.32 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.2, 166.3, 160 (d, J_{C-F} = 252 Hz), 136.5 (d, J_{C-F} = 2.6 Hz), 132.0 (d, J_{C-F} = 8.8 Hz), 129.7 (d, J_{C-F} = 3.7 Hz), 129.3 (d, J_{C-F} = 3.1 Hz), 122.0 (d, J_{C-F} = 12.1 Hz), 120.6 (d, J_{C-F} = 6.5 Hz), 115.8 (d, J_{C-F} = 22.0 Hz), 71.5, 70.6, 60.1, 58.7, 39.9, 13.8; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{23}FO_6Na[M + Na]^+$ 377.1376, found 377.1375.

*Ethyl-3-(5-chloro-2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)phenyl)acrylate (**3g**).* Colorless oil, 51.1 mg, yield 69%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (d, J = 16.0 Hz, 1H), 7.56 (s, 1H), 7.36 (d, J = 8.4 Hz, 1H), 7.24 (d, J = 6.0 Hz, 1H), 6.45 (d, J = 16.0 Hz, 1H), 5.19−5.14 (m, 1H), 4.27 (q, J = 7.2 Hz, 2H), 3.66 (s, 2H), 3.53 (d, J = 5.6 Hz, 4H), 3.33 (s, 6H), 1.34 (t, J = 7.2 Hz, 4H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.5, 166.5, 140.1, 133.7, 133.1, 132.8, 131.9, 130.2, 128.5, 121.2, 72.0, 71.1, 60.7, 59.2, 40.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{23}ClO_6Na[M + Na]^+$ 393.1081, found 393.1082.

*1,3-Dimethoxypropan-2-yl 1-(4-chloro-2-(3-ethoxy-3-oxoprop-1-en-1-yl)phenyl)cyclobutanecar-boxylate (**3h**).* Compound 3h, colorless oil, 58.2 mg, yield 71%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (d, J = 16.0 Hz, 1H), 7.55 (d, J = 2.4 Hz, 1H), 7.36 (d, J = 8.4 Hz, 1H), 7.27 (d, J = 2.4 Hz, 1H), 6.46 (d, J = 16.0 Hz, 1H), 5.14−5.09 (m, 1H), 4.28 (q, J = 7.2 Hz, 2H), 3.43 (d, J = 5.2 Hz, 4H), 3.24 (s, 6H), 2.89−2.83 (m, 2H), 2.51−2.44 (m, 2H), 2.11−2.02 (m,1H), 1.93−1.85 (m, 1H), 1.35 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 174.7, 166.5, 142.8, 140.4, 133.1, 132.4, 129.8, 129.1, 125.7, 121.1, 72.0, 71.2, 60.7, 59.2, 52.1, 32.3, 16.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{21}H_{27}ClO_6Na[M + Na]^+$ 433.1394, found 433.1393.

*Ethyl-3-(5-bromo-2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)phenyl)acrylate (**3i**).* Colorless oil, 55.5 mg, yield 67%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (d, J = 16.0 Hz, 1H), 7.55 (d, J = 8.0 Hz, 2H), 7.16 (d, J = 8.4 Hz, 1H), 6.40 (d, J = 16.0 Hz, 1H), 5.19−5.14 (m, 1H), 4.27 (q, J = 7.2 Hz, 2H), 3.64 (s, 2H), 3.53 (d, J = 4.8 Hz, 4H), 3.33 (s, 6H), 1.33 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.3, 166.4, 142.7, 134.6, 133.8, 133.4, 132.1, 128.6, 123.9, 121.4, 72.0, 71.1, 60.7, 59.2, 40.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{23}BrO_6Na[M + Na]^+$ 439.0555, found 439.0557.

*Ethyl-3-(5-bromo-2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-3-methoxyphenyl)acrylate (**3j**).* Colorless oil, 57.7 mg, yield 65%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, J = 16.0 Hz, 1H), 7.47 (s, 1H), 7.05 (s, 1H), 6.29 (d, J = 16.0 Hz, 1H), 5.18−5.13 (m, 1H), 4.24 (q, J = 7.2 Hz, 2H), 3.81 (s, 3H), 3.61 (s, 2H), 3.52 (d, J = 5.1 Hz, 4H), 3.33 (s, 6H), 1.31 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.5, 166.7, 159.2, 142.3, 129.5, 126.5, 125.3, 123.3, 118.8, 115.1, 71.8, 71.1, 60.5, 59.2, 55.9, 35.5, 14.3; HRMS

DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

(ESI-TOF) m/z Calcd for $C_{19}H_{25}BrO_7Na[M + Na]^+$ 469.0658, found 469.0657.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-5-(trifluoromethyl)phenyl)acrylate (**3k**).* Colorless oil, 54.9 mg, yield 68%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, J = 15.6 Hz, 1H), 7.81 (s, 1H), 7.58 (d, J = 8.0 Hz, 1H), 7.43 (d, J = 8.0 Hz, 1H), 6.43 (d, J = 15.6 Hz, 1H), 5.20−5.15 (m, 1H), 4.27 (q, J = 7.2 Hz, 2H), 3.87 (s, 2H), 3.52 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 1.34 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 207.0, 168.0 (d, J_{C-F} = 358 Hz), 140.2, 137.1, 135.0, 131.6, 128.9, 126.3, 123.8 (d, J_{C-F} = 4 Hz), 122.5, 72.2, 71.0, 60.8, 59.2, 30.9, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{23}F_3O_6Na$ $[M + Na]^+$ 427.1344, found 427.1344.

*1,3-Dimethoxypropan-2-yl 1-(2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-methoxyphenyl)cyclopropane-carboxylate (**3l**).* Colorless oil, 61.9 mg, yield 79%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 16.4 Hz, 1H), 7.48 (d, J = 2.0 Hz, 1H), 7.31−7.29 (m, 1H), 6.82 (d, J = 8.4 Hz, 1H), 6.51 (d, J = 16.0 Hz, 1H), 5.08−5.03 (m, 1H), 4.23 (q, J = 7.2 Hz, 2H), 3.85 (s, 3H), 3.43 (d, J = 5.2 Hz, 4H), 3.28 (s, 6H), 1.61 (q, J = 4.0 Hz, 2H), 1.31 (t, J = 7.2 Hz, 3H), 1.15 (q, J = 4.0 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.9, 167.4, 157.3, 139.9, 133.3, 131.7, 131.0, 123.0, 118.8, 110.8, 72.0, 71.1, 60.3, 59.2, 55.6, 28.3, 16.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{21}H_{28}O_7Na[M + Na]^+$ 415.1733, found 415.1732.

*Ethyl-3-(6-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-2,3,4-trimethoxyphenyl)acrylate (**3m**).* Colorless oil, 62.2 mg, yield 73%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, J = 16.4 Hz, 1H), 6.58 (s, 1H), 6.46 (d, J = 16.0 Hz, 1H), 5.14−5.09 (m, 1H), 4.19 (q, J = 7.2 Hz, 2H), 3.81 (s, 3H), 3.80 (s, 6H), 3.70 (s, 2H), 3.48 (d, J = 4.8 Hz, 4H), 3.27 (s, 6H), 1.27 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.1, 167.0, 153.5, 153.0, 141.1, 137.7, 129.3, 121.4, 120.8, 109.6, 71.4, 70.5, 60.3, 60.1, 59.7, 58.6, 55.4, 38.9, 13.8; HRMS (ESI-TOF) m/z Calcd for $C_{21}H_{30}O_9Na[M + Na]^+$ 449.1788, found 449.1782.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-1-methyl-1H-indol-3-yl)acrylate (**3n**).* Colorless oil, 46.3 mg, yield 62%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, J = 16.0 Hz, 1H), 7.66 (d, J = 8.0 Hz, 1H), 7.30−7.29 (m, 2H), 7.16−7.12 (m, 1H), 6.48 (d, J = 16.0 Hz, 1H), 5.18−5.13 (m, 1H), 4.29 (q, J = 7.2 Hz, 2H), 3.95 (s, 2H), 3.82 (s, 3H), 3.53 (d, J = 4.8 Hz, 4H), 3.31 (s, 6H), 1.36 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.8, 167.0, 138.3, 132.7, 132.2, 127.6, 124.1, 120.2, 120.2, 119.8, 111.2, 109.5, 71.9, 71.1, 60.7, 59.2, 31.4, 30.9, 14.4; HRMS (ESI-TOF) m/z Calcd for $C_{21}H_{27}NO_6Na[M + Na]^+$ 412.1736, found 412.1744.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-thiophen-3-yl)acrylate (**3o**).* Colorless oil, 41.0 mg, yield 60%, PE/EA= 5:1.^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, J = 15.6 Hz, 1H), 7.09 (d, J = 3.6 Hz, 1H), 6.90 (d, J = 3.6 Hz, 1H), 6.16 (d, J = 15.6 Hz, 1H), 5.21−5.16 (m, 1H), 4.24 (q, J = 7.2 Hz, 2H), 3.87 (s, 2H), 3.55 (d, J = 5.2 Hz, 4H), 3.35 (s, 6H), 1.32 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.4, 166.9, 139.3, 138.5, 137.1, 130.9, 128.0, 116.6, 72.4, 71.0, 60.5, 59.3, 35.9, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{16}H_{22}SO_6Na[M + Na]^+$ 365.1035, found 365.1036.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-cyclohex-1-en-1-yl)acrylate (**3p**).* Colorless oil, 53.0 mg, yield 78%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 (d, J = 15.6 Hz, 1H), 5.84 (d, J = 15.6 Hz, 1H), 5.14−5.09 (m, 1H), 4.18 (q, J = 7.2 Hz, 2H), 3.50 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 2.23 (s, 2H), 2.18 (s, 2H), 1.89−1.88 (m, 1H), 1.69 (s, 2H), 1.65−1.61 (m, 3H), 1.27 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.3, 167.6, 141.8, 138.6, 130.6, 116.6, 71.7, 71.1, 60.2, 59.2, 39.0, 38.6, 36.4, 31.9, 27.8, 25.5, 22.3, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{28}O_6Na[M + Na]^+$ 363.1784, found 363.1783.

*1,3-Dimethoxypropan-2-yl 2-(4-methoxy-2-(3-oxopent-1-en-1-yl)phenyl)acetate (**3r**).* Colorless oil, 51.1 mg, yield 73%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (d, J = 16.4 Hz, 1H), 7.47 (d, J = 2.0 Hz, 1H), 7.28−7.26 (m, 1H), 6.86 (d, J = 8.4 Hz, 1H), 6.77 (d, J = 16.4 Hz, 1H), 5.17−5.12 (m, 1H), 3.87 (s, 3H), 3.61 (s, 2H), 3.53 (d, J = 5.2 Hz, 4H), 3.33 (s, 6H), 2.70 (q, J = 7.2 Hz, 2H), 1.15 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.5, 171.2, 157.5, 137.2, 132.4, 129.2, 126.9, 126.2, 123.6, 111.3, 71.8, 71.1, 59.2, 55.6, 40.3, 33.6, 8.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{26}O_6Na[M + Na]^+$ 373.1627, found 373.1627.

*Benzyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-5-methoxyphenyl)acrylate (**3s**).* Colorless oil, 60.8 mg, yield 71%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, J = 16.4 Hz, 1H), 7.44−7.24 (m, 2H), 7.41−7.39 (m, 2H), 7.38−7.37(m, 1H), 7.35−7.33 (m, 1H), 7.28−7.25 (m, 1H), 6.86 (d, J = 8.4 Hz, 1H), 6.59 (d, J = 16.4 Hz, 1H), 5.25 (s, 2H), 5.18−5.13 (m, 1H), 3.86 (s, 3H), 3.61 (s, 2H), 3.53 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 167.3, 157.5, 140.4, 136.3, 132.4, 129.9, 128.6, 128.2, 128.1, 126.2, 123.4, 118.6, 111.3, 71.8, 71.1, 66.2, 59.2, 55.6, 40.3; HRMS (ESI-TOF) m/z Calcd for $C_{24}H_{28}O_7Na[M + Na]^+$ 451.1733, found 451.1739.

*2-Hydroxyethyl 3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethyl)-5-methoxyphenyl)-acrylate (**3t**).* Colorless oil, 42.8 mg, yield 56%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, J = 16.0 Hz, 1H), 7.43 (d, J = 2.4 Hz, 1H), 7.28−7.25 (m, 1H), 6.86 (d, J = 8.4 Hz, 1H), 6.56 (d, J = 16.0 Hz, 1H), 5.17−5.12 (m, 1H), 4.4-4.32 (m, 2H), 3.93−3.88 (m, 2H), 3.86 (s, 3H), 3.61 (s, 2H), 3.52 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 2.26 (s, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.2, 167.8, 157.6, 140.7, 132.5, 129.9, 126.2, 123.2, 118.3, 111.3, 71.8, 71.1, 66.2, 61.4, 59.2, 55.6, 40.2; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{26}O_8Na[M + Na]^+$ 405.1525, found 405.1524.

*1,3-Dimethoxypropan-2-yl 2-(2-(3-(tert-butylamino)-3-oxoprop-1-en-1-yl)-4-methoxyphenyl)-acetate (**3u**).* Colorless oil, 56.6 mg, yield 72%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 16.0 Hz, 1H), 7.36 (s, 1H), 7.20 (d, J = 8.8 Hz, 1H), 6.82 (d, J = 8.4 Hz, 1H), 6.44 (d, J = 15.6 Hz, 1H), 5.62 (s, 1H), 5.16−5.11 (m, 1H), 3.82 (s, 3H), 3.58 (s, 2H), 3.51 (d, J = 5.2 Hz, 4H), 3.31 (s, 6H), 1.41 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.3, 165.8, 157.3, 135.3, 131.3, 129.5, 125.9, 124.0, 123.1, 111.2, 71.7, 71.1, 59.2, 55.5, 51.4, 40.3, 28.9; HRMS (ESI-TOF) m/z Calcd for $C_{21}H_{31}NO_6Na[M + Na]^+$ 416.2049, found 416.2037.

*1,3-Dimethoxypropan-2-yl 2-(2-(3-(dimethylamino)-3-oxoprop-1-en-1-yl)-4-methoxyphenyl)-acetate (**3v**).* Colorless oil, 49.6 mg, yield 68%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, J = 15.6 Hz, 1H), 7.42 (s, 1H), 7.25−7.22 (m, 1H), 6.98 (d, J = 15.6 Hz, 1H), 6.86 (d, J = 8.8 Hz, 1H), 5.18−5.13 (m, 1H), 3.86 (s, 2H), 3.62 (s, 2H), 3.53 (d, J = 5.2 Hz, 4H), 3.33 (s, 6H), 3.11 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 207.0, 171.3, 157.3, 137.7, 131.4, 129.7, 126.0, 124.4, 118.4, 111.3, 71.7, 71.1, 59.2, 55.6, 40.4, 30.9, 29.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{27}NO_6Na[M + Na]^+$ 388.1736, found 388.1726.

*1,3-Dimethoxypropan-2-yl 2-(2-(2-cyanovinyl)-4-methoxyphenyl)acetate (**3w**).* Colorless oil, 42.1 mg, yield 66%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, J = 16.8 Hz, 1H), 7.33−7.26 (m, 2H), 6.88 (d, J = 8.4 Hz, 1H), 6.06 (d, J = 16.8 Hz, 1H), 5.18−5.13 (m, 1H), 3.88 (s, 3H), 3.62 (s, 2H), 3.53 (d, J = 4.4 Hz, 4H), 3.34 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.0, 157.3, 146.2, 133.1, 129.6, 126.4, 122.6, 118.9, 111.4, 97.2, 71.8, 71.1, 59.2, 55.7, 40.1; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{21}NO_5Na[M + Na]^+$ 342.1317, found 342.1312.

*Ethyl-3-(2-(3-((1,3-dimethoxypropan-2-yl)oxy)-3-oxopropyl)-5-fluorophenyl)acrylate (**5a**).* Colorless oil, 54.5 mg, yield 74%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 16.4 Hz, 1H), 7.39−7.37 (m, 1H), 7.23−7.19 (m, 1H), 7.05−7.00 (m, 1H), 6.54 (d, J = 16.4 Hz, 1H), 5.18−5.13 (m, 1H), 4.28 (q, J = 7.2 Hz, 2H), 3.51 (d, J = 5.2 Hz, 4H), 3.35 (s, 6H), 2.96 (t, J = 7.6 Hz, 2H), 2.69 (t, J = 7.6 Hz, 2H), 1.35 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.0, 166.8, 160 (d, J_{C-F} = 251 Hz), 137.2 (d, J_{C-F} = 2.5 Hz), 136.6 (d, J_{C-F} = 3.6 Hz), 131.6 (d, J_{C-F} = 8.6 Hz), 128.8 (d, J_{C-F} = 3.0 Hz), 122.3 (d, J_{C-F} = 11.9 Hz), 120.8 (d, J_{C-F} = 6.7 Hz), 116.1 (d, J_{C-F} = 22.0 Hz), 71.4, 71.2, 60.6, 59.2, 38.7, 36.4, 35.8, 30.0, 27.8, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{25}FO_6Na[M + Na]^+$ 391.1533, found 391.1537.

*Ethyl-3-(2-(2-((1,3-dimethoxypropan-2-yl)oxy)-2-oxoethoxy)-5-fluorophenyl)acrylate (**5b**).* Colorless oil, 66.6 mg, yield 90%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, J = 16.0 Hz, 1H), 7.04−7.00 (m, 2H), 6.93−6.89 (m, 1H), 6.49 (d, J = 16.0 Hz, 1H), 5.33−5.27 (m, 1H), 4.66 (s, 2H), 4.26 (q, J = 7.2 Hz, 2H), 3.55 (d, J =

DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

5.6 Hz, 4H), 3.35 (s, 6H), 1.33 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.8, 166.2, 156.0 (d, J_{C-F} = 247 Hz), 153.5 (d, J_{C-F} = 2.2 Hz), 136.4 (d, J_{C-F} = 2.5 Hz), 122.5 (d, J_{C-F} = 3.0 Hz), 120.7 (d, J_{C-F} = 6.4 Hz), 117.7 (d, J_{C-F} = 8.5 Hz), 116.5 (d, J_{C-F} = 24.0 Hz), 113.5 (d, J_{C-F} = 3.0 Hz), 71.8, 70.6, 65.5, 60.2, 58.7, 30.4, 13.8; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{23}FO_7Na[M + Na]^+$ 393.1326, found 393.1326.

*Ethyl-3-(5-bromo-2-(3-((1,3-dimethoxypropan-2-yl)oxy)-3-oxopropyl)phenyl)acrylate (**5c**).* Colorless oil, 71.0 mg, yield 83%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, J = 16.0 Hz, 1H), 7.50 (d, J = 8.0 Hz, 1H), 7.45−7.43 (m, 1H), 7.22 (d, J = 8.0 Hz, 1H), 6.38 (d, J = 16.0 Hz, 1H), 5.19−5.11(m, 1H), 4.26 (q, J = 7.2 Hz, 2H), 3.48 (d, J = 2.4 Hz, 4H), 3.32 (s, 6H), 2.93(t, J = 7.6 Hz, 2H), 2.67 (t, J = 7.6 Hz, 2H), 1.34 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.9, 166.4, 144.3, 142.8, 140.2, 133.4, 128.9, 128.2, 127.8, 117.7, 71.2, 60.7, 59.2, 35.4, 30.7, 30.3, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{19}H_{25}BrO_6Na[M + Na]^+$ 451.0732, found 451.0728.

*Ethyl-3-(2-(3-((1,3-dimethoxypropan-2-yl)oxy)-3-oxopropyl)-5-methoxyphenyl)acrylate (**5d**).* Colorless oil, 47.9 mg, yield 63%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 16.4 Hz, 1H), 7.33 (d, J = 2.0 Hz, 1H), 7.19−7.16 (m, 1H), 6.82 (d, J = 8.4 Hz, 1H), 6.51 (d, J = 16.4 Hz, 1H), 5.15−5.10 (m, 1H), 4.24 (q, J = 7.2 Hz, 2H), 3.85 (s, 3H), 3.49 (d, J = 5.2 Hz, 4H), 3.32 (s, 6H), 2.90 (t, J = 7.2 Hz, 2H), 2.65(t, J = 8.0 Hz, 2H), 1.32 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.3, 167.5, 156.9, 140.0, 132.5, 131.3, 128.8, 123.3, 118.8, 111.3, 71.2, 71.2, 60.3, 59.2, 55.6, 36.0, 30.0, 14.4; HRMS (ESI-TOF) m/z Calcd for $C_{20}H_{28}O_7Na[M + Na]^+$ 403.1733, found 403.1722.

*Ethyl-3-(2-(3-((1,3-dimethoxypropan-2-yl)oxy)-3-oxopropyl)-furan-3-yl)acrylate (**5e**).* Colorless oil, 49.0 mg, yield 70%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, J = 15.6 Hz, 1H), 6.48 (d, J = 3.2 Hz, 1H), 6.21 (d, J = 16.0 Hz, 1H), 6.12 (d, J = 3.6 Hz, 1H), 5.18−5.13 (m, 1H), 4.21 (q, J = 7.2 Hz, 2H), 3.51 (d, J = 5.2 Hz, 4H), 3.33 (s, 6H), 2.99 (t, J = 7.6 Hz, 2H), 2.72 (t, J = 7.2 Hz, 2H), 1.29 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.7, 167.2, 157.1, 149.8, 130.9, 116.0, 114.7, 108.5, 71.2, 59.2, 38.6, 32.3, 27.8, 23.7, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{25}O_7$ $[M + H]^+$ 341.1600, found 341.1600.

*Ethyl-3-(2-(3-((1,3-dimethoxypropan-2-yl)oxy)-3-oxopropyl)-thiophen-3-yl)acrylate (**5f**).* Colorless oil, 49.1 mg, yield 69%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, J = 15.6 Hz, 1H), 7.02 (d, J = 3.6 Hz, 1H), 6.74 (d, J = 3.6 Hz,, 1H), 6.08 (d, J = 15.6 Hz, 1H), 5.16−5.11 (M, 1H), 4.20 (q, J = 7.2 Hz, 2H), 3.49 (d, J = 5.2 Hz, 4H), 3.31 (s, 6H), 3.12(t, J = 7.6 Hz, 2H), 2.71 (t, J = 7.6 Hz, 2H), 1.28 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.6, 166.9, 146.9, 137.9, 137.2, 131.3, 126.0, 116.0, 71.5, 71.1, 60.4, 59.2, 35.6, 25.6, 14.3; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{24}SO_6Na[M + Na]^+$ 379.1191, found 379.1205.

*1,3-Dimethoxypropan-2-yl 2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-methoxybenzoate (**7a**).* Colorless oil, 57.0 mg, yield 81%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (s, 1H), 8.08−8.05 (m, 1H), 7.95 (d, J = 16.4 Hz, 1H), 6.93 (d, J = 8.8 Hz, 1H), 6.58 (d, J = 16.0 Hz, 1H), 5.40−5.35 (m, 1H), 4.27 (q, J = 7.2 Hz, 2H), 3.94 (s, 3H), 3.67 (d, J = 5.2 Hz, 4H), 3.39 (s, 6H), 1.34 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.2, 165.4, 161.7, 139.0, 133.3, 130.7, 123.4, 122.7, 120.0, 110.7, 71.9, 71.4, 60.5, 59.3, 55.9, 14.4; HRMS (ESI-TOF) m/z Calcd for $C_{18}H_{24}O_7Na[M + Na]^+$ 375.1420, found 375.1412.

*1,3-Dimethoxypropan-2-yl 2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-fluorobenzoate (**7b**).* Colorless oil, 50.3 mg, yield 74%, PE/EA= 5:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (d, J = 7.2 Hz, 1H), 8.09−8.06 (m, 1H), 7.80 (d, J = 16.4 Hz, 1H), 7.18−7.10 (m, 1H), 6.61 (d, J = 16.4 Hz, 1H), 5.42−5.37 (m, 1H), 4.28 (q, J = 7.2 Hz, 2H), 3.66 (d, J = 4.8 Hz, 4H), 3.39 (s, 6H), 1.35 (t, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.0, 164.2, 163.4 (d, J_{C-F} = 259 Hz), 135.6 (d, J_{C-F} = 2.4 Hz), 132.8 (d, J_{C-F} = 10.0 Hz), 130.6 (d, J_{C-F} = 4.4 Hz), 126.4 (d, J_{C-F} = 3.2 Hz), 121.7 (d, J_{C-F} = 6.4 Hz), 116.0, 115.8, 71.9, 70.8 (d, J_{C-F} = 8.0 Hz), 60.3, 58.8 (d, J_{C-F} = 6.4 Hz), 38.2, 35.9, 27.3, 13.8; HRMS (ESI-TOF) m/z Calcd for $C_{17}H_{21}FO_6Na[M + Na]^+$ 363.1220, found 363.1225.

General Procedure for the Deuterium Experiments Are Represented As Follows (Scheme 5A and 5B). Mixtures of phenylacetate **1a** (134.0 mg, 0.5 mmol, 1.0 equiv), AcOD (610.0 mg, 10 mmol, 20 equiv), $Pd(OAc)_2$ (11.2 mg, 0.05 mmol, 0.1 equiv) with and without 1,10-phenanthroline (9.0 mg, 0.05 mmol, 0.1 equiv) in a 25 mL glass vial (purged with Ar, sealed with PTFE cap) were heated at 100 °C for 30 h, respectively. The reaction mixture was cooled to room temperature and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding products.

Scheme 5A: Colorless oil. 1H NMR (400 MHz, $CDCl_3$) δ 7.20 (d, J = 8.4 Hz, 2H), 6.84 (d, J = 8.8 Hz, 1.77H), 5.16−5.11 (m, 2H), 3.78 (s, 3H), 3.60 (s, 2H), 3.52 (d, J = 5.0 Hz, 4H), 3.32 (s, 6H).

Scheme 5B: Colorless oil. 1H NMR (400 MHz, $CDCl_3$) δ 7.21−7.20 (m, 2H), 6.86−6.84 (m, 0.46H), 5.16−5.11 (m, 2H), 3.78 (s, 3H), 3.60 (s, 2H), 3.52 (d, J = 9.2 Hz, 4H), 3.33 (s, 6H).

General Procedure for Synthesis of 3q. A mixture of **1q** (0.2 mmol, 1.0 equiv), **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (4.4 mg, 0.1 equiv), Ag_2CO_3 (547.6 mg, 2.0 equiv), 1,10-phenanthroline (3.6 mg, 0.1 equiv), adamantane carboxylic acid (3.6 mg, 0.1 equiv) and HFIP (0.5 mL) in a 15 mL glass vial (sealed with PTFE cap) was heated at 100 °C for 24 h. The reaction mixture was cooled to rt and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding product, and the isolated yield is 77% yield. The regioselective is 2:3. When the temperature of this reaction is 60 °C, the isolated yield is 71% yield. The *ortho*/others is 3:2.

General Procedure for *ortho*-Olefination of Ethyl 2-Phenylacetate. A mixture of ethyl 2-phenylacetate (0.2 mmol, 1.0 equiv), **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (4.4 mg, 0.1 equiv), Ag_2CO_3 (547.6 mg, 2.0 equiv), 1,10-phenanthroline (3.6 mg, 0.1 equiv), adamantane carboxylic acid (3.6 mg, 0.1 equiv) and HFIP (0.5 mL) in a 15 mL glass vial (sealed with PTFE cap) was heated at 100 °C for 24 h. The reaction mixture was cooled to rt and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding product, and the isolated yield is 62%. The *ortho*/others is 1:1.

General Procedure for Palladium-Catalyzed Oxidative Olefination. A mixture of toluene (1.0 mmol, 5.0 equiv), **2a** (0.2 mmol, 1.0 equiv), $Pd(OAc)_2$ (4.4 mg, 0.1 equiv), Ag_2CO_3 (547.6 mg, 2.0 equiv), 1,10-phenanthroline (3.6 mg, 0.1 equiv), adamantane carboxylic acid (3.6 mg, 0.1 equiv) and HFIP (0.5 mL) in a 15 mL glass vial (sealed with PTFE cap) was heated at 60 °C for 24 h. The reaction mixture was cooled to rt, and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding product, and the isolated yield is 78%. The *ortho*/others is 1:1.

General Procedure for the Synthesis of 3a use HOAc as Solvent. A mixture of **1a** (0.2 mmol, 1.0 equiv), **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (4.4 mg, 0.1 equiv), Ag_2CO_3 (547.6 mg, 2.0 equiv), 1,10-phenanthroline (3.6 mg, 0.1 equiv), HOAc (0.5 mL) in a 15 mL glass vial (sealed with PTFE cap) was heated at 100 °C for 24 h. The reaction mixture was cooled to rt and concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel to give the corresponding product, and the isolated yield is 55%.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b00775.

Optimization of reaction conditions, and ^{1}H and ^{13}C NMR spectra for new compounds. (PDF)

■ AUTHOR INFORMATION

Corresponding Authors

*dqshi@suda.edu.cn

*yszhao@suda.edu.cn

DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We sincerely acknowledge the Natural Science Foundation of Jiangsu Province of China (BK20130294), the Young National Natural Science Foundation of China (No. 21402133), and PAPD for their financial support.

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DOI: 10.1021/acs.joc.5b00775
J. Org. Chem. 2015, 80, 7896−7904