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One-pot regioselective synthesis of functionalized and fused furans from Morita–Baylis–Hillman and Rauhut–Currier adducts of nitroalkenes†

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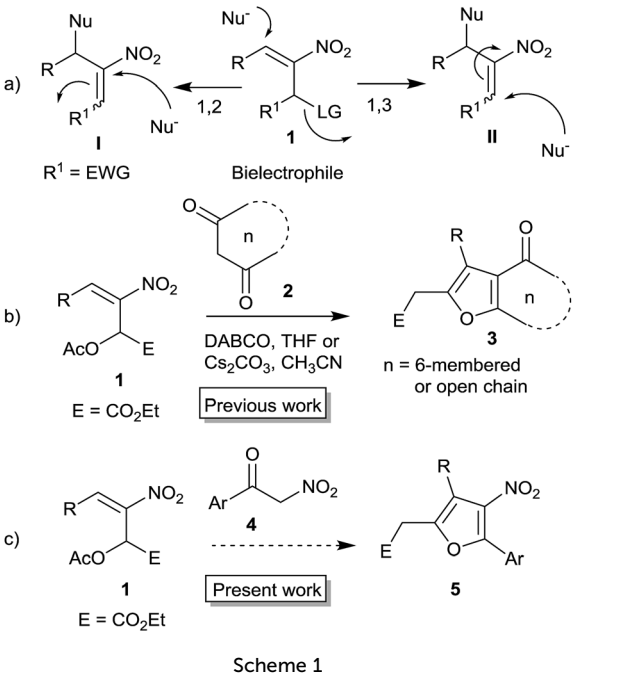
Highly functionalized and fused furans have been synthesized *via* cascade reactions of Morita–Baylis–Hillman and Rauhut–Currier adducts of nitroalkenes with active methylene compounds. The reactions involving S_N2'-intramolecular Michael addition or Michael addition-intra-molecular nucleophilic substitution take place in a regioselective manner to afford synthetically and biologically useful furans in moderate to good yields.

Introduction

Furans belong to a unique class of five membered aromatic oxygen heterocycles which constitute the core structure of numerous natural products, drugs and other bioactive molecules.[1] The diverse biological properties exhibited by furan containing compounds are well-documented in the literature.[2] The wide applicability of furans as valuable synthons in multistep reactions, including total synthesis, is well-recognized.[3] Among the several methods reported for the synthesis of furans,[4] Paal–Knorr synthesis (from 1,4-dicarbonyl compounds)[5] and Feist–Benary synthesis (typically from α-haloketones and β-dicarbonyl compounds)[6] are the prominent ones. Many highly efficient transition metal catalyzed cycloisomerization strategies have emerged in recent years.[7]

Despite the availability of numerous methods, development of novel and efficient diversity oriented approaches for the synthesis of functionalized and fused furans would be very valuable both from synthetic and biological perspectives. As part of the studies on the Morita–Baylis–Hillman (MBH)[8] and Rauhut–Currier (RC)[9] reactions of nitroalkenes and the applications of the products,[10–20] we and others have utilized the MBH acetates of nitroalkenes **1** (LG = OAc) for the synthesis of several carbocycles[11] and heterocycles.[12,13] The methodology involves a cascade S_N2' reaction of a binucleophile with MBH acetate **1** followed by an intramolecular Michael addition taking advantage of the 1,2 or 1,3-bi-electrophilic character of **1** as outlined in Scheme 1a. We and Chen *et al.* have reported the synthesis of furans *via* base mediated addition of 1,3-dicarbonyl compounds and arenols to the 1,2-bielectrophilic MBH acetates **1** (Scheme 1b).[13] Herein we report the role of α-nitroacetophenone **4** as the bi-nucleophile towards the MBH acetates **1** resulting in synthetically and biologically useful highly substituted nitrofurans **5** as single regioisomers (Scheme 1c). The vinylogous MBH (Rauhut–Currier, RC) reaction of nitroalkenes[14] and its applications for the synthesis of novel carbocyclic and heterocyclic scaffolds have also been of interest to us. We and others have employed RC adducts of nitroalkenes for the synthesis of functionalized pyrazoles,[15] decalins,[16] cycloalkanones,[17] spirocycles[18] and bridged heterobicyclics such as epibatidine.[19] The reactivity profile of a representative RC



Scheme 1

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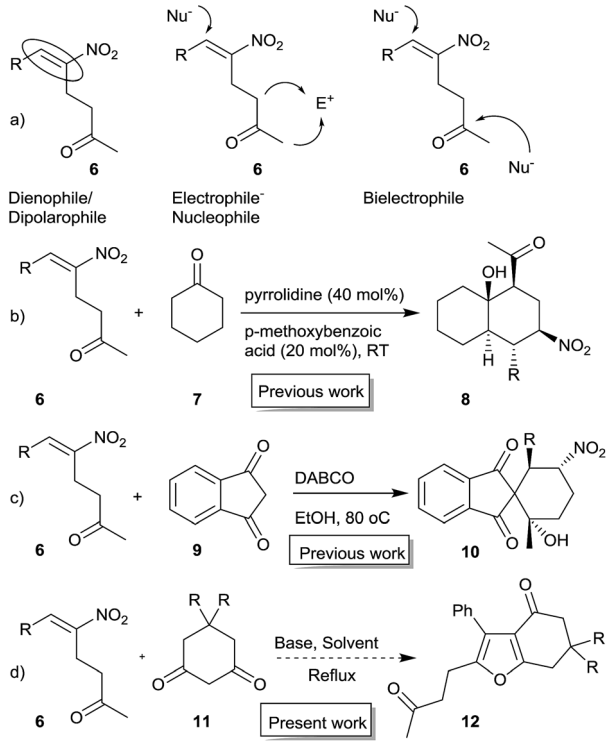
† Electronic supplementary information (ESI) available: Copies NMR spectra. See DOI: 10.1039/c5ra11471c



Scheme 2

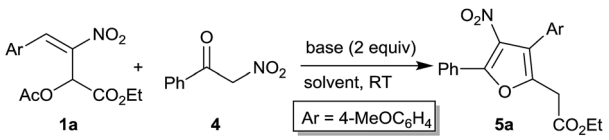
adduct **6**, derived from the imidazole/LiCl mediated RC reaction of nitroalkene with MVK, is outlined in Scheme 2a. Recently, we have reported a highly diastereoselective Michael initiated intramolecular aldol reaction involving compound **6** and cyclohexanone **7** for the synthesis of highly substituted *trans*-decalins **8** (Scheme 2b).[16] The compound **6** reacts as a 1,4-electrophile-nucleophile in this case. Chen *et al.* have reported the formation of spirocyclic compound **10** upon addition of indane-1,3-dione **9** to compound **6** in which compound **6** reacted as a 1,5-bielectrophile.[18] Surprisingly, when a 1,3-cyclohexanedione such as **11** (R = Me, dimedone) is added to compound **6**, a new reactivity profile emerges in which compound **6** reacts as a 1,2-bielectrophile without the participation of the ketoalkyl moiety to provide fused furans **12**, the results of which are also reported here.

Results and discussion

Initially, acetate **1a** and nitroketone **4** were selected as model substrates for our optimization studies for the synthesis of nitrofurans **5a** (Table 1). In the presence of 1 equiv. of DABCO, at room temperature, in dichloromethane as solvent, we isolated furan **5a** in low yield (17%, entry 1). The increase in the amount of base to 2 equiv. rendered the product **5a** in improved yield (36%) and in lower reaction time (18 h, entry 2). Further improvement in the yield to 45% and decrease in reaction time to 12 h were observed when the solvent was changed to THF (entry 3). The reaction in the presence of a non-polar solvent such as toluene also resulted in low product yield (24%, entry 4). Next, we screened Et_3N in THF which afforded the product only in low yield (22%, entry 5). However, the yield improved to 40% when the solvent was changed to dichloromethane (entry 6). In the same solvent (dichloromethane), various other organic amine bases such as diisopropylamine, Hünig's base, DMAP and DBU either provided lower yields or complex reaction mixtures (entries 7–10). The reaction in the presence of inorganic bases such as K_2CO_3 and Cs_2CO_3 also resulted in complex reaction mixtures (entries 11–13). Finally, the effect of temperature in the DABCO mediated reaction was investigated by carrying out the reaction in THF at elevated temperatures (45 °C and 65 °C, entries 14–15). Although the reaction rate improved, the yield remained unaffected at 45 °C (entries 3 and 14). At 65 °C, appreciable drop in the yield to 25% with considerable decomposition was observed (entry 15). Interestingly, the weakest base among the above, DABCO (pK_a 8.7), was best suited for nitroacetophenone **4** (pK_a 5.4), affording the product **5a** in highest yield suggesting that slow generation of the enolate was desirable in our reaction.

After screening different conditions, we identified DABCO as the best base and THF as the best solvent to afford the desired product **5a**. Thus, the above optimized conditions, *viz.* 2 equiv. of DABCO, in THF, at room temperature (Table 1, entry 3), were employed to explore the scope of the reaction between different MBH acetates **1a–i** and α-nitroacetophenone **4** (Table 2). Besides compound **1a** which provided the product **5a** in 45% yield (entry 1), MBH acetates bearing sterically and electronically diverse aryl groups **1b–i** have been treated with compound **4** under our optimized conditions to afford tetrasubstituted

Table 1 Optimization studies[a]



Entry	Base	Solvent	Time (h)	% yield[b]
1	DABCO[c]	DCM	26	17
2	DABCO	DCM	18	36
3	**DABCO**	**THF**	**12**	**45**
4	DABCO	$PhCH_3$	22	24
5	NEt_3	THF	20	22
6	NEt_3	DCM	22	40
7	iPr_2NH	DCM	18	16
8	iPr_2EtN	DCM	25	18
9	DMAP	DCM	24	—[d]
10	DBU	DCM	20	26
11	Cs_2CO_3	DCM	22	—[d]
12	Cs_2CO_3	THF	24	—[d]
13	K_2CO_3	DCM	28	—[d]
14[e]	DABCO	THF	9	44
15[f]	DABCO	THF	6	25

[a] The reactions were carried out with 0.3 mmol each of **1a** and **4** in 4 mL solvent. [b] After silica gel column chromatography. [c] 1 equivalent of DABCO was used. [d] Complex mixture. [e] Reaction temperature 45 °C. [f] Reaction temperature 65 °C.

furans **5b–i** (entries 2–9). These include MBH acetate bearing parent phenyl group **1b**, those bearing strongly electron donating substituents **1c,d** and weakly electron donating substituent **1e**, fused aromatic substituent **1f**, weakly and strongly electron withdrawing substituents **1g,h** and a hetero-aryl substituent **1i**. Although no appreciable substituent effect was discernible and the isolated yields of these nitrofurans **5** were consistently moderate (52–59%) in all the cases, the fact that such furans with well-defined substitution pattern could be easily synthesized from readily available compound **1** and compound **5a** made our approach very attractive.

The structure and regiochemistry of products **5a–i** were confirmed by detailed spectral analysis. A peak for ester group at 1736–1740 cm^{-1} and two peaks for the nitro group at 1504–1519 and 1350–1366 were characteristic in the IR spectra. The protons of CH_2 group attached to furyl appeared, in general, as singlets at δ 3.51–3.92 in ^1H NMR. However, these protons appeared as AB spin systems in **5f** and **5h** which was attributable to atropisomerism due to restricted rotation about the C–C bond connecting the furyl moiety and the aryl group at position 3. Surprisingly, such a pattern is not observed in the case of **5c**. The methylene carbon attached to furyl appeared at δ 32.8–34.0 in ^{13}C NMR. Finally, the regiochemistry was unambiguously established from a medium NOE interaction observed between the deshielded anisyl protons (*meta* to methoxy) and the methylene protons attached furyl in **5a** by ^1H–^1H NOESY experiment.

The proposed mechanism for the formation of highly substituted furans **5** is outlined in Scheme 3. DABCO mediated nucleophilic addition of α-nitroketone **4** to acetate **1** followed by elimination of acetate group in an overall S_N2' fashion generates intermediate **III**. A second enolization of the nitroketone moiety in **III**, facilitated by DABCO, followed by an intramolecular oxa-Michael addition in a 5-exo-trig fashion generates intermediate **IV** which further undergoes DABCO assisted elimination of HNO_2 to afford highly substituted furans **5**.

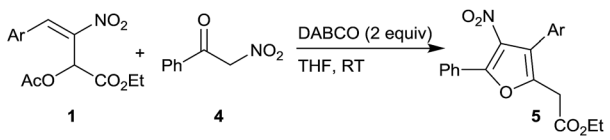
Having synthesized a variety of nitrofurans **5** in satisfactory yield from the MBH acetates of nitroalkenes **1**, we turned to RC adducts **6** as the key precursors for the synthesis of fused furans **12** as mentioned before (see Scheme 2) using six-membered cyclic 1,3-dicarbonyl compounds based on our own previous experience that 5-membered and 6-membered 1,3-dicarbonyls behaved differently in such reactions (see Scheme 1b).[20]

We have chosen compound **6a** and compound **11a** as the model substrates for our optimization studies (Table 3). When this reaction was performed in the presence of 1 equiv. of K_2CO_3 in CH_3CN under reflux conditions, fused furan **12a** was isolated in 23% yield within 9 h (entry 1). In order to improve the yield further, we screened various bases and solvents as summarized below.

The yields of furan **12a** remained low (15–22%) when the reaction was conducted in CH_3CN under reflux in the presence of 1 equiv. of different amine bases such as DABCO and Et_3N (entries 2–3). Attempted improvement in the yield using Brønsted acid additives in conjunction with amine bases such as *p*-anisic acid and TFA met with only limited success (entries 4–5). Changing the base to NaOAc and KOAc, the latter even with *p*-anisic acid as additive, did not improve the yield (28–33%, entries 6–8). At this juncture, a reaction was carried out in the presence of 2 equiv. of KOAc which led to the formation of furan **12a** in 42% yield (entry 9). This could be further improved to 68% by employing non-acidic workup conditions (entry 10). Other solvents such as THF and EtOH were less effective for our reaction (entries 11–12). Increasing the amount of base to 3 equiv. was detrimental as the yield dropped to 35% (entry 13).

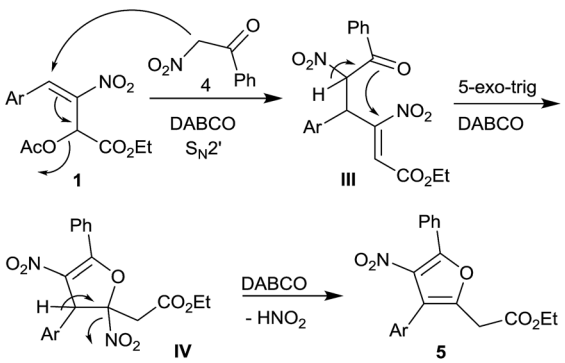
As in the previous scheme (Tables 1 and 2), the weakest base, KOAc (pK_a 4.7), appeared to give the best results in the addition of compound **11a** (pK_a 5.2) to compound **6a**. The complex reaction pattern in the presence of stronger bases, including DABCO, leading to lower yields of the desired product **12a** is attributable to side reactions involving the enolizable ketone side chain. Finally, the optimal conditions for the reaction, 2 equiv. of KOAc in CH_3CN under reflux, were employed to study the scope of the reaction as reported in Tables 4 and 5.

Table 2 Scope of MBH-acetates **1**[a]



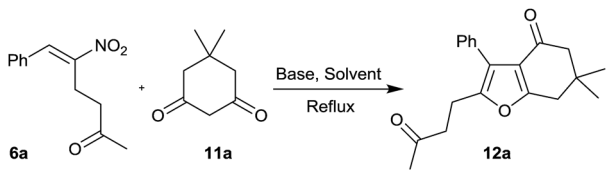
Entry	**1**, Ar	Time (h)	**5**	% yield[b]
1	**1a**, 4-$OMeC_6H_4$	12	**5a**	45
2	**1b**, C_6H_5	13	**5b**	53
3	**1c**, 2,4-$(OMe)_2C_6H_3$	7	**5c**	57
4	**1d**, 3,4-$(OCH_2O)C_6H_3$	8	**5d**	57
5	**1e**, 4-MeC_6H_4	8	**5e**	56
6	**1f**, 1-naphthyl	7	**5f**	59
7	**1g**, 4-ClC_6H_4	8	**5g**	54
8	**1h**, 2-$NO_2C_6H_4$	7	**5h**	58
9	**1i**, 2-furyl	9	**5i**	52

[a] The reactions were carried out with 0.3 mmol each of **1** and **4** in 4 mL THF. [b] After silica gel column chromatography. No side products were observed in these reactions.



Scheme 3 Plausible pathway for the formation of tetrasubstituted furans **5**.

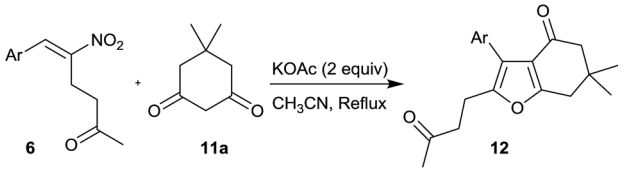
Table 3 Optimization studies[a]



Entry	Base (equiv.)	Solvent	Time (h)	% yield[b]
1	K_2CO_3 (1)	MeCN	9	23
2	DABCO (1)	MeCN	10	15
3	Et_3N (1)	MeCN	9	22
4	Et_3N (1)[c]	MeCN	9	45
5	DBU (1)[d]	MeCN	3.5	20
6	NaOAc (1)	MeCN	9	29
7	KOAc (1)	MeCN	7	33
8	KOAc (1)[c]	MeCN	3.5	28
9	KOAc (2)	MeCN	8	42[e]
10	KOAc (2)	MeCN	8	68[f]
11	KOAc (2)	THF	8	42
12	KOAc (2)	EtOH	8	51
13	KOAc (3)	MeCN	7	35

[a] The reactions were carried out with 0.92 mmol of **6a** and 0.92 mmol (1 equiv.) of **11a** in 3 mL of solvent under reflux. [b] After silica gel column chromatography. [c] +20 mol% *p*-anisic acid. [d] +10 mol% TFA. [e] With acid work up. [f] Without acid work up.

Table 4 Synthesis of furans **12** from RC adduct **6** and dimedone **11a**[a]

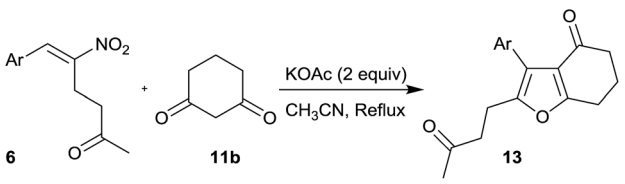


Entry	**6**, Ar	Time (h)	**12**	% yield[b]
1	**6a**, C_6H_5	9	**12a**	68
2	**6b**, 4-MeC_6H_4	11	**12b**	31
3	**6c**, 3-$OMeC_6H_4$	15	**12c**	37
4	**6d**, 4-$OMeC_6H_4$	6	**12d**	52
5	**6e**, 3,4-$(OMe)_2C_6H_3$	4	**12e**	37
6	**6f**, 3,4-$(OCH_2O)C_6H_3$	5	**12f**	34
7	**6g**, 4-ClC_6H_4	7	**12g**	55
8	**6h**, 4-BrC_6H_4	2	**12h**	35
9	**6i**, 2-thienyl	15	**12i**	29
10	**6j**, 1-naphthyl	17	**12j**	39

[a] The reactions were carried out with 0.92 mmol of **6**, 0.92 mmol of **11a** 1.80 mmol of KOAc in acetonitrile, reflux. [b] After silica-gel column chromatography. No side products were observed in these reactions.

The reaction of dimedone **11a** with different RC adducts **6a–j** was undertaken to obtain fused furans **12a–j** (Table 4). Besides the RC adduct bearing parent phenyl group **6a** which afforded the product **12a** in 68% yield (entry 1), the RC adducts with aryl groups possessing a strongly electron donating substituent and a weakly electron withdrawing substituent at the *para* position, **6d** and **6g**, respectively, delivered the corresponding products **13d** and **13g** in decent yields (52% and 55%, entries 4 and 7). The yields of fused furans from other RC adducts possessing various electron donating and withdrawing substituents on the aromatic ring *viz.* **6b,c**, **6e,f** and **6h**, remained low (31–37%, entries 2–3, 5–6 and 8). While low yield of the product **12i** was encountered in the case of heteroaryl compound **6i** (entry 9), the product yield was moderate (39%) in the case of a fused arylated compound **6j** (entry 10).

Table 5 Synthesis of furans **13** from RC adducts **6** and 1,3-cyclohexanedione **11b**[a]



Entry	**6**, Ar	Time (h)	**13**	% yield[b]
1	**6a**, C_6H_5	12	**13a**	33
2	**6b**, 4-MeC_6H_4	8	**13b**	46
3	**6c**, 3-$OMeC_6H_4$	22	**13c**	38
4	**6d**, 4-$OMeC_6H_4$	4	**13d**	46
5	**6e**, 3,4-$(OMe)_2C_6H_3$	4	**13e**	30
6	**6h**, 4-BrC_6H_4	5	**13f**	42
7	**6i**, 2-thienyl	7	**13g**	15
8	**6j**, 1-naphthyl	20	**13h**	44

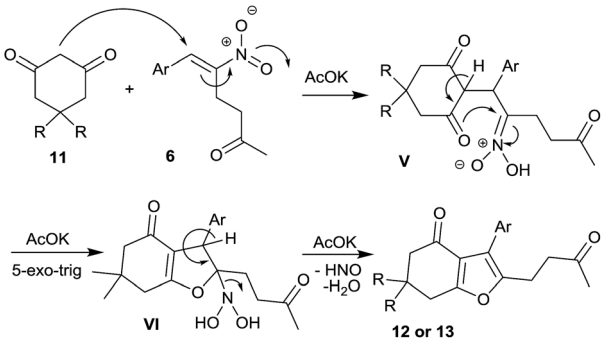
[a] The reaction were carried out with 0.92 mmol of **6**, 0.92 mmol of **11b** and 1.80 mmol of KOAc in acetonitrile, reflux. [b] After silica-gel column chromatography; no side products were observed in these reactions.

After the successful demonstration of the reactivity of different types of RC adducts **6** with dimedone **11a**, we focused our attention for the reaction of 1,3-cyclohexanedione **11b** with different types of RC adducts **6** and the results are summarized in Table 5.

In this reaction, when Ar was Ph, the product was formed in poor yield (33%, entry 1) and electron donating groups on the phenyl ring of RC adducts provided poor to moderate yield of the products (30–46%, entry 2–5). RC adducts bearing bromo and naphthyl substituents also provided moderate yields (42–44%, entries 6 and 8) and in the case of heteroaryl substituent, a substantial decrease in the yield to 15% was observed (entry 7).

It may be noted that the reaction of **6i** with **11a** and **11b** afforded the corresponding products **12i** and **13g** in lowest yields (29% and 15%, respectively, Table 4, entry 9 and Table 5 entry 7). This may be due to side reactions such as intermolecular Diels–Alder reaction between the thiophene moiety as the diene and the nitroalkene moiety as the dienophile under our experimental conditions.

As in the case of **5**, the structure and regiochemistry of products **12** and **13** were established by analysis of their spectral data. While the saturated carbonyl appears in IR at 1713–1717 cm^{-1}, the unsaturated carbonyl appears at 1672–1679 cm^{-1}.



Scheme 4 Plausible mechanism of furan formation.

The two isolated methylene protons in **12** appear, in general, as singlets at δ 2.34–2.36 and 2.71–2.74. The corresponding protons in **12j** appear as AB spin system presumably due to atropisomerism about the C–C bond connecting the furyl and the aryl group at position 3. The regiochemistry was amply evident from a medium NOE interaction between the phenyl protons and the deshielded methylene protons of the oxobutyl side chain in **12a**.

Scheme 4 outlines the plausible mechanism for the one-pot synthesis of furan by the present protocol. KOAc mediated Michael addition of 1,3-dicarbonyl compound **11** to compound **6** affords intermediate **V**. In the next step, an intramolecular oxa-Mannich type reaction takes place in a 5-exo-trig manner affording the intermediate **VI**, which on elimination affords the desired product **12** or **13**.[21]

Conclusions

Novel methods for the synthesis of highly substituted furans from the Morita–Baylis–Hillman and Rauhut–Currier adducts of nitroalkenes have been developed. These include a cascade S_N2'-intramolecular oxa-Michael addition and a cascade Michael-intramolecular oxa-Mannich reaction. Although the yields in these reactions are moderate, our approach is distinguished by the convenient access to highly functionalized and fused furans from readily available MBH and RC adducts of nitroalkenes.

Experimental section

General experimental details

The melting points recorded are uncorrected. NMR spectra (^{1}H, ^{1}H decoupled ^{13}C and ^{1}H–^{1}H NOESY) were recorded with TMS as the internal standard. The coupling constants (J values) are given in Hz. High resolution mass spectra were recorded under ESI Q-TOF conditions. MBH acetates **1**,[22] nitroacetophenone **4** [23] and RC adducts **6** (ref. 14) were prepared by literature methods.

General procedure for the preparation of tetrasubstituted furans 5 from MBH acetates 1 and α-nitroacetophenone 4

To a stirred solution of compound **1** (0.1 mmol) and compound **4** (33 mg, 0.2 mmol, 2 equiv.) in THF (3 mL) at room temperature was added DABCO (22 mg, 0.2 mmol, 2 equiv.) and the stirring was continued till the completion of the reaction (monitored by TLC, see Table 2). The reaction mixture was concentrated *in vacuo* and the crude residue was purified by silica gel column chromatography by eluting with 4–10% ethyl acetate/petroleum ether (gradient elution).

Ethyl-2-(3-(4-methoxyphenyl)-4-nitro-5-phenylfuran-2-yl)acetate (5a)

Yellow oily liquid; yield 17 mg, 45%; IR (KBr, cm^{-1}) 1739 (s), 1514 (*vs.*), 1360 (m); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81–7.84 (m, 2H), 7.46–7.50 (m, 3H), 7.28 (d, J = 8.8 Hz, 2H), 6.97 (d, J = 8.8 Hz, 2H), 4.20 (q, J = 7.1 Hz, 2H), 3.84 (s, 3H), 3.65 (s, 2H), 1.27 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 32.8, 55.4, 61.8, 114.2, 121.2, 121.3, 127.6, 128.3, 128.6, 130.6, 130.9, 131.4, 144.8, 151.4, 159.8, 168.6; MS (ES$^+$, Ar) m/z (rel intensity) 404 (MNa^+, 30), 399 ($[M + H_2O]^+$,49), 382 (MH^+, 100); HRMS (ES$^+$, Ar) calcd for $C_{21}H_{20}NO_6$ (MH^+) 382.1291, found 382.1301. Confirmed by ^{1}H–^{1}H NOESY experiment.

Ethyl-2-(4-nitro-3,5-diphenylfuran-2-yl)acetate (5b)

Yellow oily liquid; yield 19 mg, 53%; IR (KBr, cm^{-1}) 1740 (*vs.*), 1513 (m), 1358 (m); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81–7.84 (m, 2H), 7.46–7.50 (m, 3H), 7.41–7.45 (m, 3H), 7.34–7.37 (m, 3H), 4.20 (q, J = 7.1 Hz, 2H), 3.66 (s, 2H), 1.27 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 32.9, 61.8, 121.8, 127.6, 128.4, 128.7, 128.7, 128.8, 129.3, 129.7, 130.7, 134.6, 144.9, 151.6, 168.5; MS (ES$^+$) m/z (rel intensity) 413 ($[M + Na + K]^+$, 100), 390 (MK^+, 35), 374 (MNa^+, 91), 343 (15); HRMS (ESI) calcd for $C_{20}H_{17}NNaO_5$ (MNa^+) 374.0999, found 374.1002.

Ethyl-2-(3-(2,4-dimethoxyphenyl)-4-nitro-5-phenylfuran-2-yl) acetate (5c)

Yellow oily liquid; yield 23 mg, 57%; IR (KBr, cm^{-1}) 1738 (*vs.*), 1511 (s), 1366 (m); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83–7.80 (m, 2H), 7.48–7.45 (m, 3H), 7.24 (d, J = 8.3 Hz, 1H), 6.57 (dd, J = 8.3, 2.3 Hz, 1H), 6.52 (d, J = 2.3 Hz, 1H), 4.20 (q, J = 7.1 Hz, 2H), 3.85 (s, 3H), 3.72 (s, 3H), 3.65 (s, 2H), 1.29 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 33.0, 55.5, 55.6, 61.8, 99.1, 104.8, 111.0, 118.1, 127.8, 128.4, 128.6, 130.4, 131.1, 144.5, 150.9, 158.3, 161.6, 168.8; MS (ES$^+$) m/z (rel intensity) 450 (MK^+, 69), 434 (MNa^+, 78), 413 ($[M + 2]^+$, 100), 391 (10); HRMS (ES$^+$) calcd for $C_{22}H_{21}NNaO_7$ (MNa^+) 434.1210, found 434.1211.

Ethyl-2-(3-(benzo[*d*][1,3]dioxol-5-yl)-4-nitro-5-phenylfuran-2-yl)acetate (5d)

Light yellow oily liquid; yield 67 mg, 57%; IR (KBr, cm^{-1}) 1738 (*vs.*), 1504 (*vs.*), 1359 (s); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81–7.79 (m, 2H), 7.48–7.46 (m, 3H), 7.25 (s, 1H), 6.88–6.82 (m, 3H), 6.02 (s, 1H), 4.23–4.18 (q, J = 7.2 Hz, 2H), 3.65 (s, 2H), 1.28 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 32.8, 61.9, 101.5, 108.6, 110.2, 121.4, 122.6, 123.4, 127.6, 128.4, 128.7, 130.7, 145.0, 148.0, 148.1, 151.4, 168.5; MS (ES$^+$) m/z (rel intensity) 434 (MK^+, 60), 418 (MNa^+, 100), 393 ($[M - 2]^+$, 51), 355 (11), 331 (10), 307 (9); HRMS (ES$^+$) calcd for $C_{21}H_{17}NNaO_7$ (MNa^+) 418.0897, found 418.0898.

Ethyl-2-(4-nitro-5-phenyl-3-*p*-tolylfuran-2-yl)acetate (5e)

Light yellow oily liquid; yield 61 mg, 56%; IR (KBr, cm^{-1}) 1738 (*vs.*), 1513, 1358 (m); ^1H NMR (400 MHz, $CDCl_3$) δ 7.83–7.80 (m, 2H), 7.44–7.41 (m, 3H), 7.29–7.21 (m, 4H), 4.20 (q, $J = 7.2$ Hz, 2H), 3.65 (s, 2H), 2.41 (s, 3H), 1.28 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 21.5, 32.9, 61.8, 121.7, 126.2, 127.7, 128.4, 128.7, 129.3, 129.5, 130.4, 130.6, 138.6, 144.8, 151.5, 168.6; MS (ES^+) *m*/*z* (rel intensity) 404 (MK^+, 23), 388 (MNa^+, 100), 366 (MH^+, 25), 301 (20); HRMS (ES^+) calcd for $C_{21}H_{19}NNaO_5$ (MNa^+) 388.1155, found 388.1155.

Ethyl-2-(3-(naphthalen-1-yl)-4-nitro-5-phenylfuran-2-yl)acetate (5f)

Light yellow oily liquid; yield 71 mg (59%); IR (KBr, cm^{-1}) 1739 (*vs.*), 1510 (*vs.*), 1354 (m); ^1H NMR (400 MHz, $CDCl_3$) δ 7.96–7.92 (m, 4H), 7.75 (d, $J = 8.0$ Hz, 1H), 7.57–7.46 (m, 7H), 4.14–4.08 (q, $J = 7.2$ Hz, 2H), 3.59, 3.53 (AB, $J = 17.0$ Hz, 2H), 1.19 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 32.8, 61.7, 119.9, 125.1, 125.5, 126.4, 126.9, 127.7, 128.4, 128.7 ($\times$ 2), 128.7, 129.5, 130.8, 132.5, 133.7, 135.4, 145.9, 152.2, 168.3; MS (ES^+) *m*/*z* (rel intensity) 440 (MK^+, 77), 424 (MNa^+, 100), 397 (20), 357 (23), 301 (35), 243 (69), 213 (100); HRMS (ES^+) calcd for $C_{24}H_{19}NNaO_5$ (MNa^+) 424.1155, found 424.1154.

Ethyl-2-(3-(4-chlorophenyl)-4-nitro-5-phenylfuran-2-yl)acetate (5g)

Light yellow oily liquid; yield 62 mg, 54%; IR (KBr, cm^{-1}) 1739 (m), 1514 (m), 1358 (w), 739 (*vs.*); ^1H NMR (400 MHz, $CDCl_3$) δ 7.83–7.80 (m, 2H), 7.50–7.47 (m, 3H), 7.42, 7.31 (AB, $J = 8.5$ Hz, 4H), 4.20 (q, $J = 7.1$ Hz, 2H), 3.63 (s, 2H), 1.28 (t, $J = 7.1$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 32.8, 62.0, 120.8, 127.5, 127.8, 128.6, 128.7, 129.0, 130.9, 131.1, 134.9, 145.1, 152.1, 168.4; MS (ES^+) *m*/*z* (rel intensity) 426 ($[M + 2]K^+$, 10), 424 (MK^+, 30), 413 (100), 410 ($[M + 2]Na^+$, 5), 408 (MNa^+, 15), 386 (MH^+, 80); HRMS (ES^+) calcd for $C_{20}H_{17}ClNO_5$ (MH^+) 386.0790, found 386.0784.

Ethyl-2-(4-nitro-3-(2-nitrophenyl)-5-phenylfuran-2-yl)acetate (5h)

Light yellow oily liquid; yield 69 mg, 58%, mixture of atropisomers; IR (KBr, cm^{-1}) 1736 (*vs.*), 1527 (*vs.*), 1512 (*vs.*), 1350 (*vs.*); ^1H NMR (400 MHz, $CDCl_3$) δ 8.26–8.22 (m, 1H), 8.14–8.10 (m, 0.5H, due to atropisomerism), 7.90–7.86 (m, 2H), 7.74–7.69 (m, 1H), 7.66–7.60 (m, 1.5H, due to atropisomerism), 7.53–7.46 (m, 4 + 1H), 4.15 (q, $J = 7.1$ Hz, 2H), 3.62, 3.51 (AB, $J = 16.9$ Hz, 2H), 1.24 (t, $J = 7.1$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 33.0, 62.1, 118.8, 125.4, 127.4, 128.6, 129.2, 130.2, 130.4, 131.1, 132.9, 133.7, 134.4, 144.8, 148.8, 153.2, 168.0; MS (ES^+) *m*/*z* (rel intensity) 435 (MK^+, 16), 419 (MNa^+, 100), 397 (14), 303 (23); HRMS (ES^+) calcd for $C_{20}H_{16}N_2NaO_7$ (MNa^+) 419.0850, found 419.0848.

Ethyl-2-(4′-nitro-5′-phenyl-2,3′-bifuran-2′-yl)acetate (5i)

Yellow oily liquid; yield 18 mg (52%); IR (KBr, cm^{-1}) 1739 (*vs.*), 1519 (s); ^1H NMR (400 MHz, $CDCl_3$) δ 7.78–7.74 (m, 2H), 7.50 (dd, $J = 1.8$, 0.6 Hz, 1H), 7.49–7.45 (m, 3H), 6.67 (dd, $J = 3.4$, 0.6 Hz, 1H), 6.50 (m, $J = 3.4$, 1.8 Hz, 1H), 4.20 (q, $J = 7.1$ Hz, 2H), 3.92 (s, 2H), 1.28 (t, $J = 7.1$ Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 34.0, 42.5, 61.9, 110.9, 111.5, 127.2, 128.3, 128.8, 130.8, 142.8, 143.2, 145.5, 151.8, 168.4; MS (ES^+) *m*/*z* (rel intensity) 380 (MK^+, 34), 364 (MNa^+, 58), 360 (39), 349 (100); HRMS (ES^+) calcd for $C_{18}H_{15}NNaO_6$ (MNa^+) 364.0792, found 364.0792.

Representative procedure for the synthesis of substituted furans 12 and 13

To a stirred solution of 1,3-diketone **11** (0.92 mmol) in MeCN (3 mL) was added potassium acetate (0.180 g, 1.84 mmol, 2 equiv.) followed by Rauhut–Currier adduct **6** (0.92 mmol, 1 equiv.). The resulting reaction mixture was refluxed till the completion of the reaction. After the completion of the reaction (monitored by TLC, see Tables 4 and 5), the reaction mixture was concentrated *in vacuo* and the crude residue was purified by silica gel column chromatography (pet ether : ethyl acetate 5–10%, gradient elution).

6,6-Dimethyl-2-(3-oxobutyl)-3-phenyl-6,7-dihydrobenzofuran-4(5*H*)-one (12a)

White solid; yield 194 mg, 68%; mp 88–89 °C; IR (KBr, cm^{-1}) 1717 (s), 1678 (*vs.*); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.39–7.28 (m, 5H), 2.93 (t, $J = 7.0$ Hz, 2H), 2.78 (t, $J = 7.0$ Hz, 2H), 2.74 (s, 2H), 2.36 (s, 2H), 2.13 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 28.7, 30.0, 35.1, 37.8, 41.8, 53.1, 118.7, 119.6, 127.4, 128.1, 129.9, 131.4, 151.2, 165.2, 193.6, 207.1; MS (ES^+) *m*/*z* (rel intensity) 333 (MNa^+, 75), 311 (MH^+, 100), 254 (6), 253 (29); HRMS (ES^+) calcd for $C_{20}H_{23}O_3$ (MH^+) 311.1647, found 311.1651.

3-(4-Methylphenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzenefuran-4(5*H*)-one (12b)

Brown solid; yield 92 mg, 31%; mp 128–130 °C; IR (KBr, cm^{-1}) 1717 (s), 1677 (*vs.*); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.25, 7.18 (AB, $J = 7.9$ Hz, 4H), 2.93 (t, $J = 7.1$ Hz, 2H), 2.77 (t, $J = 7.1$ Hz, 2H), 2.73 (s, 2H), 2.36 (s, 3H), 2.35 (s, 2H), 2.13 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 21.4, 28.8, 30.0, 35.1, 37.8, 41.8, 53.2, 118.8, 119.5, 128.3, 128.9, 129.8, 137.1, 151.0, 165.1, 193.6, 207.1; MS (ES^+) *m*/*z* (rel intensity) 347 (MNa^+, 38), 325 (MH^+, 100), 268 (10), 267 (48); HRMS (ES^+) calcd for $C_{21}H_{25}O_3$ (MH^+), 325.1804, found 325.1797.

3-(3-Methoxyphenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12c)

Yellow brown amorphous solid; yield 116 mg, 37%; IR (KBr, cm^{-1}) 1714 (s), 1678 (*vs.*); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.28 (t, $J = 7.9$ Hz, 1H), 6.94 (d, $J = 2.2$ Hz, 1H), 6.93 (d, $J = 7.9$ Hz, 1H), 6.85 (dd, $J = 7.9$, 2.4 Hz, 1H), 3.82 (s, 3H), 2.94 (t, $J = 7.5$ Hz, 2H), 2.77 (t, $J = 7.5$ Hz, 2H), 2.73 (s, 2H), 2.36 (s, 2H), 2.13 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.6, 28.8, 30.0, 35.1, 37.8, 41.8, 53.2, 55.4, 113.3, 115.7, 119.5, 122.4, 129.1, 132.7, 151.3, 159.3, 165.2, 193.5, 207.1; MS (ES^+) *m*/*z* (rel intensity) 379 (MK^+, 100), 363 (MNa^+, 30), 341 (MH^+, 5); HRMS (ES^+) calcd for $C_{21}H_{24}O_4K$ (MK^+), 379.1306, found 379.1306.

3-(4-Methoxyphenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12d)

Yellow solid; yield 163 mg, 52%; mp 109–110 °C; IR (KBr, cm^{-1}) 1716 (s), 1675 (*vs.*); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.29 (d, $J = 9.5$ Hz, 2H), 6.91 (d, $J = 9.5$ Hz, 2H), 3.82 (s, 3H), 2.92 (t, $J = 7.1$ Hz, 2H), 2.77 (t, $J = 7.1$ Hz, 2H), 2.72 (s, 2H), 2.35 (s, 2H), 2.13 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 28.7, 30.0, 35.0, 37.8, 41.8, 53.1, 55.4, 113.6, 118.7, 119.2, 123.6, 131.0, 150.8, 159.0, 165.1, 193.7, 207.2; MS (ES^+) *m*/*z* (rel intensity) 363 (MNa^+, 60), 341 (MH^+, 100), 284 (19), 283 (85), 190 (4); HRMS (ES^+) calcd for $C_{21}H_{25}O_4$ (MH^+), 341.1753, found 341.1750.

3-(3,4-Dimethoxyphenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12e)

Yellow solid; yield 126 mg, 37%; 112–113 °C; IR (KBr, cm^{-1}) 1716 (s), 1676 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.00 (s, 1H), 6.89, 6.86 (AB, $J = 8.2$ Hz, 2H), 3.89 (s, 3H), 3.88 (s, 3H), 2.94 (t, $J = 7.8$ Hz, 2H), 2.79 (t, $J = 7.8$ Hz, 2H), 2.72 (s, 2H), 2.35 (s, 2H), 2.13 (s, 3H), 1.14 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 28.6, 29.9, 34.9, 37.7, 41.5, 53.1, 55.9, 56.0, 110.7, 113.6, 118.5, 119.2, 122.0, 123.8, 148.3, 150.7, 165.1, 193.6, 207.0; MS (ES^+) *m*/*z* (rel intensity) 393 (MNa^+, 10), 371 (MH^+, 100), 314 (7), 313 (29); HRMS (ES^+) calcd for $C_{22}H_{27}O_5$ (MH^+), 371.1858, found 371.1873.

3-(Benzo[*d*][1,3]dioxol-5-yl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12f)

Yellow solid; yield 111 mg, 34%; mp 109–111 °C; IR (KBr, cm^{-1}) 1716 (s), 1677 (*vs.*); ^1H ($CDCl_3$, 400 MHz) δ 6.84 (s, 1H), 6.81–6.77 (m, unresolved AB, 2H), 5.95 (s, 2H), 2.90 (t, $J = 7.4$ Hz, 2H), 2.76 (t, $J = 7.4$ Hz, 2H), 2.71 (s, 2H), 2.34 (s, 2H), 2.13 (s, 3H), 1.14 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 28.7, 30.0, 35.0, 37.8, 41.7, 53.1, 101.1, 108.1, 110.6, 118.7, 119.3, 123.3, 125.0, 147.0, 147.4, 151.0, 165.1, 193.6, 207.1; MS (ES^+) *m*/*z* (rel intensity) 393 (MK^+, 100), 377 (MNa^+, 25); HRMS (ES^+) calcd for $C_{21}H_{22}O_5K$ (MK^+) 393.1099, found 393.1098.

3-(4-Chlorophenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12g)

White solid; yield 174 mg, 55%; mp 86–88 °C; IR (KBr, cm^{-1}) 1713 (s), 1672 (*vs.*), 737 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.34, 7.31 (AB, $J = 8.6$ Hz, 4H), 2.90 (t, $J = 7.4$ Hz, 2H), 2.78 (t, $J = 7.4$ Hz, 2H), 2.73 (s, 2H), 2.35 (s, 2H), 2.14 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.4, 28.7, 30.0, 35.1, 37.8, 41.5, 53.1, 118.5, 118.6, 128.3, 129.9, 131.3, 133.4, 151.4, 165.4, 193.7, 206.9; MS (ES^+) *m*/*z* (rel intensity) 347 ($[M + 2]H^+$, 35), 345 (MH^+, 100), 289 (27), 287 (81), 242 (4), 192 (7); HRMS (ES^+) calcd for $C_{20}H_{22}ClO_3$ (MH^+) 345.1257, found 345.1259.

3-(4-Bromophenyl)-6,6-dimethyl-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12h)

Brown solid; yield 125 mg, 35%; mp 109–110 °C; IR (KBr, cm^{-1}) 1716 (s), 1677 (*vs.*), 758 (m); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.51 (d, $J = 8.4$ Hz, 2H), 7.27 (d, $J = 8.4$ Hz, 2H), 2.92 (t, $J = 7.4$ Hz, 2H), 2.79 (t, $J = 7.4$ Hz, 2H), 2.75 (s, 2H), 2.37 (s, 2H), 2.16 (s, 3H), 1.17 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.4, 28.7, 30.0, 35.1, 37.8, 41.5, 53.1, 118.5, 118.6, 121.6, 130.4, 131.3, 131.6, 151.4, 165.4, 193.7, 206.9; MS (ES^+) *m*/*z* (rel intensity) 429 ($MK + 2]^+$, 90), 427 (MK^+, 91), 413 ($[MNa + 2]^+$, 98), 411 (MNa^+, 100), 129 (12); HRMS (ES^+) calcd for $C_{20}H_{21}O_3BrNa$ (MNa^+) 411.0566, found 411.0570.

6,6-Dimethyl-2-(3-oxobutyl)-3-(thiophen-2-yl)-6,7-dihydrobenzofuran-4(5H)-one (12i)

Black solid; yield 84 mg, 29%; mp 128–130 °C; IR (KBr, cm^{-1}) 717 (s), 1677 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.36 (dd, $J = 3.5$ Hz, $J = 1.1$ Hz, 1H), 7.30 (dd, $J = 5.2$ Hz, $J = 1.1$ Hz, 1H), 7.05 (dd, $J = 5.2$ Hz, $J = 3.5$ Hz, 1H), 3.07 (t, $J = 7.2$ Hz, 2H), 2.81 (t, $J = 7.2$ Hz, 2H), 2.72 (s, 2H), 2.38 (s, 2H), 2.16 (s, 3H), 1.15 (s, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.2, 28.7, 30.0, 34.9, 37.8, 41.7, 53.2, 113.1, 118.6, 125.4, 127.2, 128.6, 131.9, 151.9, 165.3, 193.4, 207.0; MS (ES^+) *m*/*z* (rel intensity) 317 (MH^+, 84), 259 (100); HRMS (ES^+) calcd for $C_{18}H_{21}O_3S$ (MH^+) 317.1211, found 317.1218.

6,6-Dimethyl-3-(naphthalen-1-yl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (12j)

Brown solid; yield 129 mg, 39%; mp 116–118 °C; IR (KBr, cm^{-1}) 1717 (s), 1679 (*vs.*); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.86 (t, $J = 7.2$ Hz, 2H), 7.59 (d, $J = 8.5$ Hz, 1H), 7.52–7.35 (m, 4H), 2.85, 2.80 (AB, $J = 16.0$ Hz, 2H), 2.78–2.71 (m, 2H), 2.70–2.62 (m, 2H), 2.45, 2.33 (AB, $J = 16.0$ Hz, 2H), 2.00 (s, 3H), 1.21 (s, 3H), 1.18 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.6, 28.8, 28.8, 29.8, 35.2, 37.8, 41.6, 52.7, 117.1, 120.4, 125.3, 125.7, 125.8, 126.0, 127.9, 128.3, 128.4, 129.5, 132.7, 133.6, 152.2, 164.9, 192.9, 206.9; MS (ES^+) *m*/*z* (rel intensity) 399 (MK^+, 399), 383 (MNa^+, 100), 361 (20), HRMS (ES^+) calcd for $C_{24}H_{24}O_3Na$ (MNa^+) 383.1618, found 383.1617.

2-(3-Oxobutyl)-3-phenyl-6,7-dihydrobenzofuran-4(5*H*)-one (13a)

Dark brown solid; yield 86 mg, 33%; mp 63–65 °C; IR (KBr, cm^{-1}) 1716 (s), 1676 (*vs.*); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.38–7.28 (m, 5H), 2.92 (t, $J = 7.5$ Hz, 2H), 2.86 (t, $J = 6.4$ Hz, 2H), 2.76 (t, $J = 7.5$ Hz, 2H), 2.46 (t, $J = 6.4$ Hz, 2H), 2.16 (quint, $J = 6.4$ Hz, 2H), 2.12 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.4, 22.6, 23.8, 29.9, 38.7, 41.7, 119.7, 119.9, 127.4, 128.1, 129.9, 131.5, 150.9, 166.1, 194.1, 207.0; HRMS (ES^+) calcd for $C_{18}H_{18}O_3Na$ (MNa^+) 305.1148 found 305.1150.

2-(3-Oxobutyl)-3-*p*-tolyl-6-7-dihydrobenzenefuran-4(5*H*)-one (13b)

Brown solid; yield 125 mg, 46%; mp 91–92 °C; IR (KBr, cm^{-1}) 1716 (s), 1677 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.25, 7.18 (AB, $J = 8.0$ Hz, 4H), 2.91 (t, $J = 7.3$ Hz, 2H), 2.86 (t, $J = 6.2$ Hz, 2H), 2.76 (t, $J = 7.3$ Hz, 2H), 2.46 (t, $J = 6.2$ Hz, 2H), 2.36 (s, 3H), 2.16 (quint, $J = 6.2$ Hz, 2H), 2.12 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.4, 21.4, 22.6, 23.8, 30.0, 38.8, 41.8, 119.6, 120.0, 128.4, 128.9, 129.7, 137.1, 150.7, 166.0, 194.1, 207.1; MS (ES^+) *m*/*z* (rel intensity) 297 (MH^+, 90), 239 (100), 204 (5), 200 (7); HRMS (ES^+) calcd for $C_{19}H_{21}O_3$ (MH^+) 297.1491, found 297.1493.

3-(3-Methoxyphenyl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (13c)

Brown solid; yield 109 mg, 38%; mp 117–119 °C; IR (KBr, cm^{-1}) 1716 (s), 1676 (*vs.*); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.27 (t, $J = 7.9$ Hz, 1H), 6.94 (dd, $J = 2.4$, 1.5 Hz, 1H), 6.91 (dd, $J = 7.9$, 1.5 Hz, 1H), 6.85 (dd, $J = 7.9$, 2.4 Hz, 1H), 3.81 (s, 3H), 2.93 (t, $J = 7.5$ Hz, 2H), 2.86 (t, $J = 6.4$ Hz, 2H), 2.76 (t, $J = 7.5$ Hz, 2H), 2.46 (t, $J = 6.4$ Hz, 2H), 2.16 (quint, $J = 6.4$ Hz, 2H), 2.12 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.5, 22.6, 23.9, 30.0, 38.8, 41.7, 55.4, 113.3, 115.6, 119.6, 119.9, 122.3, 129.0, 132.8, 151.0, 159.3, 166.1, 194.0, 207.0; MS (ES^+) *m*/*z* (rel intensity) 351 (MK^+, 98), 335 (MNa^+, 100); HRMS (ES^+) calcd for $C_{19}H_{20}O_4Na$ (MNa^+) 335.1254, found 335.1253.

3-(4-Methoxyphenyl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (13d)

Yellow solid; yield 132 mg, 46%; mp 136–137 °C; IR (KBr, cm^{-1}) 1716 (m), 1673 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.29 (d, $J = 8.6$ Hz, 2H), 6.90 (d, $J = 8.6$ Hz, 2H), 3.81 (s, 3H), 2.90 (t, $J = 7.8$ Hz, 2H), 2.86 (t, $J = 6.3$ Hz, 2H), 2.76 (t, $J = 7.8$ Hz, 2H), 2.46 (t, $J = 6.3$ Hz, 2H), 2.17 (quint, $J = 6.3$ Hz, 2H), 2.12 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.4, 22.6, 23.9, 30.0, 38.8, 41.8, 55.4, 113.6, 119.3, 120.0, 123.7, 131.0, 150.5, 158.9, 166.0, 194.3, 207.1; MS (ES^+) *m*/*z* (rel intensity) 335 (MNa^+, 50), 313 (MH^+, 100), 256 (18), 255 (96); HRMS (ES^+) calcd for $C_{19}H_{21}O_4$ (MH^+) 313.1440, found 313.1437.

3-(3,4-Dimethoxyphenyl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (13e)

Yellow solid; yield 94 mg, 30%; mp 113–114 °C; IR (KBr, cm^{-1}) 1716 (s), 1674 (*vs.*); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.00 (s, 1H), 6.90–6.88 (unresolved AB, 2H), 3.90 (s, 6H), 2.95 (t, $J = 7.0$ Hz, 2H), 2.88 (t, $J = 6.1$ Hz, 2H), 2.78 (t, $J = 7.0$ Hz, 2H), 2.48 (t, $J = 6.1$ Hz, 2H), 2.18 (quint, $J = 7.0$ Hz, 2H), 2.14 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 20.5, 22.6, 23.9, 30.0, 38.8, 41.7, 56.0, 56.1, 110.8, 113.7, 119.5, 119.9, 122.0, 124.0, 148.4, 150.6, 166.1, 194.3, 207.1; MS (ES^+) *m*/*z* (rel intensity) 365 (MNa^+, 60), 343 (MH^+, 88), 286 (21), 285 (100); HRMS (ES^+) calcd for $C_{20}H_{23}O_5$ (MH^+) 343.1545, found 343.1545.

3-(4-Bromophenyl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (13f)

Brown solid; yield 139 mg, 42%; mp 90–92 °C; IR (KBr, cm^{-1}) 1717 (s), 1676 (*vs.*), 762 (m); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.49 (d, $J = 8.4$ Hz, 2H), 7.23 (d, $J = 8.4$ Hz, 2H), 2.90 (t, $J = 7.4$ Hz, 2H), 2.87 (t, $J = 6.4$ Hz, 2H), 2.76 (t, $J = 7.4$ Hz, 2H), 2.47 (t, $J = 6.4$ Hz, 2H), 2.17 (quint, $J = 6.4$ Hz, 2H), 2.13 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.2, 22.4, 23.7, 29.9, 38.5, 41.4, 118.6, 119.6, 121.5, 130.3, 131.1, 131.4, 150.9, 166.1, 194.0, 206.7; MS (ES^+) *m*/*z* (rel intensity) 385 ([M + 2]Na^+, 100), 383 (MNa^+, 98); HRMS (ES^+) calcd for $C_{18}H_{17}O_3BrNa$ (MNa^+) 383.0253 found 383.0253.

2-(3-Oxobutyl)-3-(thiophen-2-yl)-6,7-dihydrobenzofuran-4(5*H*)-one (13g)

Black solid; yield 40 mg, 15%; mp 104–105 °C; IR (KBr, cm^{-1}) 1715 (s), 1676 (s); ^1H NMR ($CDCl_3$, 400 MHz) δ 7.31–7.29 (m, 2H), 7.05 (dd, $J = 5.1$, 3.6 Hz, 1H), 3.04 (t, $J = 6.9$ Hz, 2H), 2.85 (t, $J = 6.1$ Hz, 2H), 2.79 (t, $J = 6.9$ Hz, 2H), 2.48 (t, $J = 6.1$ Hz, 2H), 2.21–2.14 (m, 2H), 2.15 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.0, 22.4, 23.8, 30.0, 38.8, 41.7, 113.1, 119.8, 125.5, 127.2, 128.5, 131.9, 151.7, 166.1, 194.0, 207.0; MS (ES^+) *m*/*z* (rel intensity) 289 (MH^+, 70), 233 (5), 232 (15), 231 (100), 220; HRMS (ES^+) calcd for $C_{16}H_{17}O_3S$ (MH^+) 289.0898, found 289.0887.

3-(Naphthalen-1-yl)-2-(3-oxobutyl)-6,7-dihydrobenzofuran-4(5*H*)-one (13h)

Dark brown solid; yield 134 mg, 44%; mp 91–93 °C; IR (KBr, cm^{-1}) 1715 (m), 1678 (*vs.*); ^1H NMR ($CDCl_3$, 500 MHz) δ 7.85 (t, $J = 8.2$ Hz, 2H), 7.59 (d, $J = 8.2$ Hz, 1H), 7.49–7.33 (m, 4H), 2.95 (AB, $J = 6.4$ Hz, 2H), 2.78–2.70 (m, 2H), 2.68–2.58 (m, 2H), 2.50–2.38 (m, 2H), 2.24–2.18 (m, 2H), 2.00 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 20.6, 22.7, 23.9, 29.8, 38.5, 41.6, 117.3, 121.7, 125.4, 125.8, 125.8, 126.1, 127.9, 128.4, 128.5, 129.6, 132.7, 133.7, 151.9, 165.8, 193.7, 207.0; MS (ES^+) *m*/*z* (rel intensity) 371 (MK^+, 12), 355 (MNa^+, 100), 305 (4); HRMS (ES^+) calcd for $C_{22}H_{20}O_3Na$ (MNa^+) 355.1305, found 355.1303.

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