HETEROCYCLES, Vol. 85, No. 1, 2012, pp. 43 - 56. © 2012 The Japan Institute of Heterocyclic Chemistry
Received, 9th August, 2011, Accepted, 8th November, 2011, Published online, 14th November, 2011
DOI: 10.3987/COM-11-12333

UNEXPECTED TANDEM REACTION OF NEW TYPE MORITA-BAYLIS-HILLMAN ADDUCTS PROMOTED BY [HMIM]HSO_4/$NANO_3$ SYSTEM

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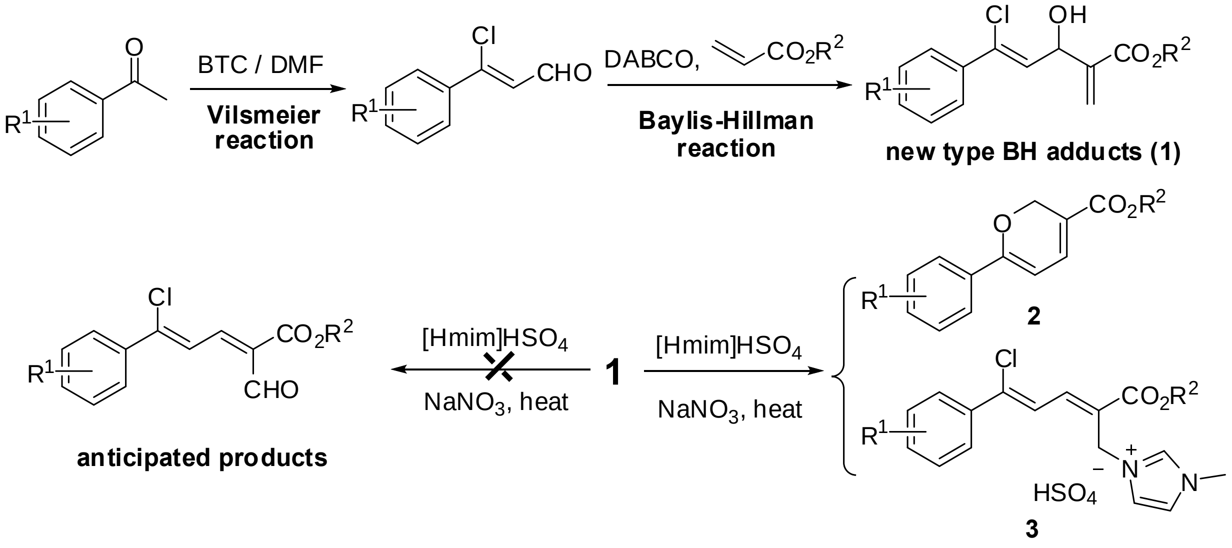
Abstract – A tandem reaction of new type Baylis-Hillman adducts **1** was prompted by ionic liquid [Hmim]HSO_4/$NaNO_3$ system and the unexpected products 6-aryl-2*H*-pyran-3-carboxylates **2** and imidazolium salts **3** were efficiently formed *via* the rearrangement and substitution reaction. While mediated by [Emim]HSO_4/$NaNO_3$ system, the key intermediates **4** were isolated. A plausible mechanism for the transformation was given.

INTRODUCTION

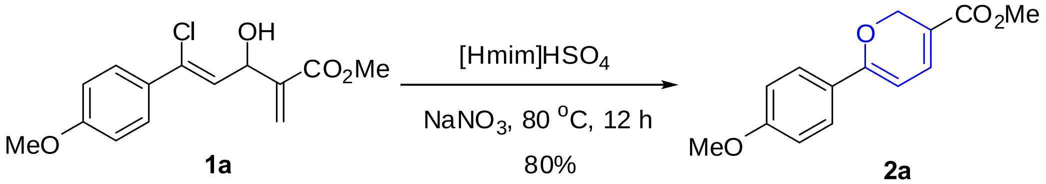
Tandem reactions are of great importance in organic synthesis due to generation of some important products in a single operation with high atom economy and bond-forming efficiency. Recently, more and more novel types of tandem reactions, including tandem Michael addition,[1] substitution,[2] cyclization[3-5] and rearrangement reaction,[6] were extensively applied to organic synthesis, especially the synthesis of natural optically active products[7] and heterocyclic compounds. The Baylis-Hillman reaction is a synthetically useful method for carbon-carbon bond-forming reactions to yield functionalized allylic alcohols,[8] thereby providing handles for further manipulation in a multitude of synthetic organic transformations.[9] In continuation of our research on new type Baylis-Hillman adducts **1** prepared from aryl methyl ketones *via* a combination of the Vilsmeier and the Baylis-Hillman reactions,[10-13] we investigated the tandem reaction of new type Baylis-Hillman adduct **1** under the [Hmim]HSO_4/$NaNO_3$ system[14] (Scheme 1). To our surprise, the unexpected products 6-aryl-2*H*-pyran-3-carboxylates **2** and/or imidazolium salt **3** were isolated.



Scheme 1

RESULTS AND DISCUSSION

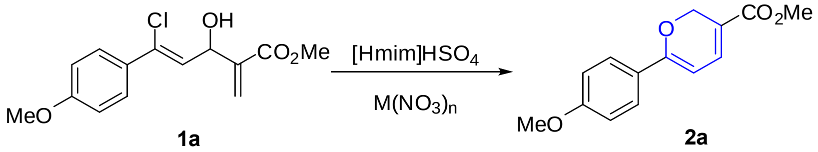
Initially, we mixed 1.0 mmol of (*Z*)-methyl 5-chloro-3-hydroxy-5-(4-methoxyphenyl)-2-methylenepent-4-enoate **1a** with 1.1 mmol of $NaNO_3$ in ionic liquid [Hmim]HSO_4 at 80 °C for 12 h, the unexpected product methyl 6-(4-methoxyphenyl)-2*H*-pyran-3-carboxylate **2a** was isolated in 80% yield(Scheme 2).



Scheme 2

Encouraged by this result, several other nitrate salts have been used to investigate the above reaction and the results were summarized in Table 1. No desired product **2a** was detected using NH_4NO_3-[Hmim]HSO_4 system at 80 °C for 12 h (Table 1, entry 2). $Zn(NO_3)_2$-[Hmim]HSO_4 system could produce **2a** with only 10% yield (Table 1, entry 3). Compared to the $NaNO_3$-[Hmim]HSO_4 system, a slightly lower yield was found using KNO_3-[Hmim]HSO_4 system (Table 1, entry 4). The highest yield (80%) of **2a** was obtained in $NaNO_3$-[Hmim]HSO_4 system at 80 °C for 12 h (Table 1, entry 1). Moreover, proper temperature was found to be essential to this reaction and the system showed homogeneous at 80 °C. At lower temperatures, **2a** was obtained in lower yield even with longer reaction time (Table 1, entries 5 and 6), while higher temperatures led to unknown side reactions and very complicated results (Table 1, entries 7 and 8).

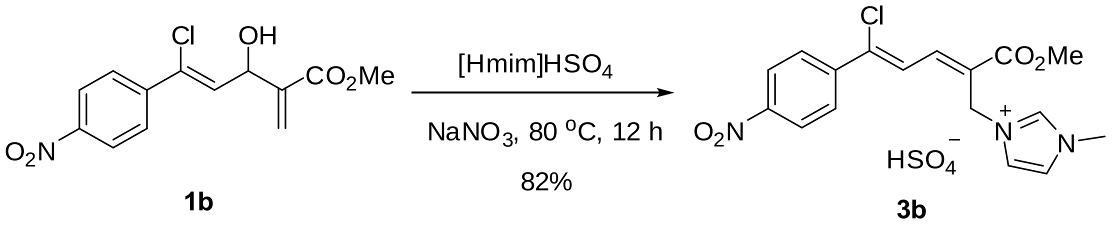
Table 1. Reaction of **1a** with M(NO$_3$)$_n$-[Hmim]HSO$_4$



Entry	M(NO$_3$)$_n$	Temp.(℃)	Time (h)	Yield[a] of **2a** (%)
1	NaNO$_3$	80	12	80
2	NH$_4$NO$_3$	80	12	0
3	Zn(NO$_3$)$_2$	80	12	10
4	KNO$_3$	80	12	78
5	NaNO$_3$	40	72	0
6	NaNO$_3$	60	48	34
7	NaNO$_3$	100	10	67
8	NaNO$_3$	120	10	46

[a] Isolated yield based on **1a**.

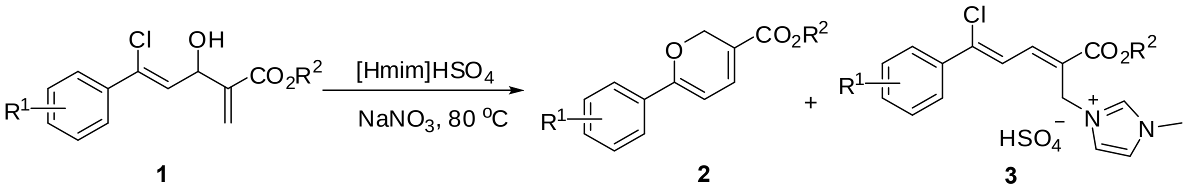
Another type BH adduct **1b** with a *para*-nitro group on the aromatic ring was also investigated under the similar conditions. To our surprise, when substrate **1b** was mixed with the NaNO$_3$-[Hmim]HSO$_4$ system at 80 °C for 12h, only imidazolium salt **3b** was isolated in 82%, which was confirmed by ^{1}H-NMR, ^{13}C-NMR and MS spectra (Scheme 3). This interesting result indicated that the different type of the substituted groups on the aromatic ring had evident influence on the products.



Scheme 3

In order to confirm our presumption, various new type Baylis-Hillman adducts **1** were used for the tandem rearrangement-substitution reaction under similar conditions and the full results are summarized in Table 2. It was found that the substrates **1** with electron-donoring groups on the aromatic ring gave the corresponding 2*H*-pyrans **2** in good yields (80-75%) (Table 2, entries 1, 3 and 4), while those with electron-withdrawing groups produced the corresponding imidazolium salts **3** in good yields (98-78%) (Table 2, entries 2, 6-9). Interestingly, the substrates **1e** could give both of the products with the ratio of **2e : 3e** = 1 : 2. In addition, when 2.2 equivalents of NaNO$_3$ was added to this reaction, the ratio of these two products was not obviously changed (Table 2, entry 5).

Table 2. Reaction of new type BH adducts **1** with $NaNO_3$-[Hmim]HSO_4

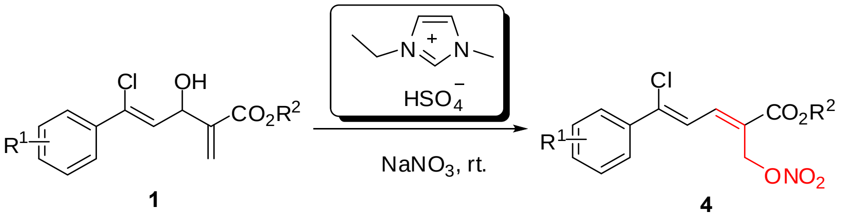


Entry	Substrates	R^1	R^2	Time (h)	Yield of products [a]	
					2	**3**
1	**1a**	*p*-MeO	Me	12	**2a** (80)	-
2	**1b**	*p*-NO_2	Me	12	-	**3b** (82)
3	**1c**	*p*-Me	Me	13	**2c** (78)	-
4	**1d**	*p*-MeO	Et	13	**2d** (75)	-
5[b]	**1e**	H	Me	12	**2e** (25)	**3e** (50)
6	**1f**	*m*-Cl	Me	11	-	**3f** (80)
7	**1g**	*p*-NO_2	Et	13	-	**3g** (78)
8	**1h**	*p*-F	Me	11	-	**3h** (98)
9	**1i**	*p*-F	Et	12	-	**3i** (83)

[a] Isolated yield based on **1**.
[b] The ratio of **2e** and **3e** was not obviously changed when 2.2 mmol of $NaNO_3$ was added.

In order to clarify the formation mechanism of these products, ionic liquid [Emim]HSO_4 was prepared,[15] which could avoid theoretical formation of imidazolium salts **3**. As we anticipated, the reactions of the Baylis-Hillman adducts **1** under the ionic liquid [Emim]HSO_4/$NaNO_3$ system gave S_N2' products (2*E*,4*Z*)-5-chloro-2-(nitrooxymethyl)-5-arylpenta-2,4-dienoates **4** with satisfactory yields (Table 3).

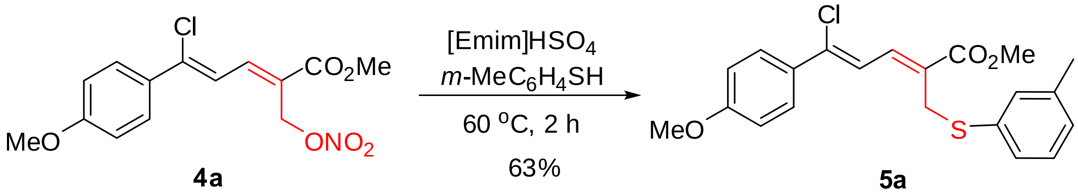
Table 3. Reactions of new type BH adducts **1** with $NaNO_3$-[Emim]HSO_4



Entry	Substrates	R^1	R^2	Time (h)	Yield of **4** [a] (%)
1	**1a**	*p*-MeO	Me	3	**4a** (65)
2	**1f**	*m*-Cl	Et	2	**4b** (76)
3	**1h**	*p*-F	Me	2	**4c** (83)

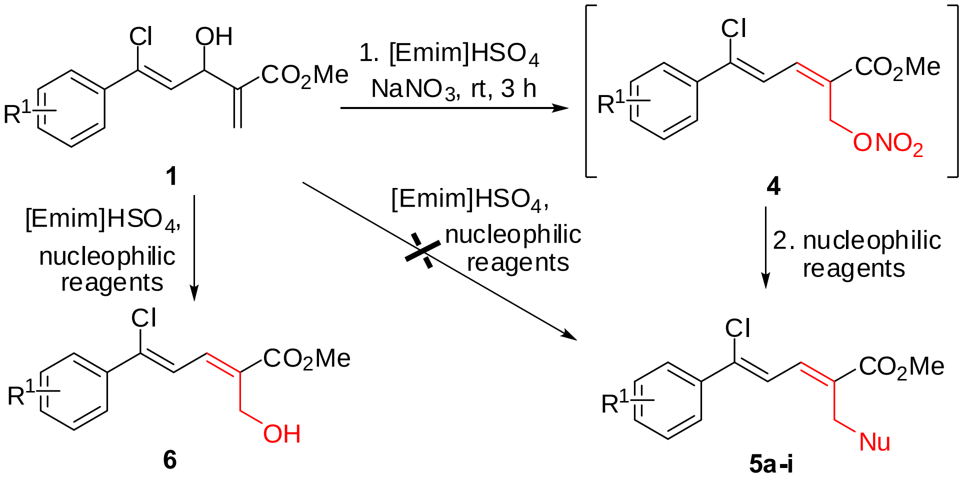
[a] Isolated yield based on **1**.

However, these intermediates **4a-c** were unstable at high temperature. Treatment of this intermediate **4a** with 3-methylbenzenethiol afforded the desired product (2*Z*,4*Z*)-methyl 5-chloro-5-(4-methoxyphenyl)-2-(*m*-tolylthiomethyl)penta-2,4-dienoate **5a** in 63% yield (Scheme 4).



Scheme 4

To confirm the regularity, we used various of nucleophilic reagents to react with the Baylis-Hillman adducts **1** under the ionic liquid [Emim]HSO_4/$NaNO_3$ system in one pot, and afforded the compounds **5a-i** in good yields (Scheme 5, Table 4). During our experiments, we found without addition of $NaNO_3$, not desired compounds **5**, but the rearrangemented compound **6** (R^1= *p*-Cl) was isolated and conformed by NMR and MS, which demonstrated the $NaNO_3$ play an important role in the reactions, and the intermediates **4** were existed in the reaction paths (Scheme 5). It was also found from Table 4 that the substrates **1** with electron-donoring groups on the aromatic ring gave the higher yields than those with electron-withdrawing groups. In other words, the more stable the intermediates **4** with electron-donoring groups are, the more possible to form the 2*H*-pyrans **2** in [Hmim]HSO_4/$NaNO_3$ system.



nucleophilic reagents: m-MeC_6H_4SH, p-MeC_6H_4SH, p-ClC_6H_4SH, p-$MeC_6H_4NH_2$, NaN_3
Nu: m-MeC_6H_4S-, p-MeC_6H_4S-, p-ClC_6H_4S-, p-MeC_6H_4NH-, N_3-

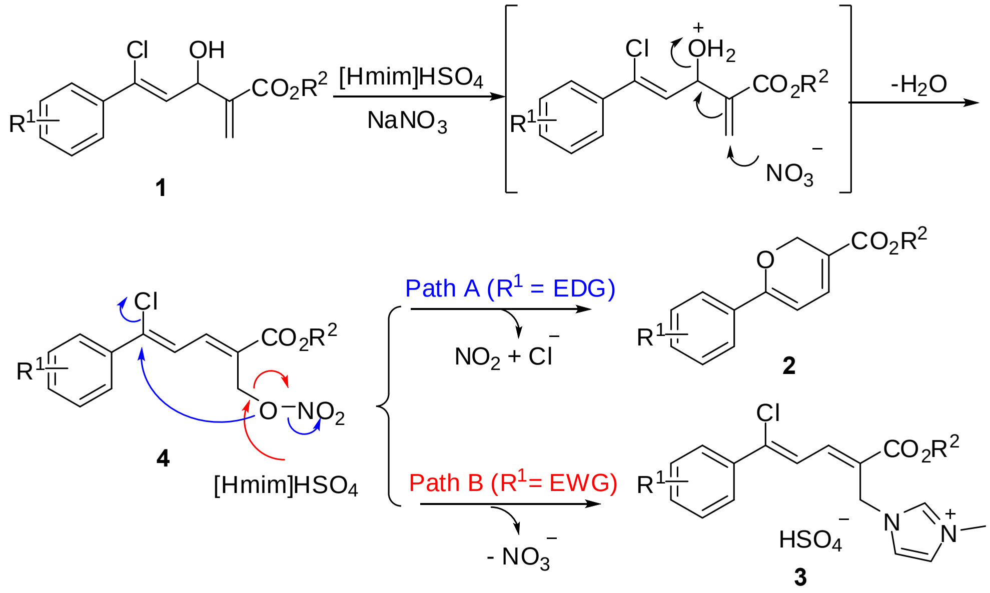
Scheme 5

Table 4. Reactions of new type BH adducts **1** with $NaNO_3$-[Emim]HSO_4 and nucleophilic reagents

Entry	Substrates	R^1	Nu	Yield of **5**^{a} (%)
1	**1a**	*p*-MeO	*m*-MeC_6H_4S	**5a** (63)[b]
2	**1a**	*p*-MeO	*p*-MeC_6H_4S	**5b** (83)
3	**1a**	*p*-MeO	*p*-ClC_6H_4S	**5c** (81)
4	**1a**	*p*-MeO	*p*-MeC_6H_4NH	**5d** (78)
5[c]	**1a**	*p*-MeO	N_3	**5e** (76)
6	**1h**	*p*-F	*p*-MeC_6H_4S	**5f** (74)
7	**1h**	*p*-F	*p*-ClC_6H_4S	**5g** (76)
8	**1h**	*p*-F	*p*-MeC_6H_4NH	**5h** (67)
9[c]	**1h**	*p*-F	N_3	**5i** (70)

[a] Isolated yield based on **1**.
[b] This reaction was carried out in two step and intermediate **4a** was isolated.
[c] NaN_3 was added dissolved in DMF.

According to the above results, a plausible mechanism[16] for the formation of products **2**, **3** and **4** was shown in Scheme 6. Firstly, the BH adduct **1** was attacked by nitrate anion in ionic liquid to give S_N2’ products **4**, where [Hmim]HSO_4 played a dual role of Brønsted acid catalyst and solvent for both rearrangement and substitution.[12] Intermediates **4** are unstable at high temperature and could be readily converted into **2** and **3** *via* path A or path B dependent on the activities of substrates.



Scheme 6

In summary, the present study investigated the tandem reaction of new type Morita-Baylis-Hillman adducts in ionic liquids/$NaNO_3$ system, which provided a new and efficient way for the synthesis of 2*H*-pyrans and imidazolium salts. The new applications of ionic liquids/$NaNO_3$ system are now being investigated in our lab.

EXPERIMENTAL

Unless otherwise indicated, chemicals and solvents were purchased from commercial suppliers and without further purification. Flash column chromatography was performed using silica gel (200-400 mesh). IR spectra were recorded on a Nicolet Avatar-370 instrument. Mass spectra were measured with Termo Finnigan LCQ-Advantage. ^{1}H NMR and ^{13}C NMR spectra were recorded at VARAIN-400 or BRUKER AVANCE III-500 using $CDCl_3$ or DMSO as the solvent with tetramethylsilane (TMS) as an internal standard at room temperature. Chemical shifts were given in δ relative to TMS, the coupling constants *J* were given in Hertz. The low-resolution mass spectra were obtained with the Thermo Trace GC Ultra-DSQ II and Agilent 6120 (Quadrapole LC-MS) mass spectrometer. High resolution mass spectra (HRMS) analyze were measured on an Agilent 6210 TOF LC/MS using ESI or EI (electrospray ionization) techniques.

General procedure for the synthesis of 2*H*-pyrans 2 and/or imidazolium salts 3

A mixture of Baylis-Hillman adducts **1** (1 mmol) and $NaNO_3$ (1.1 mmol) was stirred in 2 mL of [Hmim]HSO_4 at 80 °C for 12 h. The reaction mixture was cooled to rt. After completion of the reaction (monitored by TLC), the product was extracted with EtOAc (3 × 10 mL). The combined extract was dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography (CH_2Cl_2-MeOH, 16 : 1) to afford the products **2** and **3**.

General procedure for the synthesis of (2*E*,4*Z*)-5-chloro-2-(nitrooxymethyl)-5-arylpenta-2,4-dienoates 4

A mixture of Baylis-Hillman adducts **1** (1 mmol) and $NaNO_3$ (1.1 mmol) was stirred in 2 mL of [Emim]HSO_4 at rt for 3 h. After completion of the reaction (monitored by TLC), the product was extracted with EtOAc (3 × 10 mL). The combined extract was dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography (hexane-EtOAc, 8 : 1) to afford the desired products **4**.

General procedure for the synthesis of compounds 5

A mixture of Baylis-Hillman adducts **1** (1 mmol) and $NaNO_3$ (1.1 mmol) was stirred in 2 mL of

[Emim]HSO_4 at rt for 3 h. The reaction mixture was heat to 60 °C and *o*-MeC_6H_4SH (1.1 mmol) was added. The mixture was further stirred at rt for 2-3 h. After completion of the reaction (monitored by TLC), the product was extracted with EtOAc (3 × 10 mL). The combined extract was dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography (hexane-EtOAc, 8 : 1) to afford the desired product **5**.

Methyl 6-(4-methoxyphenyl)-2*H*-pyran-3-carboxylate (2a)

White solid. Mp 166-169 °C. IR (KBr) (ν_{max}, cm^{-1}): 3188, 2936, 1670. ^1H NMR (400 MHz, DMSO-d_6) δ_H: 3.75 (3H, s, COOC*H*$_3$), 3.82 (3H, s, Ar-OC*H*$_3$), 4.66 (2H, s, O-C*H*$_2$-C=C), 7.04-7.79 (4H, m, Ar*H*), 7.61 (1H, d, *J* = 11.2 Hz, O-C=C*H*-C), 7.73 (1H, d, *J* = 11.2 Hz, C*H*=C-COOMe). ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 52.1, 55.5, 59.8, 92.2, 104.5, 114.3(2C), 119.1, 128.4, 128.7, 137.5, 139.8, 161.0, 166.6; MS (CI) 246.0 $[M]^+$. HRMS (CI) calcd for [$C_{14}H_{14}O_4$]: 246.0892; found: 246.0895.

Methyl 6-*p*-tolyl-2*H*-pyran-3-carboxylate (2c)

White solid. Mp 166-169 °C. IR (KBr) (ν_{max}, cm^{-1}): 3183, 2943, 1674. ^1H-NMR (400 MHz, DMSO-d_6) δ_H: 2.36 (3H, s, Ar-C*H*$_3$), 3.76 (3H, s, COOC*H*$_3$), 4.67 (2H, s, OC*H*$_2$C), 7.30 (1H, d, *J* = 8.0, O-C=C*H*), 7.64-7.71 (4H, m, Ar*H*), 7.74 (1H, d, *J* = 2.8, MeOOC-C=C*H*); ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 20.8, 52.1, 59.8, 120.2, 126.6(2C), 129.4(2C), 129.5, 133.2, 137.1, 139.9, 140.4, 166.6; MS (CI) 231.3 $[M+1]^+$. HRMS (CI) calcd for [$C_{14}H_{14}O_3$]: 230.0943; found: 230.0939.

Ethyl 6-(4-methoxyphenyl)-2*H*-pyran-3-carboxylate (2d)

White solid. Mp 166-169 °C. IR (KBr) (ν_{max}, cm^{-1}): 3176, 2945, 1665. ^1H NMR (400 MHz, DMSO-d_6) δ_H: 1.27 (3H, t, *J* = 7.2, CH$_2$C*H*$_3$), 3.82 (3H, s, Ar-OC*H*$_3$), 4.42 (2H, q, *J* = 7.2, C*H*$_2$CH$_3$), 4.66 (2H, s, OC*H*$_2$), 7.04 (2H, m, Ar*H*), 7.62 (1H, d, *J* = 11.2, C=CH-C*H*=C-O), 7.73 (1H, d, *J* = 11.2, C=C*H*-CH=C-O), 7.78-7.80 (2H, m, Ar*H*); ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 14.1, 55.4, 59.8, 60.6, 144.2(2C), 119.1, 128.3(2C), 128.9, 137.2, 139.5, 160.9, 166.1(2C); MS (CI) 261.3 $[M+1]^+$. HRMS (CI) calcd for [$C_{15}H_{16}O_4$]: 260.1049; found: 260.1045.

Methyl 6-phenyl-2*H*-pyran-3-carboxylate (2e)

White solid. Mp 163-165 °C. IR (KBr) (ν_{max}, cm^{-1}): 3163, 2959, 1660. ^1H NMR (400 MHz, DMSO-d_6) δ_H: 3.87 (3H, s, COOC*H*$_3$), 4.42 (2H, s, OC*H*$_2$C), 7.30 (1H, d, *J* = 11.2, O-C=C*H*), 7.24 (H, s, Ar*H*), 7.42 (2H, d, *J* = 3.6, Ar*H*), 7.73 (2H, d, *J* = 3.6, Ar*H*), 7.42 (2H, d, *J* = 11.2, MeOOC-C=C*H*); ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 52.1, 59.8, 121.0, 126.6(2C), 128.8(2C), 129.9, 130.3, 135.9, 136.9, 139.7, 166.5; MS (ESI) 217.1 $[M+1]^+$. HRMS (ESI) calcd for [$C_{13}H_{12}O_3$]: 216.0786; found: 216.0780.

1-((2*E*,4*Z*)-5-Chloro-2-(methoxycarbonyl)-5-(4-nitrophenyl)penta-2,4-dienyl)-3-methyl-1*H*-imidazol-3-iumhydrogensulfate (3b)

Yellow solid. Mp 260-262 °C. IR (KBr) (ν_{max}, cm^{-1}): 3442, 2945, 1694. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: δ (ppm) 3.77 (3H, s, N-CH_3), 3.86 (3H, s, COOCH_3), 5.43 (2H, s, N-CH_2), 7.36-7.40 (2H, m, Ar*H*), 7.77 (1H, d, *J* = 5.6 Hz, Cl-C=C*H*), 7.86 (1H, d, *J* = 11.2 Hz, Me-N-C*H*=C), 7.95 (1H, d, *J* = 11.2 Hz, N-C*H*=C), 8.06 (1H, d, *J* = 5.6 Hz, ClC=C-C*H*=C), 8.07-8.09 (2H, m, Ar*H*), 9.21 (1H, s, N=C*H*-C). ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 36.8, 52.1, 59.8, 121.0, 126.7(2C), 128.8(2C), 129.9, 130.3, 135.9, 136.9, 139.6, 141.8, 147.4, 148.0, 166.5; MS (ESI) 362.1 [M]$^+$. HRMS (ESI) calcd for [$C_{17}H_{17}ClN_3O_4^+$]: 362.0908; found: 362.0900.

3-((2*E*,4*Z*)-5-Chloro-2-(methoxycarbonyl)-5-phenylpenta-2,4-dienyl)-1-methyl-1*H*-imidazol-3-ium-hydrogensulfate (3e)

White solid. Mp 260-262 °C. IR (KBr) (ν_{max}, cm^{-1}): 3443, 2942, 1699. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: 3.76 (3H, s, N-CH_3), 3.86 (3H, s, COOCH_3), 4.67 (2H, s, N-CH_2), 7.29 (2H, d, *J* = 8.8 Hz, Ar*H*), 7.65 (2H, d, *J* = 3.2 Hz, Cl-C=C*H*, ClC=C-C*H*=C), 7.66 (2H, d, *J* = 6.4 Hz, Me-N-C*H*=C, N-C*H*=C), 7.70 (2H, d, *J* = 8.8 Hz, Ar*H*), 7.74 (H, d, *J* = 3.2 Hz, Ar*H*), 9.03 (1H, s, N=C*H*-C). ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 35.8, 44.8, 61.2, 118.7, 122.7, 123.5, 125.7, 127.3(2C), 129.3(2C), 133.0, 136.7, 139.1, 141.0, 143.1, 165.4; MS (ESI) 317.1 [M]$^+$. HRMS (ESI) calcd for [$C_{17}H_{18}ClN_2O_2^+$]: 317.1057; found: 317.1062.

3-((2*E*,4*Z*)-5-Chloro-5-(3-chlorophenyl)-2-(methoxycarbonyl)penta-2,4-dienyl)-1-methyl-1*H*-imidazol-3-ium hydrogensulfate (3f)

White solid. Mp 265-268 °C. IR (KBr) (ν_{max}, cm^{-1}): 3456, 2938, 1676. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: 3.77 (3H, s, N-CH_3), 3.87 (3H, s, COOCH_3), 5.44 (2H, s, N-CH_2), 7.54-7.58 (2H, m, ArH), 7.59-7.61 (2H, m, Ar*H*), 7.73 (1H, d, *J* = 13.6 Hz, Me-N-C*H*=C), 7.75 (1H, d, *J* = 8.8 Hz, Cl-C=C*H*), 7.94 (1H, d, *J* = 13.6 Hz, N-C*H*=C), 7.95 (1H, d, *J* = 8.8 Hz, ClC=C-C*H*=C), 9.20 (1H, s, N=C*H*-C). ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 35.9, 44.7, 52.6, 121.1, 122.7, 123.5, 126.2, 126.7, 126.9, 130.5, 130.7, 133.7, 136.8, 137.7, 138.6, 140.8, 165.8; MS (ESI) 351.0 [M]$^+$. HRMS (ESI) calcd for [$C_{17}H_{17}Cl_2N_2O_2^+$]: 351.0667; found: 351.0653.

3-((2*E*,4*Z*)-5-Chloro-2-(ethoxycarbonyl)-5-(4-nitrophenyl)penta-2,4-dienyl)-1-methyl-1*H*-imidazol-3-ium hydrogensulfate (3g)

Yellow solid. Mp 272-273 °C. IR (KBr) (ν_{max}, cm^{-1}): 3469, 2934, 1689. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: 1.24 (3H, t, *J* = 7.2, COOCH$_2$CH_3), 3.86 (3H, s, N-CH_3), 4.22 (2H, q, *J* = 7.2, COOCH_2CH$_3$), 5.48 (2H, s, N-CH_2), 7.73-7.78 (2H, m, N-*H*C=C*H*-N), 7.95 (1H, d, *J* = 11,6, ClC=C-C*H*=C), 8.12 (1H, d, *J* = 11.2, ClC=*H*C-C=C), 8.29-8.34 (4H, m, Ar*H*), 9.24 (1H, s, N=C*H*-N); ^{13}C NMR (100 MHz, DMSO-d_6)

δ_C: 13.9, 35.8, 44.8, 61.5, 122.8, 123.5, 123.8(2C), 128.3, 128.7(2C), 136.9, 138.1, 139.9, 141.5, 148.2(2C), 165.1; MS (ESI) 376.1 $[M]^+$. HRMS (ESI) calcd for $[C_{18}H_{19}ClN_3O_4^+]$: 376.1064; found: 376.1067.

1-((2*E*,4*Z*)-5-Chloro-5-(4-fluorophenyl)-2-(methoxycarbonyl)penta-2,4-dienyl)-3-methyl-1*H*-imidazol-3-ium hydrogensulfate (3h)

White solid. Mp 257-258 °C. IR (KBr) (ν_{max}, cm^{-1}): 3455, 2940, 1705. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: 3.77 (3H, s, N-C*H*$_3$), 3.86 (3H, s, COOC*H*$_3$), 5.43 (2H, s, N-C*H*$_2$), 7.38 (2H, t, *J* = 8.8 Hz, Ar*H*), 7.23 (1H, d, *J* = 3.6 Hz, Cl-C=C*H*), 7.64 (1H, d, *J* = 3.6 Hz, ClC=C-C*H*=C), 7.86 (1H, d, *J* = 11.2 Hz, Me-N-C*H*=C), 7.95 (1H, d, *J* = 11.2 Hz, N-C*H*=C), 8.06-8.09 (2H, m, Ar*H*), 9.21 (1H, s, N=C*H*-C). ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 35.8, 44.8, 52.6, 115.8 (*J* = 22 Hz, 2C), 119.7, 122.6, 123.5, 126.1, 130.0 (*J* = 9 Hz, 2C), 132.3, 136.8, 139.0, 141.7, 162.2, 165.9; MS (ESI) 335.0 $[M]^+$. HRMS (ESI) calcd for $[C_{17}H_{17}ClFN_2O_2^+]$: 335.0963; found: 335.0962.

3-((2*E*,4*Z*)-5-Chloro-2-(ethoxycarbonyl)-5-(4-fluorophenyl)penta-2,4-dienyl)-1-methyl-1H-imidazol-3-ium hydrogensulfate (3i)

White solid. Mp 263-266 °C. IR (KBr) (ν_{max}, cm^{-1}): 3449, 2966, 1673. ^{1}H NMR (400 MHz, DMSO-d_6) δ_H: 1.24 (3H, t, *J* = 7.2, COOCH$_2$C*H*$_3$), 3.72 (3H, s, N-C*H*$_3$), 4.20 (2H, q, *J* = 7.2Hz, COOC*H*$_2$CH$_3$), 5.37 (2H, s, N-C*H*$_2$), 7.39 (2H, t, *J* = 8.8 Hz, Ar*H*), 7.68 (1H, t, *J* = 1.6Hz N-HC=C*H*-N), 7.72 (1H, t, *J* = 1.6 Hz, N-*H*C=CH-N), 7.77 (1H, d, *J* = 11.6, ClC=*H*C-C=C), 7.95 (1H, d, *J* = 11.6 Hz, ClC=C-C*H*=C), 8.02 (2H, m, J_1 = 5.6 Hz, J_2=9.2Hz, Ar*H*), 9.10 (1H, s, N=C*H*-N); ^{13}C NMR (100 MHz, DMSO-d_6) δ_C: 14.1, 36.0, 44.9, 61.5, 115.9 (*J* = 22 Hz, 2C), 119.7, 122.8, 123.6, 126.3, 130.0 (*J* = 9 Hz, 2C), 132.5, 136.8, 138.9, 141.8, 163.7 (*J* = 226 Hz), 165.5; MS (ESI) 349.1 $[M]^+$. HRMS (ESI) calcd for $[C_{18}H_{19}ClFN_2O_2^+]$: 349.1119; found: 349.1102.

(2*E*,4*Z*)-Methyl-5-chloro-5-(4-methoxyphenyl)-2-(nitrooxymethyl)penta-2,4-dienoate(4a)

Yellow solid. Mp 78-80 °C. IR (KBr) (ν_{max}, cm^{-1}): 3157, 2925, 1656. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.84 (3H, s, C*H*$_3$), 3.85 (3H, s, C*H*$_3$), 4.42 (2H, s, C*H*$_2$), 6.91-6.93 (2H, m, Ar*H*), 6.99 (1H, d, *J* = 11.6 Hz, CH=C*H*), 7.67-7.70 (2H, m, Ar*H*), 7.87 (1H, d, *J* = 11.6 Hz, C*H*=CH). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 25.3, 52.8, 55.8, 114.3(2C), 118.0, 128.6, 128.8(2C), 129.6, 137.9, 143.2, 161.5, 166.3. MS (EI): *m/z* (%) = 265(69, M-62), 223(71), 205(92), 179(100). HRMS (EI) calcd for $[C_{14}H_{14}ClNO_6]$: 327.0510; found: 327.0515.

(2*E*,4*Z*)-Ethyl-5-chloro-5-(3-chlorophenyl)-2-(nitrooxymethyl)penta-2,4-dienoate(4b)

White solid. Mp 80-83 °C. IR (KBr) (ν_{max}, cm^{-1}): 3139, 2921, 1671. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 1.37 (3H, t, *J* = 7.2 Hz, CH$_2$C*H*$_3$), 4.32 (2H, q, J_1 = 7.2 Hz, J_2 = 14.4 Hz, C*H*$_2$CH$_3$), 4.41 (2H, s, C*H*$_2$), 7.06 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.33-7.38 (2H, m, Ar*H*), 7.58-7.69 (2H, m, Ar*H*), 7.82 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 29.7, 37.4, 52.5, 119.8, 123.7, 128.3, 128.9, 129.7, 130.7, 135.3, 136.5, 137.4, 141.9, 166.2. MS (EI): *m/z* (%) = 329 (5, [M-16]$^+$), 283(32), 237(100). HRMS (EI) calcd for [$C_{14}H_{13}C_{l2}NO_5$]: 345.0171; found: 345.0175.

(2*E*,4*Z*)-Methyl-5-chloro-5-(4-fluorophenyl)-2-(nitrooxymethyl)penta-2,4-dienoate(4c)

White solid. Mp 85-87 °C. IR (KBr) (ν_{max}, cm^{-1}): 3148, 2959, 1668. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.86 (3H, s, C*H*$_3$), 4.40 (2H, s, C*H*$_2$), 7.01 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.13-7.08 (2H, m, Ar*H*), 7.82-7.70 (2H, m, Ar*H*), 7.84 (1H, d, *J* = 11.6 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 24.5, 52.5, 115.7 (*J* = 22 Hz, 2C), 119.4, 128.9 (*J* = 8 Hz, 2C), 129.6, 133.1, 136.9, 141.6, 163.6 (*J* = 250 Hz), 165.8. MS (EI): *m/z* (%) = 299 (12, [M-16]$^+$), 253(37), 221(100), 193(77), 157(32). HRMS (EI) calcd for [$C_{13}H_{11}ClFNO_5$]: 315.0310; found: 315.0308.

(2*Z*,4*Z*)-Methyl-5-chloro-5-(4-methoxyphenyl)-2-(*m*-tolylthiomethyl)penta-2,4-dienoate (5a)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3134, 2955, 1661. ^{1}H-NMR (CDCl$_3$, 400MHz): δ (ppm) 2.24 (3H, s, C*H*$_3$), 3.82 (3H, s, CO$_2$C*H*$_3$), 3.83 (3H, s, OC*H*$_3$), 3.91 (2H, s, SC*H*$_2$), 6.44 (1H, d, *J* = 12 Hz, C*H*=C*H*), 6.84 (2H, dd, J_1 = 2 Hz, J_2 = 4.4 Hz, Ar*H*), 6.95 (1H, d, *J* = 4.0 Hz, Ar*H*), 7.13-7.09 (1H, m, Ar*H*), 7.27-7.24 (2H, m, Ar*H*), 7.41-7.39 (2H, dd, J_1 = 2 Hz, J_2 = 3.2 Hz, Ar*H*), 7.73 (1H, d, *J* = 11.6 Hz, C*H*=C*H*). ^{13}C-NMR (CDCl$_3$, 100MHz): δ (ppm) 21.3, 32.8, 52.3, 55.5, 113.6(2C), 118.3, 128.2(2C), 128.4, 128.6, 129.5, 129.9, 130.8, 133.3, 134.9, 135.5, 138.6, 140.4, 160.7, 167.1; MS (EI): *m/z* (%) = 388 (5, M$^+$), 265(100), 233(80), 205(55), 179(52). HRMS (EI) calcd for [$C_{21}H_{21}ClO_3S$]: 388.0900; found: 388.0904.

(2*Z*,4*Z*)-Methyl 5-chloro-5-(4-methoxyphenyl)-2-(*p*-tolylthiomethyl)penta-2,4-dienoate (5b)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3135, 2942, 1689. ^{1}H-NMR (CDCl$_3$, 400 MHz) : δ (ppm) 2.24 (3H, s, C*H*$_3$), 3.67 (3H, s, C*H*$_3$), 3.82 (3H, s, C*H*$_3$), 3.91 (2H, s, C*H*$_2$), 6.40 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 6.58 (2H, d, *J* = 8.8 Hz, Ar*H*), 6.73-6.86 (4H, m, Ar*H*), 7.38 (2H, d, *J* = 8.8 Hz, Ar*H*), 7.73 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 21.2, 39.1, 52.2, 56.0, 114.8(2C), 126.6, 126.9, 128.8(2C), 129.3(2C), 130.1(2C), 131.8, 132.9, 136.7, 136.8, 136.9, 161.5, 163.4. MS (ESI) 389.9 [M+1]$^+$. HRMS (ESI) calcd for [$C_{21}H_{21}ClO_3S$]: 388.9076; found: 388.9082.

(2*Z*,4*Z*)-Methyl-5-chloro-2-((4-chlorophenylthio)methyl)-5-(4-methoxyphenyl)penta-2,4-dienoate (5c)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3157, 2925, 1656. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.87 (3H, s, C*H*$_3$), 3.90 (3H, s, C*H*$_3$), 3.95(2H, s, C*H*$_2$), 6.94 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.26-7.54 (8H, m, Ar*H*), 7.7 7(1H, d, *J* =11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 39.1, 52.1, 56.0, 114.8(2C), 126.5, 126.9, 128.9(2C), 129.3(2C), 131.6(2C), 131.8, 133.1, 134.3, 136.7, 136.9, 161.5, 163.4. MS (ESI) 410.2 [M+1]$^+$. HRMS (ESI) calcd for [$C_{20}H_{18}Cl_2O_3S$]: 409.3261; found: 409.3269.

(2*E*,4*Z*)-Methyl-5-chloro-5-(4-methoxyphenyl)-2-((*p*-tolylamino)methyl)penta-2,4-dienoate (5d)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3457, 3130, 2931, 1650. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 2.21 (3H, s, C*H*$_3$), 3.60 (3H, s, C*H*$_3$), 3.84 (3H, s, C*H*$_3$), 4.14 (2H, s, C*H*$_2$), 6.48 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 6.65 (2H, d, *J* = 8.8 Hz, Ar*H*), 6.73-6.80 (4H, m, Ar*H*), 7.28 (2H, d, *J* = 8.8 Hz, Ar*H*), 7.74 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 21.1, 41.8, 52.0, 56.0, 114.3(2C), 114.8(2C), 126.5, 126.7, 128.9(2C), 130.0(2C), 131.8, 135.1, 136.7, 140.7, 144.9, 161.5, 166.7. MS (ESI) 372.9 [M+1]$^+$. HRMS (ESI) calcd for [$C_{21}H_{22}ClNO_3$]: 371.8573; found: 371.8564.

(2*E*,4*Z*)-Methyl-2-(azidomethyl)-5-chloro-5-(4-methoxyphenyl)penta-2,4-dienoate (5e)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3154, 2922, 1956, 1658. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.81 (3H, s, C*H*$_3$), 3.83 (3H, s, C*H*$_3$), 4.23 (2H, s, C*H*$_2$), 6.91-6.93 (2H, m, Ar*H*), 7.01 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.77-7.80 (2H, m, Ar*H*), 7.88 (1H, d, *J* =11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 49.4, 52.0, 56.0, 114.8(2C), 126.5, 128.9(2C), 131.8, 135.8, 136.7, 138.1, 161.5, 167.2. MS (ESI) 308.7 [M+1]$^+$. HRMS (ESI) calcd for [$C_{14}H_{14}ClN_3O_3$]: 307.7323; found: 307.7326.

(2*Z*,4*Z*)-Methyl-5-chloro-5-(4-fluorophenyl)-2-(*p*-tolylthiomethyl)penta-2,4-dienoate (5f)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3149, 2933, 1641. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 2.47 (3H, s, C*H*$_3$), 3.82 (3H, s, C*H*$_3$), 3.91 (2H, s, C*H*$_2$), 7.01 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.35-7.37 (4H, m, Ar*H*), 7.49-7.83 (4H, m, Ar*H*), 7.84 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 21.3, 32.1, 52.3, 115.4(2C), 119.8, 128.0(2C), 129.2(2C), 131.6, 131.7(2C), 133.1 (*J* = 61 Hz), 137.5, 140.3, 146.4, 147.9 (*J* = 37 Hz), 162.1, 167.2. MS (ESI) 377.9 [M+1]$^+$. HRMS (ESI) calcd for [$C_{20}H_{18}ClFO_2S$]: 376.8721; found: 376.8719.

(2*Z*,4*Z*)-Methyl-5-chloro-2-((4-chlorophenylthio)methyl)-5-(4-fluorophenyl)penta-2,4-dienoate (5g)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3174, 2934, 1689. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.88 (3H, s, C*H*$_3$), 3.94 (2H, s, C*H*$_2$), 7.00 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.21-7.31 (4H, m, Ar*H*), 7.47-7.63 (4H, m, Ar*H*), 7.84 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 32.1, 52.3, 115.4(2C), 119.8, 128.0(2C), 129.0(2C), 130.7, 131.2(2C), 132.2 (*J* = 123 Hz), 134.5, 140.3, 146.3, 147.9 (*J* = 32 Hz), 162.1, 167.2. MS (ESI) 398.3 [M+1]$^+$. HRMS (ESI) calcd for [$C_{19}H_{15}Cl_2FO_2S$]: 397.2906; found: 397.2914.

(2*E*,4*Z*)-Methyl-5-chloro-5-(4-fluorophenyl)-2-[(*p*-tolylamino)methyl]penta-2,4-dienoate (5h)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3467, 3199, 2913, 1687. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 2.43 (3H, s, C*H*$_3$), 3.85 (3H, s, C*H*$_3$), 4.12 (2H, s, C*H*$_2$), 7.01 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.31-7.37 (4H, m, Ar*H*), 7.64-7.74 (4H, m, Ar*H*), 7.84 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 21.3, 48.5, 52.3, 113.4 (2C), 115.4 (2C), 119.8, 128.0 (2C), 129.6, 130.7 (*J* = 180 Hz, 2C), 134.4, 139.3, 144.6, 146.2, 147.9 (*J* = 30 Hz), 162.1, 167.1. MS (ESI) 360.8 [M+1]$^+$. HRMS (ESI) calcd for [$C_{20}H_{19}ClFNO_2$]: 359.8218; found: 359.8215.

(2*E*,4*Z*)-Methyl-2-(azidomethyl)-5-chloro-5-(4-fluorophenyl)penta-2,4-dienoate (5i)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3145, 2911, 1949, 1662. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.84 (3H, s, C*H*$_3$), 4.22 (2H, s, C*H*$_2$), 7.01 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.13-7.18 (2H, m, Ar*H*), 7.67-7.69 (2H, m, Ar*H*), 7.87 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 49.4, 52.0, 115.0 (2C), 126.5, 130.9 (*J* = 132 Hz, 2C), 134.0, 136.3 (*J* = 89 Hz), 138.1, 141.6, 162.9 (*J* = 101 Hz), 167.2. MS (ESI) 296.7 [M+1]$^+$. HRMS (EI) calcd for [$C_{13}H_{11}ClFN_3O_2$]: 295.6967; found: 295.6959.

(2*E*,4*Z*)-Methyl-5-chloro-5-(4-chlorophenyl)-2-(hydroxymethyl)penta-2,4-dienoate (6)

Yellow liquid. IR (KBr) (ν_{max}, cm^{-1}): 3644, 2953, 1648. ^{1}H-NMR (CDCl$_3$, 400 MHz): δ (ppm) 3.87 (3H, s, C*H*$_3$), 4.51 (2H, s, C*H*$_2$), 7.09 (1H, d, *J* = 11.2 Hz, C*H*=C*H*), 7.09-7.41 (2H, m, Ar*H*), 7.65-7.68 (2H, m, Ar*H*), 7.89 (1H, d, *J* = 11.2 Hz, C*H*=C*H*). ^{13}C-NMR (100 MHz, CDCl$_3$) δ (ppm) 37.4, 52.5, 119.8, 123.7, 128.3 (2C), 128.9 (2C), 129.7, 130.7, 135.4, 136.5, 166.2. MS (ESI) 288.4 [M+1]$^+$. HRMS (ESI) calcd for [$C_{13}H_{12}Cl_2O_3$]: 287.1386; found: 287.1380.

ACKNOWLEDGEMENTS

We thank the National Natural Science Foundation of China [21076194] for financial support.

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