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Weihui Zhong [a], Yongzhi Zhao [a], Baoming Guo [a], Peng Wu [a] & Weike Su [a]
[a] College of Pharmaceutical Sciences, Zhejiang University of Technology, Zhejiang Key Laboratory of Pharmaceutical Engineering, Hangzhou, China
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Dramatically Accelerated Addition Under Solvent-Free Conditions: An Efficient Synthesis of (*E*)-1,2,4-Triazole-Substituted Alkenes from Baylis–Hillman Acetates

Weihui Zhong, Yongzhi Zhao, Baoming Guo, Peng Wu, and Weike Su

College of Pharmaceutical Sciences, Zhejiang University of Technology, Zhejiang Key Laboratory of Pharmaceutical Engineering, Hangzhou, China

Abstract: The addition of 1,2,4-triazole to Baylis–Hillman acetates mediated by Et_3N was dramatically accelerated under solvent-free conditions to afford (*E*)-1,2,4-triazole-substituted alkenes **3** with excellent yields.

Keywords: Acceleration, Baylis–Hillman acetates, solvent-free conditions, (*E*)-1,2,4-triazole-substituted alkenes

Since the first report of the Baylis–Hillman reaction in 1972,[1] it has been widely used as a powerful carbon–carbon bond-forming method in organic synthesis.[2] During the past decade, Baylis–Hillman adducts were proven to be useful precursors for the synthesis of a variety of useful compounds with biological activities.[3,4]

The synthesis of triazole derivatives has recently gained prominence[5] because of their interesting biological properties[6] such as antiallergic, antibacterial, antifungal, analgesic, anti-inflammatory, antitubercular, anti-HIV, and cytokinin activities. There are several reports on the synthesis of triazole derivatives from Baylis–Hillman adducts: (1) Gong et al. reported the reaction of Baylis–Hillman acetate and 1,2,4-triazole in the presence of 1,4-diazebicyclo[2.2.2]octane

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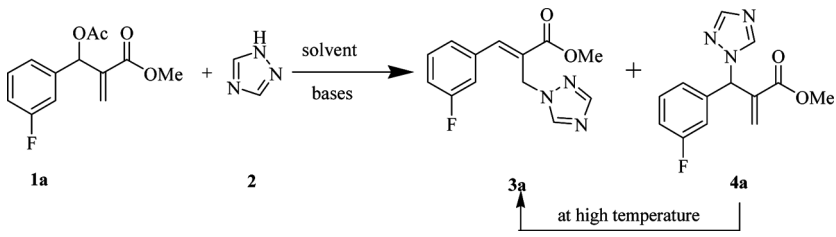
Address correspondence to Weike Su, College of Pharmaceutical Sciences, Zhejiang University of Technology, Zhejiang Key Laboratory of Pharmaceutical Engineering, Hangzhou 310014, China. E-mail: suweike@zjut.edu.cn

(DABCO) at room temperature for 5 days, and a mixture of products was obtained with moderate yield,[4d] (2) Chandrasekhar et al. developed a novel access to substituted triazoles through three-component coupling of alkynes, Baylis–Hillman adducts, and sodium azide.[7] (3) Sreedhar et al. claimed 1,4-disubsituted 1,2,3-triazoles can be prepared via nucleophilic substitution and 1,3-dipolar cycloaddition.[8] Here we describe an efficient synthesis of (*E*)-1,2,4-triazole-substituted alkenes via the addition of 1,2,4-triazole to Baylis–Hillman acetates mediated by different bases under solvent or solvent-free conditions.

Primary experiments were performed under solvent conditions using Baylis–Hillman acetate adduct **1a** as a model compound (Scheme 1). When this reaction was carried out in ethanol in the presence of K_2CO_3, only (*E*)-1,2,4-triazole-substituted alkene **3a** was isolated, whereas its isomer **4a** was not detected either at room temperature or under reflux. The structure of product **3a** was characterized by ^{1}H NMR, ^{13}C NMR, and mass spectra.[4d]

To obtain the optimized condition, the kinds of bases and solvents were screened, and the results were summarized in Table 1. It was found that ethanol is an efficient solvent for this addition, whereas water is a poor medium even under refluxing conditions. Both Et_3N and K_2CO_3 can selectively provide (*E*)-1,2,4-triazole-substituted alkenes **3a**, but Et_3N can provide a higher yield than that of K_2CO_3 (entries 1, 6). Without any bases, the addition was very slow because of the formation of side product AcOH, and only a trace product was detected by thin-layer chromatography (TLC) (entry 10), so we chose Et_3N to promote this addition reaction.

On the other hand, we also investigated the nucleophilic substitution promoted by DABCO. It was found that a mixture of **3a** and **4a** could be obtained, and their ratios were largely influenced by reaction temperature and time. In the presence of DABCO, compound **4a** is the main product at room temperature within a short time (entry 11), whereas **3a** was a major product when elevating the reaction temperature or prolonging



Scheme 1.

Table 1. The influence of the reaction condition on the product yields[a]

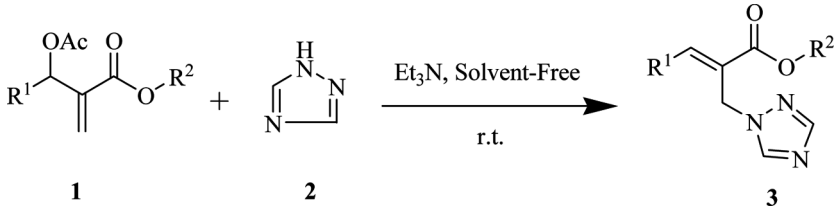
Entry	Bases	Solvents	T (°C)	Time	Product (yield, %)[b]
1	K_2CO_3	EtOH	rt	3 h	**3a** (28)
2	K_2CO_3	EtOH	80	3 h	**3a** (72)
3	K_2CO_3	MeOH	60	5 h	**3a** (60)
4	K_2CO_3	THF/H_2O(2/1)	60	5 h	**3a** (61)
5	K_2CO_3	H_2O	100	3 h	**3a** (—)[c]
6	K_2CO_3	H_2O	rt	4 days	**3a** (26)[d]
7	Et_3N	EtOH	80	3 h	**3a** (75)
8	Et_3N	MeOH	60	5 h	**3a** (63)
9	Et_3N	THF-H_2O(2/1)	60	5 h	**3a** (65)
10	—	EtOH	80	3 h	**3a** (trace)
11	DABCO	EtOH	rt	5	**3a**/**4a** = 1/5 (24)[e]
12	DABCO	EtOH	rt	48	**3a**/**4a** = 3/2 (60)[e]
13	DABCO	EtOH	80	5	**3a**/**4a** = 9/1 (70)[e]

[a]2.0 mmol of Baylis–Hillman acetates, 2.2 mmol of triazole, and 1.1 mmol of K_2CO_3 or 2.2 mmol of Et_3N were used.
[b]Isolated yields based on Baylis–Hillman acetates.
[c]Complex mixture was obtained.
[d]The starting material was recovered.
[e]The ratio of **3a** and **4a** was determined from the ^1H NMR spectrum.

the reaction time (entries 12, 13). This result showed that **4a** is thermodynamically unstable and thus the isomerization from **4a** to **3a** would be favored on standing or under reflux.

Recently, considerable attention has been paid to solvent-free reactions, which are not only of interest from an environmental point of view, but in many cases also offer considerable synthetic advantages in terms of yield, selectivity, and simplicity of the reaction procedure. To the best of our knowledge, the S_N2' substitution of Baylis–Hillman acetates under solvent-free conditions has not been exploited. When 2 mmol of Baylis–Hillman acetate **1a**, 2.2 mmol of 1,2,4-triazole, and 2.2 mmol of Et_3N were stirred at room temperature for 15 min, TLC indicated that the Baylis–Hillman acetate **1a** was consumed, and the S_N2' product **3a** was isolated with 85% yield (Scheme 2). The possible explanation is that the high concentration favored this addition, and the addition rate can be dramatically accelerated under solvent-free conditions.

Encouraged by this excellent result, we started to explore the reaction scope with various Baylis–Hillman acetates **1b–n**. The results are summarized in Table 2.



Scheme 2.

According to Table 2, under solvent-free conditions, the Baylis–Hillman acetates derived from aromatic aldehydes could produce the corresponding products **3** with good to excellent yields, and no evident substitute effect on aromatic rings was observed. However, when R^1 is the alkyl group (*i*-butyl), the addition is complex, and only 42% of the corresponding product **3o** can be isolated. (entry 15).

In summary, we have disclosed a fast, efficient, and ecofriendly process for the synthesis of (*E*)-1,2,4-triazole-substituted alkenes **3** via Et_3N-mediated addition of 1,2,4-triazole to Baylis–Hillman acetates under solvent-free conditions. The advantages of this method are

Tabel 2. Synthesis of (*E*)-1,2,4-triazole-substituted alkenes **3** mediated by Et_3N under solvent-free conditions[a]

Entry	R^1	R^2	Time (min)	Product (yield, %)[b]
1	*p*-FC_6H_4	Me	15	**3a** (85)[c]
2	*m*-$NO_2C_6H_4$	Me	15	**3b** (82)
3	C_6H_5	Me	15	**3c** (75)
4	*o*-ClC_6H_4	Me	15	**3d** (78)
5	2-F-6-ClC_6H_3	Me	14	**3e** (85)
6	2-furyl	Me	15	**3f** (78)
7	4-methylthiazol-5-yl	Me	15	**3g** (87)
8	C_6H_5	Et	15	**3h** (86)
9	*m*-$NO_2C_6H_4$	Et	12	**3i** (85)
10	*p*-FC_6H_4	Et	15	**3j** (85)
11	*o*-ClC_6H_4	Et	15	**3k** (82)
12	2-F-6-ClC_6H_3	Et	15	**3l** (83)
13	2-furyl	Et	15	**3m** (89)
14	4-methylthiazol-5-yl	Et	15	**3n** (90)
15	*i*-Bu	Me	60	**3o** (42)

[a]2.0 mmol of Baylis–Hillman acetates, 2.2 mmol of triazole, and 2.2 mmol of Et_3N were used.

[b]Isolated yields based on Baylis–Hillman acetates.

[c]The addition was very slow in the absence of Et_3N.

simple operation, short reaction time, good to excellent yields, and high regioselectivity. The further studies on the application of Baylis–Hillman adduct acetates are now in progress in our laboratory.

EXPERIMENTAL

Melting points were recorded on a digital melting-point apparatus WRS-1B and are uncorrected. Infrared spectra were recorded on Nicolet Aviatar-370 infrared spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were measured on a Varian Mercury plus-400 instrument using $CDCl_3$ as the solvent with tetramethylsilane (TMS) as an internal standard. Mass spectra were obtained on a Thermo Finnigan LQC-advantage (ESI) and Finnigan Truce DSQ (EI). Elemental analyses were carried out on a Vario EL III instrument. High-resolution mass spectral (HRMS) analyses were measured on an Apex (Bruker) mass III spectrometer using ESI (electrospray ionization) techniques. Baylis–Hillman adducts was prepared from arylaldehyde derivatives with methyl acrylate or ethyl acrylate. All reagents are commercially available and were used without further purification.

Typical Procedure for the Synthesis of 3a Under Solvent Conditions

Method A

1,2,4-Triazole (2.2 mmol) was added to a mixture of Baylis–Hillman acetates **1a** (2.0 mmol) and triethylamine (2.2 mmol) or K_2CO_3 (1.1 mmol) in ethanol (10 mL). The reaction mixture was refluxed for the given time (Table 1). After completion of the reaction (monitored by TLC), the solvent was evaporated in vacco, and the crude product was purified by column chromatography over silica gel (ethyl acetate–petroleum ether 3:2) to afford the corresponding 1,2,4-triazole derivatives **3a**.

Method B

DABCO (2.2 mmol) was added to a solution of Baylis–Hillman acetates **1a** (2.0 mmol) in ethanol (10 mL), and the mixture was stirred for 10 min at room temperature. Then 1,2,4-triazole (2.2 mmol) was added, and the mixture was stirred at room temperature for the given time (Table 1). After completion of the reaction (monitored by TLC), the solvent was evaporated in vacco, and the crude product was purified by column chromatography over silica gel (ethyl acetate–petroleum ether 3:2) to afford a mixture of **3a** and **4a**.

General Procedure for the Synthesis of Product 3 Under Solvent-Free Conditions

1,2,4-Trizole (2.2 mmol) was added to a mixture of Baylis–Hillman acetates **1** (2.0 mmol) and Et_3N (2.2 mmol), and the mixture was stirred at room temperature for the given time (Table 2). After the completion of the reaction (monitored by TLC), CH_2Cl_2 (20 mL) was added, and the mixture was washed with brine and dried over sodium sulfate. After concentrated in vacco, the residue was purified by silica-gel column chromatography to afford the product **3**.

Data

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(4-fluorophenyl) acrylate (**3a**)

Colorless crystal, mp: 71.1–72.3 °C; IR (KBr) ν_{max}: 3125, 2949, 1710 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.27 (s, 1H), 8.01 (s, 1H), 7.97 (s, 1H), 7.78 (dd, 2H, $J_1 = 8.8$ Hz, $J_2 = 6$ Hz), 7.16 (dd, 2H, $J_1 = J_2 = 8.8$ Hz), 5.17 (s, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.6, 163.3 (d, $^1J_{C,F} = 250.2$ Hz), 151.5, 144.1, 144.0, 131.6, 131.5, 129.8, 124.8, 115.8, 115.7, 52.2, 45.8; MS m/z (%): 261 (M^+, 45), 202 (100), 133 (80). Anal. calcd. for $C_{13}H_{12}FN_3O_2$: C, 59.77; H, 4.63; N, 16.08. Found: C, 59.79; H, 4.51; N, 16.21.

Methyl 2-((4-Fluorophenyl)(1*H*-1,2,4-triazol-1-yl)methyl)acrylate (**4a**)

Oil; IR (KBr) ν_{max}: 3120, 2949, 1720, 1654 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): 8.03 (s, 1H), 8.01 (s, 1H), 7.30–7.27 (m, 2H), 7.10 (d, 1H, $J = 8.4$ Hz), 7.08 (d, 1H, $J = 8.4$ Hz), 6.62 (s, 1H), 6.59 (s, 1H), 5.43 (s, 1H), 3.74 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.3, 162.4 (d, $^1J_{C,F} = 238.4$ Hz), 151.7, 144.7, 138.1, 131.4, 129.6, 129.5, 128.8, 115.7, 115.5, 62.1, 51.9; MS m/z (%): 261 (M^+, 28), 229 (100), 201 (47), 133 (85). HRMS (ESI) calcd. for $C_{13}H_{12}FN_3O_2$ $(M + H)^+$, 262.0994; found: $(M + H)^+$, 262.0999.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(3-nitrophenyl) acrylate (**3b**)

Light yellow crystal, mp 141.7–142.0 °C. IR (KBr) ν_{max}: 3137, 2949, 1707 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.64 (s, 1H), 8.27 (m, 3H),

8.06 (s, 1H), 7.99 (s, 1H), 7.69 (m, 1H), 5.17 (s, 2H), 4.29 (q, 2H, $J = 7.2$ Hz), 1.34 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.5, 151.8, 148.4, 144.4, 141.9, 135.4, 135.1, 129.9, 128.1, 124.3, 124.1, 61.8, 45.5, 14.0; MS m/z (%): 288 (M^+, 15), 229 (100), 161 (20), 115 (28). Anal. calcd. for $C_{13}H_{12}N_4O_4$: C, 54.17; H, 4.20; N, 19.44. Found: C, 54.05; H, 4.27; N, 19.36.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-phenylacrylate (**3c**)

Yellow oil.[4d] IR (neat) ν_{max}: 3117, 2952, 1712 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.26 (s, 1H), 8.07 (s, 1H), 7.98 (s, 1H), 7.72 (s, 1H), 7.70 (s, 1H) 7.46 (m, 3H), 5.20 (s, 2H), 3.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.5, 151.4, 145.0, 143.8, 133.4, 129.5, 129.2, 128.5, 124.8, 52.1, 45.7; MS m/z (%): 244 ($M^+ + H$, 34), 175 (100), 143 (10), 115 (16). HRMS (ESI) calcd. for $C_{13}H_{13}N_3O_2$: $(M + H)^+$, 244.1088; found: $(M + H)^+$, 244.1083.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(2-chlorophenyl) acrylate (**3d**)

Colorless crystal, mp 99.8–100.9 °C; IR (KBr) ν_{max}: 3133, 2941, 1725; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.23 (s, 1H), 8.12 (s, 1H), 8.02 (m, 1H), 7.95 (s, 1H), 7.47 (m, 1H), 7.37 (m, 2H), 5.08 (s, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.1, 151.6, 144.1, 141.9, 134.0, 132.2, 130.6, 130.5, 129.5, 127.0, 126.9, 52.4, 45.9; MS m/z (%): 278 ($M^+ + H$, 14), 242 (100). Anal. calcd. for $C_{13}H_{12}ClN_3O_2$: C, 56.22; H, 4.36; N, 15.13. Found: C, 56.15; H, 4.47; N, 15.01.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(2-chloro-6-fluorophenyl) acrylate (**3e**)

Yellow oil. IR (neat) ν_{max}: 3142, 2958, 1723 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.11 (s, 1H), 7.83 (s, 1H), 7.68 (s, 1H), 7.63 (s, 1H), 6.90 (d, 1H, $J = 3.6$ Hz), 6.55 (m, 1H), 5.52 (s, 2H), 3.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.0, 158.5 (d, $^1J_{C,F} = 220.6$ Hz), 150.8, 144.4, 133.8, 133.3, 131.8, 131.2, 125.6, 120.9, 114.9, 52.4, 46.0; MS m/z (%): 296 ($M^+ + H$, 12), 298 (5), 260 (100). HRMS (ESI) calcd. for $C_{13}H_{11}ClFN_3O_2$: $(M + H)^+$, 295.0604; found: $(M + H)^+$, 295.0606.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(furan-2-yl)acrylate (**3f**)

Yellow oil. IR (neat) ν_{max}: 3131, 2938, 1697 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.18 (s, 1H), 7.91 (s, 1H), 7.68 (s, 1H), 7.64 (s, 1H), 6.91 (d, 1H, $J = 3.6$ Hz), 6.56 (m, 1H), 5.54 (s, 2H), 3.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 167.1, 151.3, 149.9, 146.2, 143.2, 130.3, 120.0, 119.3, 112.6, 52.45, 46.12; MS m/z (%): 234 ($M^+ + H$, 100), 165 (46). HRMS (ESI) calcd. for $C_{11}H_{11}N_3O_3$: $(M + H)^+$, 233.0880; found: $(M + H)^+$, 233.0878.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(4-methylthiazol-5-yl) acrylate (**3g**)

Colorless crystal, mp 137.0–138.3 °C; IR (KBr) ν_{max}: 3100, 2953, 1705 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.88 (s, 1H), 8.19 (s, 2H), 7.92 (s, 1H), 5.35 (s, 2H), 3.84 (s, 3H), 2.65 (s, 3H); ^{13}C NMR (100 MHz, MHz, $CDCl_3$) δ: 166.4, 158.8, 154.7, 151.8, 143.3, 133.9, 124.1, 122.2, 52.5, 45.7, 16.0; MS m/z (%): 264 (M^+, 14), 195 (72), 136 (100). Anal. calcd. for $C_{11}H_{12}N_4O_2S$: C, 49.99; H, 4.58; N, 21.20. Found: C, 49.86; H, 4.47; N, 21.42.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-phenylacrylate (**3h**)

Yellow oil. IR (neat) ν_{max}: 3117, 2978, 1704 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.25 (s, 1H), 8.06 (s, 1H), 7.97 (s, 1H), 7.70 (s, 1H), 7.71 (s, 1H), 7.43 (m, 3H), 5.19 (s, 2H), 4.26 (q, 2H, $J = 7.2$ Hz), 1.30 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.2, 151.5, 145.0, 143.9, 133.6, 129.6, 129.3, 128.7, 125.3, 61.2, 45.9, 13.9; MS m/z (%): 258.0 ($M^+ + H$, 45), 188.9 (100). HRMS (ESI) calcd. for $C_{14}H_{15}N_3O_2$: $(M + H)^+$, 258.1244; found: $(M + H)^+$, 258.1247.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(3-nitrophenyl)acrylate (**3i**)

Yellow crystal, mp 143.0–143.9 °C; IR (KBr) ν_{max}: 3121, 2978, 1702 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.64 (s, 1H), 8.27 (m, 3H), 8.06 (s, 1H), 7.99 (s, 1H), 7.68 (t, 1H, $J = 7.6$ Hz), 5.14 (s, 1H) 4.29 (q, 2H, $J = 7.2$ Hz), 1.34 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 164.8, 160.2, 157.7, 150.8, 143.2, 134.9, 134.4, 130.9, 125.5, 121.3, 114.4, 61.6, 46.8, 13.9; MS m/z (%): 302 (M^+, 15), 229 (100), 161 (50), 115 (20). Anal. calcd. for $C_{14}H_{14}N_4O_4$: C, 55.63; H, 4.67; N, 18.53. Found: C, 55.59; H, 4.61; N, 18.65.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(4-fluorophenyl) acrylate (**3j**)

Colorless crystal, mp 101.2–101.9 °C; IR (KBr) ν_{max}: 3137, 2974, 1693 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 8.27 (s, 1H), 8.01 (s, 1H), 7.97 (s, 1H), 7.78 (dd, 2H, $J_1 = 5.2$ Hz, $J_2 = 8.8$ Hz), 7.15 (dd, 2H, $J_1 = J_2 = 8.8$ Hz), 5.17 (s, 2H), 4.26 (q, 2H, $J = 7.2$ Hz), 1.32 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.2, 164.4 (d, $^1J_{C,F} = 250$ Hz), 151.7, 144.2, 143.9, 131.7, 131.6, 129.2, 125.2, 116.1, 115.9, 61.5, 45.9 and 14.0; MS m/z (%): 276.1 ($M^+ + H$, 100). Anal. calcd. for $C_{14}H_{14}FN_3O_2$: C, 61.08; H, 5.13; N, 15.26. Found: C, 60.99; H, 5.26; N, 15.21.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(2-chlorophenyl) acrylate (**3k**)

White solid, mp 81.3–83.0 °C; IR (KBr) ν_{max}: 3145, 2978, 1703 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.22 (s, 1H), 8.11 (s, 1H), 7.99 (m, 1H), 7.94 (s, 1H), 7.46 (m, 1H), 7.37 (m, 2H), 5.07 (s, 2H), 4.28 (d, 2H, $J = 7.2$ Hz), 1.31 (t, 3H, $J = 7.2$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.8, 151.8, 148.3, 141.9, 135.3, 134.3, 132.5, 130.7, 130.7, 129.7, 127.5, 61.6, 46.2, 14.1; MS m/z (%): 292.2 ($M^+ + H$, 82), 294.2 (25). Anal. calcd. for $C_{14}H_{14}ClN_3O_2$: C, 57.64; H, 4.84; N, 14.40. Found: C, 57.68; H, 4.71; N, 14.52.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(2-chloro-6-fluorophenyl) acrylate (**3l**)

Yellow oil, IR (neat) ν_{max}: 3138, 2952, 1719 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.20 (s, 1H), 7.86 (s, 1H), 7.75 (s, 1H), 7.35 (m, 2H), 7.09 (m, 1H), 5.03 (s, 2H), 4.26 (q, 2H, $J = 7.2$ Hz), 1.27 (t, 3H, $J = 7.2$ Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 164.7, 159.9 (d, $^1J_{C,F} = 248.7$ Hz), 150.8, 143.21, 134.9, 134.5, 130.9, 130.8, 125.5, 121.2 (d, $^2J_{C,F} = 189$ Hz), 114.3 (d, $^2J_{C,F} = 227$ Hz), 61.6, 46.8, 13.9; MS m/z (%): 310 ($M^+ + H$, 100), 312 (31), 311 (17). HRMS (ESI) calcd. for $C_{14}H_{13}ClFN_3O_2$: $(M + H)^+$, 310.0760; found: $(M + H)^+$, 310.0764.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(furan-2-yl)acrylate (**3m**)

Colorless crystal, mp 99.1–100.4 °C. IR (KBr) ν_{max}: 3121, 2986, 1692 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.18 (s, 1H), 7.92 (s, 1H),

7.68 (s, 1H), 7.62 (s, 1H), 6.91 (d, 1H, $J = 3.6$ Hz), 6.56 (dd, 1H, $J_1 = 3.6$ Hz, $J_2 = 2$ Hz), 5.53 (s, 2H), 4.26 (q, 2H, $J = 7.2$ Hz), 1.30 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.5, 151.5, 149.8, 146.0, 143.2, 129.9, 120.4, 118.9, 112.5, 61.3, 45.9, 14.0; MS m/z (%): 248 ($M^+ + H$, 100), 179 (34). Anal. calcd. for $C_{12}H_{13}N_3O_3$: C, 58.29; H, 5.30; N, 16.99. Found: C, 58.41; H, 5.23; N, 17.10.

(*E*)-Ethyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-3-(4-methylthiazol-5-yl) acrylate (**3n**)

Yellow oil. IR (neat) ν_{max}: 3113, 2982, 1704 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.88 (s, 1H), 8.20 (m, 2H), 7.94 (s, 1H), 5.36 (s, 2H), 4.30 (q, 2H, $J = 7.2$ Hz), 2.65 (s, 3H), 1.33 (t, 3H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 165.6, 158.3, 154.5, 151.3, 143.1, 133.9, 122.3, 61.3, 45.4, 15.7, 13.7; MS m/z (%): 278 (M^+, 35), 136 (100). HRMS (ESI) calcd. for $C_{12}H_{14}N_4O_2S$: $(M + H)^+$, 279.0917; found: $(M + H)^+$, 279.0913.

(*E*)-Methyl 2-((1*H*-1,2,4-Triazol-1-yl)methyl)-5-methylhex-2-enoate (**3o**)

Colorless oil. IR (neat) ν_{max}: 3106, 2992, 1710 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.17 (s, 1H), 7.89 (s, 1H), 7.18 (t, 1H, $J = 7.5$ Hz), 5.06 (s, 2H), 3.76 (s, 3H), 2.38 (t, 2H, $J = 7.5$ Hz), 1.84 (m, 1H), 0.971 (d, 6H, $J = 7$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.5, 151.5, 149.2, 143.4, 126.3, 52.2, 44.8, 37.8, 28.2, 22.4, 22.4; MS m/z (%): 223 (M^+, 5), 167 (100). HRMS (ESI) calcd. for $C_{11}H_{17}N_3O_2$: $(M + H)^+$, 224.1401; found: $(M + H)^+$, 224.1404.

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