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Tetrahedron 62 (2006) 1258–1272
Tetrahedron

Efficient synthesis of 1,4-dihydronaphthalenelignans from 5-methylene-4-substituted-2(5*H*)-furanones and a concise synthesis of solafuranone

Vishal A. Mahajan, Hanumant B. Borate and Radhika D. Wakharkar*

Division of Organic Chemistry: Technology, National Chemical Laboratory, Pune 411 008, India

Received 29 July 2005; revised 30 September 2005; accepted 20 October 2005

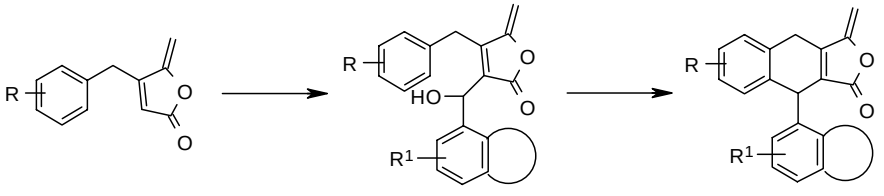
Available online 18 November 2005

Abstract—A short synthetic strategy for synthesis of lignan analogues involving 5-methylene-4-substituted-2(5*H*)-furanones as the key intermediates has been developed. Various lignans including the natural product solafuranone and analogues of dihydrotaiwanin C and deoxydehydropodophyllotoxin were synthesized in good yields.

1. Introduction

The furanone moiety is the structural feature of a large number of biologically active compounds such as alkaloids,[1] lignans,[2] and pheromones[3] and γ-alkylidene furanones constitute an important subclass of the furanone family with a wide range of biological activity.[4] Considering the importance of this class of compounds, we recently reported[5a] the synthesis of 5-methylene-4-substituted-2(5*H*)-furanones involving Stobbe condensation of ethyl levulinate with substituted aryl aldehydes to give arylidenelevulinic acids followed by treatment with sodium acetate and acetic anhydride. We envisioned the utility of 5-methylene-4-substituted-2(5*H*)-furanones in the synthesis of various lignan derivatives. The wide spectrum of biological activity including anti-cancer activity,[6] anti-inflammatory activity,[7] analgesic activity,[8] anti-fungal activity,[9] anti-asthmatic activity[10] and anti-rheumatic activity[11] exhibited by lignans and their analogues make them an attractive target for synthetic chemists. The different methods reported[12] for the synthesis of naturally occurring lignan lactones and their analogues include cyclization of substituted propiolic acids, propiolic esters or oxazolines and a Pummerer–Diels–Alder reaction sequence. In our endeavor to develop methods for synthesis of novel lignans, the 5-methylene-4-substituted-2(5*H*)-furanones (**1**) obtained from arylidenelevulinic acids were used as the building blocks (Scheme 1).

The 5-methylene-4-substituted-2(5*H*)-furanones (**1**) were reacted with various aromatic aldehydes to obtain the acyclic lignans **2** which were further transformed into a number of cyclic lignans **3** with a wide variety of substituents and the detailed results are reported herein. The utility of 5-methylene-4-substituted-2(5*H*)-furanones (**1**) was further explored for the synthesis of naphthalene lignan derivatives as many naturally occurring naphthalene lignans, with a wide spectrum of biological activity, have a



1 2 3

Scheme 1.

Keywords: Lignans; Furanones; Exomethylene furanones; Podophyllotoxin; Dihydrotaiwanin; Solafuranone.
* Corresponding author. Tel.: +91 20 25902284; fax: +91 20 5893614; e-mail: rd.wakharkar@ncl.res.in

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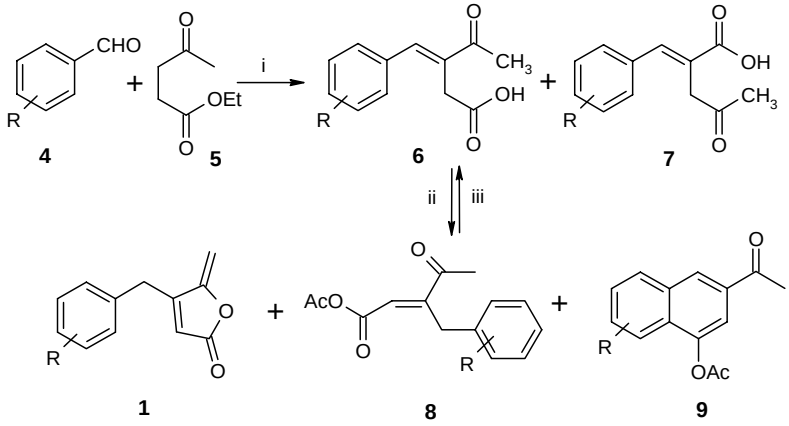
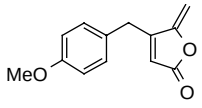
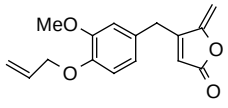
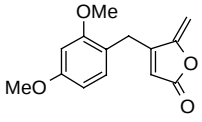
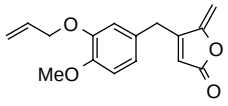
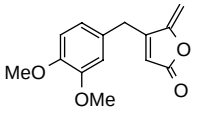
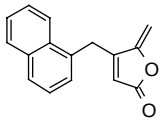
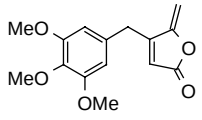
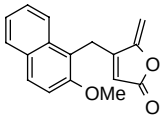
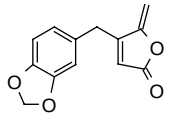
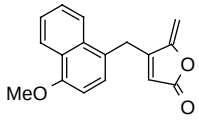
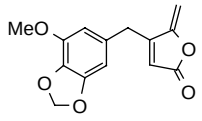
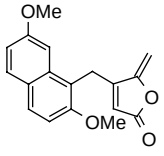
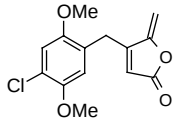
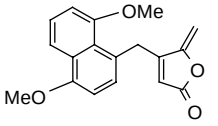
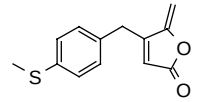
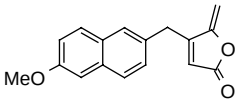
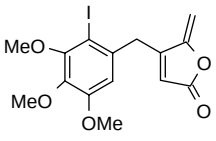
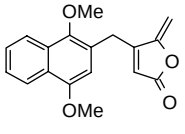
doi:10.1016/j.tet.2005.10.054

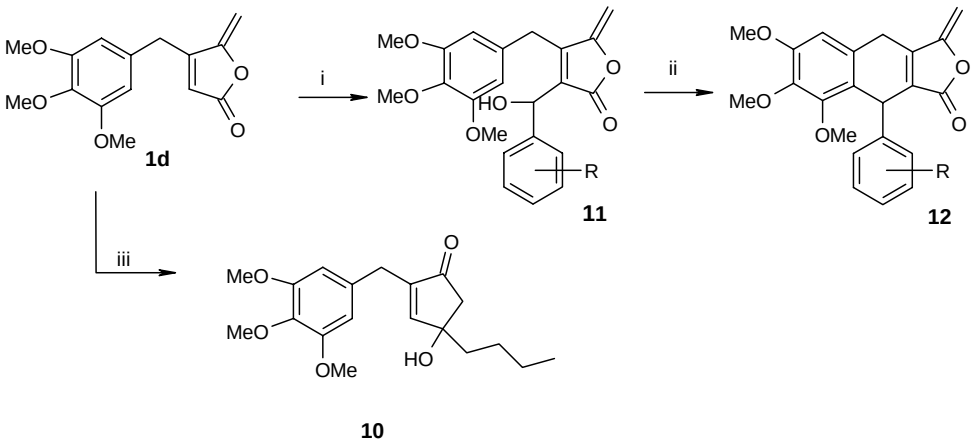


Scheme 2. Reagents and conditions: (i) Aq. NaOH, ethanol, −10 °C, 4–5 h, (7, 80–95%); (ii) Anhydr. NaOAc, Ac_2O, 80 °C, 3 h; (iii) Aq. NaOH, ethanol, rt, 2–3 h.

Table 1. 5-Methylene-4-substituted-2(5*H*)-furanones

Comp. no.	Structure	Yield (%)[a]	Comp. no.	Structure	Yield (%)[a]
1a		52	**1j**		48
1b		64	**1k**		57
1c		67	**1l**		67
1d		72	**1m**		61
1e		56	**1n**		62
1f		55	**1o**		52
1g		75	**1p**		58
1h		63	**1q**		57
1i		57	**1r**		64

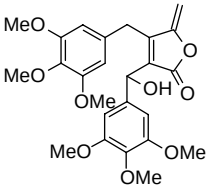
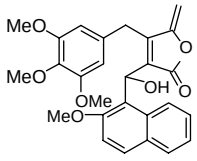
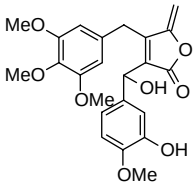
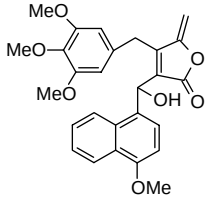
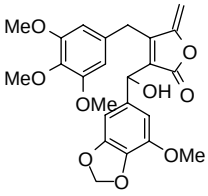
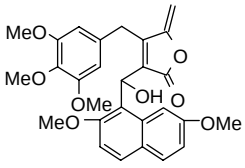
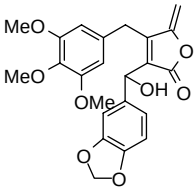
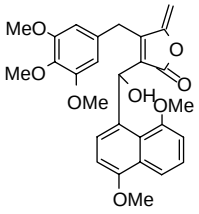
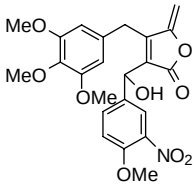
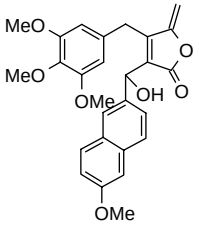
[a] Isolated yield.



Scheme 3. Reagents and conditions: (i) LDA, substituted arylaldehydes, −78 °C; (ii) TFA, dichloromethane, rt; (iii) *n*-BuLi, −78 °C, 40%.

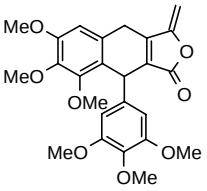
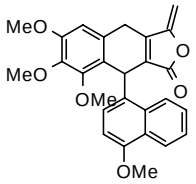
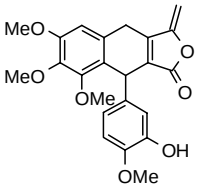
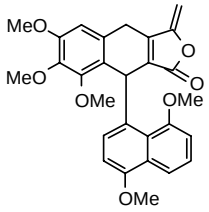
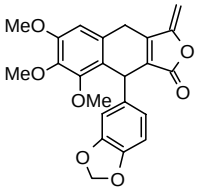
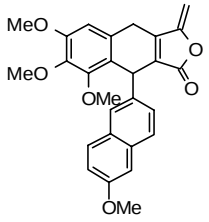
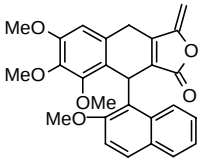
lactone moiety as the core unit in their structure.[13] A number of novel naphthalene lignans including analogues of dihydrotaiwanin and deoxydehydropodophyllotoxin were synthesized from 5-methylene-4-substituted-2(5*H*)-furanones (**1**) demonstrating the importance of these easily accessible chemical entities. Extension of the work on exploitation of 5-methylene-4-substituted-2(5*H*)-furanones (**1**) for the synthesis of natural products having furanone as

Table 2. Hydroxy lignans prepared

Comp. no.	Structure	Yield (%)[a]	Comp. no.	Structure	Yield (%)[a]
11a		48	**11f**		52
11b		55	**11g**		75
11c		52	**11h**		57
11d		60	**11i**		55
11e		49	**11j**		57

[a] Isolated yields.

Table 3. Novel lignans prepared

Comp. no.	Structure	Yield (%)[a]	Comp. no.	Structure	Yield (%)[a]
12a		78	**12e**		81
12b		74	**12f**		63
12c		91	**12g**		89
12d		61			

[a] Isolated yields.

a structural feature resulted in the first synthesis of solafuranone,[14] a folk medicine used as an analgesic for toothache and rhinitis.

2. Results and discussion

The various 5-methylene-4-substituted-2(5*H*)-furanones (**1**)[5a] were synthesized by a two-step reaction sequence (Scheme 2).

Stobbe condensation[5b] of substituted aryl aldehydes **4** with ethyl levulinate (**5**) in the presence of ethanolic sodium hydroxide[5a] afforded a mixture of arylidene levulinic acids **6** and **7** in varying amounts depending upon the temperature of the reaction and the substitution pattern of the aromatic aldehydes **4**. The required acid **6** was obtained in maximum amount at lower temperature (−10 °C) while the acid **7** was the exclusive product when the condensation was performed in the presence of DBU in refluxing THF. In some cases it was possible to isolate pure acids **6** and **7** while in some cases the acids were obtained as an inseparable mixture and the characterization was done by comparison of the spectral data of analogous acids obtained in pure form. Reaction of acid **6** with anhydrous sodium acetate and acetic anhydride afforded the desired furanones **1** in 48–75% yield (Table 1) along with 10–32% mixed anhydrides **8** and 2–20% naphthalene derivatives **9**. The structures of the furanones **1** were assigned on the basis of spectral data.

We envisaged that the furanones **1** could be utilized as valuable intermediates in the synthesis of various lignan derivatives by generation of an anion on the carbon α to the lactone carbonyl function of furanones **1** and reaction with various aldehydes to result in the formation of hydroxy lignans **2** (Scheme 1). Cyclization of these hydroxy lignans under acidic conditions would lead to the cyclic lignan lactones that would have potential to generate a wide variety of novel lignan derivatives with a unique structural ensemble.

A number of methods are reported for α-alkylation of the saturated lactones using various bases while the alkylation of unsaturated lactones is less explored.[15] To study the α-alkylation of furanone derivatives, furanone **1d** was selected as the 3,4,5-trimethoxy group is commonly present

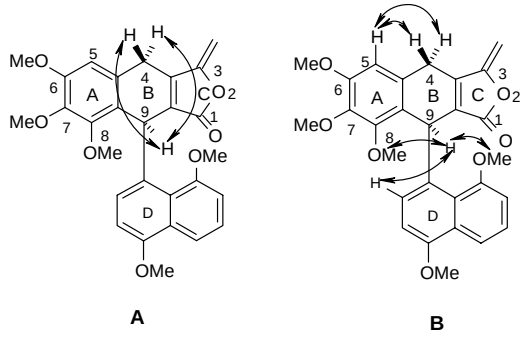
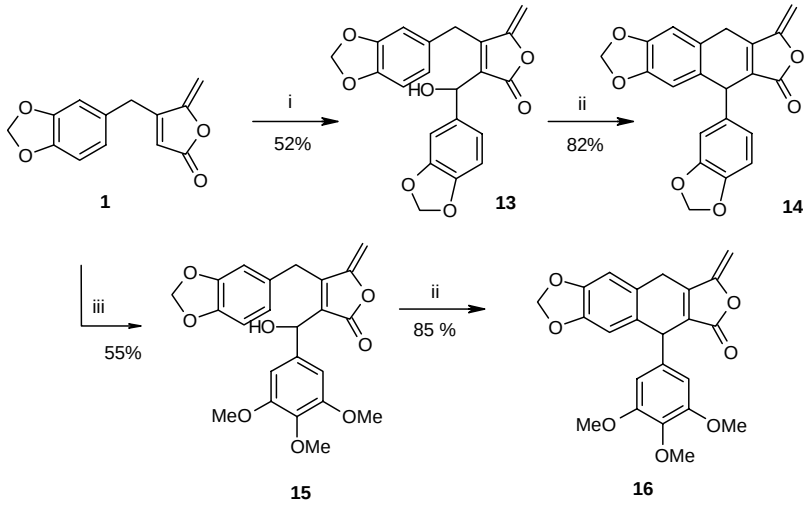
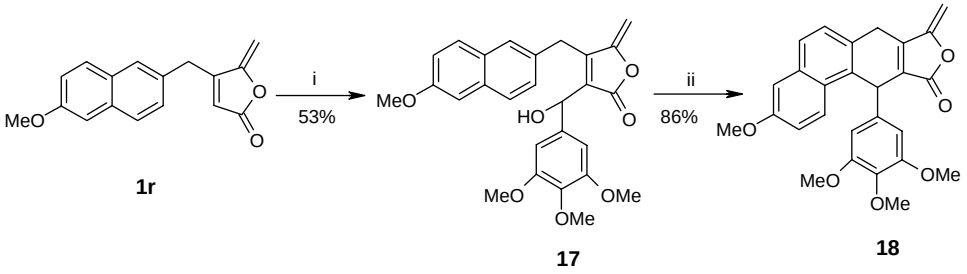


Figure 1. Selected COSY and NOESY correlations.



Scheme 4. Reagents and conditions: (i) 3,4-Methylene dioxybenzaldehyde, LDA, THF, −78 °C; (ii) TFA, CH_2Cl_2, rt; (iii) 3,4,5-Trimethoxybenzaldehyde, LDA, THF, −78 °C.



Scheme 5. Reagents and conditions: (i) 3,4,5-Trimethoxy benzaldehyde, LDA, THF, −78 °C; (ii) TFA, CH_2Cl_2, rt.

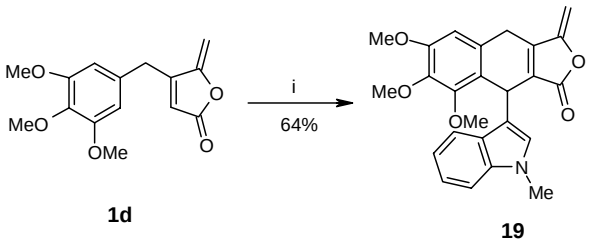
in naturally occurring bioactive lignans. It is noteworthy that in the preliminary screening study of base for anion generation, in the presence of *n*-butyllithium exomethylene furanone derivative **1d** underwent addition of *n*-butyl group followed by rearrangement to give serendipitously 4-hydroxy-4-butyl-cyclopentenone derivative **10** (Scheme 3) while the aldehydes that were added remained unreacted. LDA was found to be the best choice to generate α-vinyl carbanion of exomethylenefuranone **1** without disturbing its basic molecular skeleton. The presence of exomethylene moiety on furanone **1** facilitated the exclusive generation of α-carbanion rather than γ-carbanion formation to afford the desired products **11**. The formation of α-carbanion was confirmed by quenching it with D_2O and disappearance of proton at δ 5.85 in the ^1H NMR spectrum. The spectral data for hydroxy lignans **11** were in good agreement with the assigned structures. Various exomethylenefuranones **1** were reacted with a number of aldehydes to generate a wide array of novel hydroxylignans **11** as shown in Table 2.

The potential of these new chemical entities as intermediates in the synthesis of natural as well as synthetic lignans was evident from the structural diversity of the hydroxy lignans prepared in the present work.

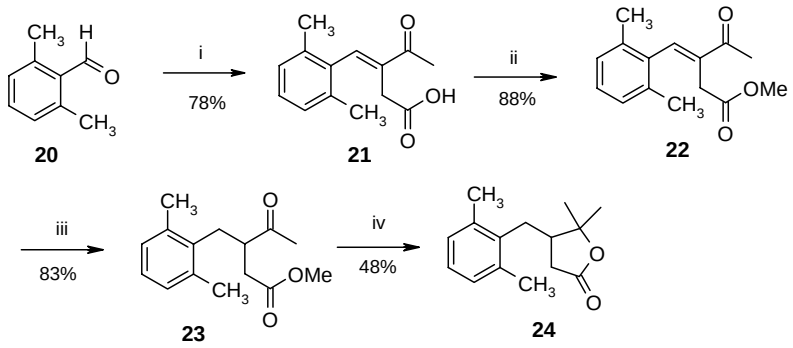
The hydroxy lignan lactones **11** were treated with trifluoroacetic acid to afford the desired cyclic lignans **12** in good yields as shown in Table 3. It was gratifying to obtain a number of novel lignans in a few steps using easily available chemicals.

The structures of the lignans **3** were assigned on the basis of spectral data. The benzylic protons exhibited long-range coupling, which was confirmed by ^1H–^1H COSY and NOESY spectra of selected molecules (Figure 1).

The potential of this strategy for synthesis of exomethylene analogues of various natural products was evident from the products obtained from the reaction of furanone **1e** with piperonaldehyde and 3,4,5-trimethoxybenzaldehyde (Scheme 4). The corresponding hydroxylignans **13** and **15** on cyclization with trifluoroacetic acid afforded the compounds **14** and **16**, the analogues of biologically active 1,4-dihydrotaiwanin C[16] and podophyllotoxin,[17] respectively.



Scheme 6. Reagents and conditions: (i) (a) *N*-Methyl indole-3-carboxaldehyde, LDA, THF, −78 °C; (b) Dilute acetic acid.



Scheme 7. Reagents and conditions: (i) aq. NaOH, methanol, −10 °C, 4–5 h; (ii) CH_2N_2, methanol, rt; (iii) H_2, Pd/C, methanol, rt; (iv) CH_3MgI, ether, −78 °C, 5 h.

The versatility of this synthetic sequence was demonstrated by the synthesis of angular lignan **18** from the corresponding 4-(6′-methoxynaphthalen-2-yl)methyl-5-methylene-2(5*H*)-furanone (**1r**) as shown in Scheme 5.

It was noteworthy that the reaction of *N*-methylindole-3-carboxaldehyde with furanone **1d** in the presence of LDA followed by acidic work up afforded the cyclic lignan **19** directly and the intermediate hydroxylignan was not isolated. This represents a convergent three-step synthesis of highly functionalized heterocyclic lignan **19** starting from 3,4,5-trimethoxybenzaldehyde (Scheme 6).

The utility of the present work for the synthesis of natural products was further exemplified by the synthesis of solafuranone **24** as depicted in Scheme 7.

Thus, Stobbe condensation of 2,6-dimethyl benzaldehyde with ethyl levulinate afforded the arylidenelevulinic acid **21** as a major component along with the minor regioisomer which was esterified with diazomethane to give the ester **22** in quantitative yield. The ester **22** was hydrogenated and reacted with methylmagnesium iodide in presence of anhydrous cerium chloride to afford racemic solafuranone **24**.

3. Conclusion

In summary, we have developed a short synthetic sequence for novel lignans involving 5-methylene-4-substituted-2(5*H*)-furanones (**1**) as the key intermediates. It has potential for wide application in organic synthesis as it is possible to have various functional groups at the desired positions of the products. The strategy has been exemplified by the synthesis of the natural product solafuranone and lignan analogues including analogues of 1,4-dihydrotaiwanin C and deoxydehydropodophyllotoxin as new chemical entities, which can be studied for their biological activity[18] as well as used as important intermediates in organic synthesis.

4. Experimental

Melting points are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker Avance DPX 200 (200 and 50.3 MHz, respectively) spectrometer. IR spectra were recorded on Perkin-Elmer Spectrum 683 B or 160S FT IR spectrophotometer. Elemental analysis was performed on a Perkin-Elmer Model 2400 analyser. Thin layer chromatography was performed on silica/alumina plates. Column chromatography was performed on silica gel (60–120 mesh).

4.1. A typical procedure for the synthesis of acid 6

To a well-stirred mixture of substituted benzaldehyde (12.7 mmol) and ethyl levulinate (31.7 mmol) in methanol (25 mL), aqueous sodium hydroxide solution (31.7 mmol) was added dropwise at −10 °C. After complete addition, reaction mixture was stirred at same temperature for 4–5 h and the reaction was monitored by thin layer chromatography. After completion of reaction, methanol was removed under vacuum, reaction mixture was diluted with water (20 mL), washed with ethyl acetate (2×10 mL) and aqueous layer was acidified with conc HCl (3 mL). The yellow oil separated was extracted with ethyl acetate (2×20 mL) and it was repeatedly washed with water to remove traces of levulinic acid followed by brine, dried over sodium sulfate and evaporated to yield the desired acid **6** (yield ranges from 45 to 85%).

4.1.1. 3-Acetyl-4-(4-methoxyphenyl)-but-3-enoic acid (6a). Yellow solid; Yield: 1.78 g, 60%; Mp: 138–140 °C (lit.[5b] 142 °C); IR (Chloroform): ν 3020, 1716, 1663, 1217, 757 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.44 (s, 3H), 3.52 (s, 2H), 3.80 (s, 3H), 6.92 (d, J=8.0 Hz, 2H), 7.34 (d, J=8.0 Hz, 2H), 7.66 (s, 1H), 9.46 (br s, 1H); MS (ES): m/z 234 (M^+), 257 (M^++Na); Anal. Calcd for $C_{13}H_{14}O_4$: C, 66.66; H, 5.98; Found: C, 66.80; H, 5.73%.

4.1.2. 3-Acetyl-4-(2,4-dimethoxyphenyl)-but-3-enoic acid (6b). White solid; Yield: 2.07 g, 62%; Mp: 114 °C; IR (Chloroform): ν 3022, 1715, 1630, 1506, 1430, 1216, 756 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.44 (s, 3H), 3.43 (s, 2H), 3.76 (s, 6H), 6.38–6.55 (m, 2H), 7.23 (d, J=8.0 Hz, 1H), 7.82 (s, 1H), 9.55 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 200.2, 176.8, 162.4, 158.8, 139.5, 132.6, 130.9, 116.3, 104.6, 98.3, 55.4 (2C), 33.2, 25.3; MS (ES): m/z 265 (M^++1), 283 (M+1+H_2O); Anal. Calcd for $C_{14}H_{16}O_5$: C, 63.63; H, 6.06; Found: C, 66.69; H, 6.18%.

4.1.3. 3-Acetyl-4-(3,4-dimethoxyphenyl)-but-3-enoic acid (6c). Yellow thick oil;[5b] Yield: 2.58 g, 77%; IR (Chloroform): ν 2922, 1698, 1654, 1504, 1281, 1209 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.42 (s, 3H), 3.50 (s, 2H), 3.76 (s, 6H), 6.75–6.93 (m, 2H), 7.31 (d, $J=8.0$ Hz, 1H), 7.63 (s, 1H), 9.55 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 208.2, 174.2, 160.5, 142.1, 136.4, 135.9, 127.0, 125.9, 107.3, 106.6, 55.1 (2C), 33.4, 30.6; MS (ES): *m/z* 265 ($M^+ +1$), 283 ($M+1+H_2O$); Anal. Calcd for $C_{14}H_{16}O_5$: C, 63.63; H, 6.06; Found: C, 66.48; H, 5.90%.

4.1.4. 3-Acetyl-4-(3,4,5-trimethoxyphenyl)-but-3-enoic acid (6d). Yellow solid; Yield: 2.80 g, 75%; Mp: 118–120 °C; IR (Chloroform): ν 3016, 1709, 1655, 1581, 1239, 1129, 755 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.55 (s, 3H), 3.55 (s, 2H), 3.86 (s, 9H), 6.68 (s, 2H), 7.67 (s, 1H), 8.80 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 199.4, 176.1, 153.0, 143.4, 138.8 (2C), 133.8, 129.8, 106.3 (2C), 60.6 (2C), 55.9, 32.8, 25.1; MS (*m/z*): 295 ($M+1$), 313 ($M+1+H_2O$); Anal. Calcd for $C_{15}H_{18}O_6$: C, 61.22; H, 6.12; Found: C, 60.97; H, 6.25%.

4.1.5. 3-Acetyl-4-benzo [1,3] dioxol-5-yl-but-3-enoic acid (6e). Pink solid; Yield: 2.33 g, 74%; Mp: 148–150 °C (lit.[5b] 152 °C); IR (Chloroform): ν 3010, 1732, 1680, 1486, 1236, 1038, 933, 697 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.29 (s, 3H), 3.30 (s, 2H), 5.85 (s, 2H), 6.51 (d, $J=2.0$ Hz, 1H), 6.58–6.64 (m, 1H), 6.68 (d, $J=8.0$ Hz, 1H), 7.44 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 198.5, 172.7, 147.4, 141.6, 133.8, 128.4, 123.7, 119.5, 108.6, 108.0, 100.9, 32.1, 25.0; MS (ESI): *m/z* 249 ($M^+ +1$), 266 ($M^+ +H_2O$); Anal. Calcd for $C_{13}H_{12}O_5$: C, 62.90; H, 4.83; Found: C, 63.11; H, 4.98%.

4.1.6. 3-Acetyl-4-(7-methoxybenzo[1,3]dioxol-5-yl)-but-3-enoic acid (6f). Brown solid; Yield: 2.01 g, 57%; Mp: 113–115 °C; IR (Chloroform): ν 2998, 1710, 1682, 1510, 1221 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.48 (s, 3H), 3.54 (s, 2H), 3.90 (s, 3H), 6.02 (s, 2H), 6.59 (br s, 1H), 6.66 (br s, 1H), 7.61 (s, 1H), 8.96 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 197.7, 171.4, 146.5, 140.8, 132.5, 127.5, 122.9, 119.1, 107.0, 105.2, 100.2, 53.6, 30.9, 23.7; MS: *m/z* 278, 233, 263, 247, 233, 203, 189, 161, 103, 77; Anal. Calcd for $C_{14}H_{14}O_6$: C, 60.43; H, 5.03; Found: C, 60.24; H, 5.23%.

4.1.7. 3-Acetyl-4-(4-chloro-2,5-dimethoxyphenyl)-but-3-enoic acid (6g). Yellow solid; Yield: 3.22 g, 85%; Mp: 127–130 °C; IR (Chloroform): ν 3020, 1712, 1670, 1495, 1215, 758 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.52 (s, 3H), 3.53 (s, 2H), 3.81 (s, 3H), 3.85 (s, 3H), 6.67 (s, 1H), 6.69 (s, 1H), 7.81 (s, 1H); MS: *m/z* 298, 268, 196, 152, 89; Anal. Calcd for $C_{14}H_{15}O_5Cl$: C, 56.37; H, 5.03; Cl, 11.91; Found: C, 56.39; H, 5.28; Cl, 12.20%.

4.1.8. 3-Acetyl-4-(4-methylsulfanylphenyl)-but-3-enoic acid (6h). Yellow solid; Yield: 2.28 g, 72%; Mp: 121–124 °C; IR (Chloroform): ν 3021, 1786, 1653, 1593, 1419, 1217, 978, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.03 (s, 3H), 2.56 (s, 3H), 3.50 (s, 2H), 7.12 (d, $J=8.0$ Hz, 2H), 7.22 (d, $J=8.0$ Hz, 2H), 7.65 (s, 1H), 10.49 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 199.4, 176.1, 142.7, 140.9, 134.1, 133.7, 130.7, 129.5, 126.2, 125.6, 32.5, 25.1, 14.8; MS (ES): *m/z* 251 ($M^+ +1$); Anal. Calcd for $C_{13}H_{14}O_3S$: C, 62.40; H, 5.60; S, 12.80; Found: C, 62.38; H, 5.82; S, 12.64%.

4.1.9. 3-Acetyl-4-(2-iodo-3,4,5-trimethoxyphenyl)-but-3-enoic acid (6i). Brown solid; Yield: 3.62 g, 68%; Mp: 120–122 °C; IR (Chloroform): ν 3013, 1710, 1672, 1477, 1382, 1201, 1104, 755 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 2.52 (s, 3H), 3.36 (s, 2H), 3.80 (s, 3H), 3.88 (s, 6H), 6.85 (s, 1H), 7.62 (s, 1H), 10.20 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 199.2, 176.3, 158.5, 153.6, 153.1, 146.6, 142.1, 134.5, 133.6, 108.9, 60.8, 60.6, 56.0, 32.6, 26.3; MS: *m/z* 420 (M^+), 438 ($M^+ +H_2O$); Anal. Calcd for $C_{15}H_{17}O_6I$: C, 42.85; H, 4.04; Found: C, 42.90; H, 4.27%.

4.1.10. 3-Acetyl-4-(4-allyloxy-3-methoxyphenyl)-but-3-enoic acid (6j). Semisolid; Yield: 2.20 g, 60%; IR (Chloroform): ν 3029, 1716, 1680, 1210, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.50 (s, 3H), 3.59 (s, 2H), 3.85 (s, 3H), 4.60–4.68 (m, 2H), 5.28–5.46 (m, 2H), 6.01–6.15 (m, 1H), 6.72–7.03 (m, 3H), 7.70 (s, 1H), 8.20 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 199.6, 175.2, 148.7, 148.6, 143.2, 132.5, 132.3, 127.1, 122.5, 117.8, 112.4, 112.2, 69.1, 55.4, 32.3, 24.8; MS: *m/z* 290, 249, 175, 151, 116, 91; Anal. Calcd for $C_{16}H_{18}O_5$: C, 66.20; H, 6.20; Found: C, 66.32; H, 5.16%.

4.1.11. 3-Acetyl-4-(3-allyloxy-4-methoxyphenyl)-but-3-enoic acid (6k). Thick liquid; Yield: 2.50 g, 68%; IR (Chloroform): ν 3029, 1718, 1686, 1212, 758 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.49 (s, 3H), 3.56 (s, 2H), 3.91 (s, 3H), 4.62–4.68 (m, 2H), 5.24–5.45 (m, 2H), 5.97–6.15 (m, 1H), 6.90–7.08 (m, 3H), 7.67 (s, 1H), 9.48 (br s, 1H); MS (ES): *m/z* 291 ($M^+ +1$), 308 ($M+H_2O$); Anal. Calcd for $C_{16}H_{18}O_5$: C, 66.20; H, 6.20; Found: C, 66.13; H, 6.18%.

4.1.12. 3-Acetyl-4-naphthalen-1-yl-but-3-enoic acid (6l). Yellow solid; Yield: 1.87 g, 58%; Mp: 118–120 °C; IR (Chloroform): ν 3020, 1719, 1680, 1488, 1183, 1041, 757, 668 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.62 (s, 3H), 3.43 (s, 2H), 7.28–7.60 (m, 4H), 7.82–7.92 (m, 3H), 8.24 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 207.9, 176.3, 148.7, 148.5, 143.0, 137.1, 136.2, 133.0, 128.4, 123.5, 109.3, 103.1, 102.8, 102.1, 37.1, 28.9; MS (ES): *m/z* 255 ($M^+ +1$), 272 ($M^+ +H_2O$); Anal. Calcd for $C_{16}H_{14}O_3$: C, 75.59; H, 5.51; Found: C, 75.62; H, 5.60%.

4.1.13. 3-Acetyl-4-(2-methoxynaphthalen-1-yl)-but-3-enoic acid (6m). Yellow solid; Yield: 1.62 g, 45%; Mp: 148–151 °C; IR (Chloroform): ν 3030, 1722, 1667, 1512, 1212, 755 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.17 (s, 3H), 3.49 (s, 2H), 3.80 (s, 3H), 6.82 (d, $J=8.0$ Hz, 1H), 7.40–7.58 (m, 3H), 7.75–7.95 (m, 1H), 8.21 (s, 1H); MS (ES): *m/z* 284 (M^+), 307 ($M^+ +Na$); Anal. Calcd for $C_{17}H_{16}O_4$: C, 71.83; H, 5.63; Found: C, 71.60; H, 5.69%.

4.1.14. 3-Acetyl-4-(4-methoxynaphthalen-1-yl)-but-3-enoic acid (6n). Greenish yellow solid; Yield: 2.59 g, 72%; Mp: 131–133 °C; IR (Chloroform): ν 3020, 1784, 1719, 1613, 1503, 1216, 757 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.60 (s, 3H), 3.48 (s, 2H), 4.02 (s, 3H), 6.86 (d, $J=8.0$ Hz, 1H), 7.25–7.60 (m, 3H), 7.77–7.79

(m, 1H), 8.25–8.40 (m, 2H); MS (ES): *m/z* 284 (M^+), 307 ($M^+ + Na$); Anal. Calcd for $C_{17}H_{16}O_4$: C, 71.83; H, 5.63; Found: C, 71.72; H, 5.56%.

4.1.15. 3-Acetyl-4-(2,7-dimethoxynaphthalen-1-yl)-but-3-enoic acid (6o). Brownish yellow solid; Yield: 1.83 g, 46%; Mp: 98–100 °C; IR (Chloroform): ν 3019, 1714, 1670, 1215, 757 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.63 (s, 3H), 3.57 (s, 2H), 3.82 (s, 3H), 3.93 (s, 3H), 6.85–7.12 (m, 3H), 7.55–7.85 (m, 3H); MS (ES): *m/z* 315 ($M^+ + 1$), 332 ($M^+ + H_2O$); Anal. Calcd for $C_{18}H_{18}O_5$: C, 68.78; H, 5.73; Found: C, 68.83; H, 5.61%.

4.1.16. 3-Acetyl-4-(4,8-dimethoxynaphthalen-1-yl)-but-3-enoic acid (6p). Brownish yellow solid; Yield: 2.31 g, 58%; Mp: 153–155 °C; IR (Chloroform): ν 3029, 1720, 1680, 1513, 755 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.16 (s, 3H), 3.48 (s, 2H), 3.88 (s, 3H), 3.96 (s, 3H), 6.70 (d, $J=8.0$ Hz, 1H), 6.92 (t, $J=8.0$, 2.0 Hz, 2H), 7.39 (t, $J=8.0$, 2.0 Hz, 1H), 7.81–7.90 (m, 2H), 9.75 (br s, 1H); MS (ES): *m/z* 314 (M^+); Anal. Calcd for $C_{18}H_{18}O_5$: C, 68.78; H, 5.73; Found: C, 68.69; H, 5.75%.

4.1.17. 3-Acetyl-4-(6-methoxynaphthalen-2-yl)-but-3-enoic acid (6q). Yellow solid; Yield: 2.41 g, 67%; Mp: 122–123 °C; IR (Chloroform): ν 3019, 1718, 1686, 1530, 1216, 757 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.52 (s, 3H), 3.63 (s, 2H), 3.93 (s, 3H), 7.11–7.20 (m, 2H), 7.46 (d, $J=8.0$ Hz, 1H), 7.73–7.86 (m, 4H), 10.14 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 202.1, 158.6, 143.5, 134.7, 130.0, 129.2, 128.4, 127.1, 126.7, 125.2, 123.2, 119.5, 105.5, 55.2, 32.1, 25.3; MS (ES): *m/z* 285 ($M^+ + 1$), 302 ($M^+ + H_2O$); Anal. Calcd for $C_{17}H_{16}O_4$: C, 71.83; H, 5.63; Found: C, 71.89; H, 5.58%.

4.1.18. 3-Acetyl-4-(1,4-dimethoxynaphthalen-2-yl)-but-3-enoic acid (6r). Brownish yellow solid; Yield: 2.19 g, 55%; Mp: 117–120 °C; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.16 (s, 3H), 3.57 (s, 2H), 3.80 (s, 3H), 3.92 (s, 3H), 6.47 (s, 1H), 7.11(s, 1H), 7.50–7.53 (m, 2H), 8.08–8.17 (m, 2H), 10.23 (br s, 1H); MS (ES): *m/z* 314 (M^+), 332 ($M^+ + H_2O$); Anal. Calcd for $C_{18}H_{18}O_5$: C, 68.78; H, 5.73; Found: C, 68.82; H, 5.65%.

4.2. Typical procedure for the synthesis of 4-benzyl (substituted)-5-methylene-2(5*H*)-furanones (1)

The carboxylic acid **6** (10.2 mmol) was mixed with acetic anhydride (4.8 mL, 51 mmol) and anhydrous sodium acetate (20.4 mmol) and allowed to stir at 85 °C under nitrogen atmosphere for 3 h. The mixture was allowed to cool to room temperature, the reaction mixture was poured over ice (100 g), stirred vigorously for 30 min and extracted with ethyl acetate (100 mL). The organic layer was washed repeatedly with fresh portions of water followed by dilute sodium bicarbonate solution to remove all traces of acetic anhydride and acetic acid. The organic layer was washed with brine, dried over anhydrous sodium sulfate and concentrated under reduced pressure. Purification of residue by column chromatography (EtOAc/petroleum ether 1:4) provided desired furanones in 48–75% yields.

4.2.1. 4-(4-Methoxybenzyl)-5-methylene-2(5*H*)-furanone (1a). Viscous oil; Yield: 1.14 g, 52%; IR (Chloroform): ν 3020, 1764, 1513, 1249 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.72 (s, 2H), 3.81 (s, 3H), 4.94 (d, $J=2.7$ Hz, 1H), 5.15–5.19 (m, 1H), 5.81 (br s, 1H), 6.87 (d, $J=8.6$ Hz, 2H), 7.11 (d, $J=8.6$ Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.3, 158.4, 155.1 (2C), 129.5 (2C), 127.5, 117.7, 113.9 (2C), 94.5, 54.8, 31.3; MS: *m/z* 216, 201,145,121, 77; Anal. Calcd for ($C_{13}H_{12}O_3$): C, 72.22; H, 5.55; Found: C, 72.29; H, 5.37%.

4.2.2. 4-(2,4-Dimethoxybenzyl)-5-methylene-2(5*H*)-furanone (1b). Viscous oil; Yield: 1.61 g, 64%; IR (Chloroform): ν 3021, 1764, 1216 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.71 (s, 2H), 3.78 (s, 3H), 3.80 (s, 3H), 5.01 (d, $J=2.7$ Hz, 1H), 5.13–5.17 (m, 1H), 5.75 (br s, 1H), 6.44–6.53 (m, 2H), 7.02 (d, $J=8$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.4, 158.3, 157.5, 155.1, 130.1, 116.9, 116.2, 107.9, 104.0, 98.1, 93.9, 54.7 (2C), 25.9; MS (ESI): *m/z* 247 $(MH)^+$; Anal. Calcd for $C_{14}H_{14}O_4$: C, 68.29; H, 5.69; Found: C, 68.16, H, 5.74%.

4.2.3. 4-(3,4-Dimethoxybenzyl)-5-methylene-2(5*H*)-furanone (1c). Viscous oil; Yield: 1.68 g, 67%; IR (Chloroform): ν 3020, 1778, 1760, 1709, 1502, 1237 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.71 (br s, 2H), 3.82 (s, 3H), 3.83 (s, 3H), 4.91 (d, $J=2.7$ Hz, 1H), 5.11–5.14 (m, 1H), 5.79 (br s, 1H), 6.66 (dd, $J=7.8$, 2.0 Hz, 1H), 6.73 (dd, $J=7.8$, 2.0 Hz, 1H), 6.79 (d, $J=7.8$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 168.5, 158.2, 155.2, 149.0, 148.0, 128.0, 120.7, 117.9, 111.6, 111.3, 94.7, 55.6 (2C), 32.0; MS (ESI): *m/z* 246 $(MH)^+$; Anal. Calcd for $C_{14}H_{14}O_4$: C, 68.29; H, 5.69; Found: C, 68.35; H, 5.66%.

4.2.4. 5-Methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (1d). White solid; Yield: 2.03 g, 72%; Mp: 115–117 °C; IR (Chloroform): ν 3016, 1753, 1500, 1217, 1037, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.74 (s, 2H), 3.84 (s, 9H), 4.96 (d, $J=2.9$ Hz, 1H), 5.16–5.21 (m, 1H), 5.85 (br s, 1H), 6.39 (s, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.4, 157.8, 155.7, 153.8 (2C), 137.6, 131.5, 118.6, 106.2 (2C), 94.6, 60.8, 56.2 (2C), 33.0; MS (ESI): *m/z* 276 (M+), 261, 245, 217, 181, 166; Anal. Calcd for $C_{15}H_{16}O_5$: C, 65.21; H, 5.79; Found: C, 65.45; H, 5.58%.

4.2.5. 4-(1,3-Benzodioxol-5-ylmethyl)-5-methylene-2(5*H*)-furanone (1e). Viscous oil; Yield: 1.31 g, 56%; IR (Chloroform): ν 3018, 1787, 1764, 1217 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.71 (s, 2H), 4.93 (d, $J=2.3$ Hz, 1H), 5.13–5.17 (m, 1H), 5.84 (br s, 1H), 5.95 (s, 2H), 6.60–6.69 (m, 2H), 6.75 (d, $J=8.5$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.2, 157.9, 155.0, 147.6, 129.2, 121.5, 117.8, 108.7, 108.1 (2C), 100.8, 94.5, 31.8; MS (ESI): *m/z* 231 $(MH)^+$; Anal. Calcd for $C_{13}H_{10}O_4$: C, 67.82; H, 4.31; Found: C, 67.61; H, 4.26%.

4.2.6. 4-[(7-Methoxy-1,3-benzodioxol-5-yl)methyl]-5-methylene-2(5*H*)-furanone (1f). Brownish yellow solid; Yield: 1.46 g, 55%; Mp: 150 °C; IR (Chloroform): ν 3020, 1788, 1766, 1512, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.69 (unresolved doublet, 2H), 3.86 (s, 3H), 4.93 (d, $J=2.7$ Hz, 1H), 5.12–5.18 (m, 1H), 5.83

(br s, 1H), 5.94 (s, 2H), 6.34 (unresolved doublet, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.2, 157.8, 155.2, 149.1, 143.6, 130.0, 118.2, 108.3, 108.2, 102.7, 101.4, 94.8, 56.5, 32.7; MS (ESI): *m/z* 261 $(MH)^+$; Anal. Calcd for $C_{14}H_{12}O_5$: C, 64.61; H, 4.61; Found: 64.53; H, 4.49%.

4.2.7. 4-(4-Chloro-2,5-dimethoxybenzyl)-5-methylene-2(5*H*)-furanone (1g). Pale yellow solid; Yield: 2.15 g, 75%; Mp: 115–117 °C; IR (Chloroform): ν 3019, 1788, 1763, 1499, 1216 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.73 (s, 2H), 3.77 (s, 3H), 3.82 (s, 3H), 4.98 (d, J= 2.9 Hz, 1H), 5.13–5.18 (m, 1H), 5.74 (br s, 1H), 6.73 (s, 1H), 6.92 (s, 1H); ^{13}C NMR: (50 MHz, $CDCl_3+CCl_4$): δ 168.6, 157.3, 155.5, 151.3, 149.3, 123.7, 122.1, 118.0, 115.1, 113.5, 94.4, 57.0, 56.0, 26.9; MS (ESI): *m/z* 282 and 280 (M^+), 244, 221, 185, 158, 89; Anal. Calcd for $C_{14}H_{13}O_4Cl$: C, 59.89; H, 4.64; Found: C, 60.12; H, 4. 70%.

4.2.8. 5-Methylene 4-(4-thiomethyl)benzyl-2(5*H*)-furanone (1h). Yellow solid; Yield: 1.49 g, 63%; Mp: 55–57 °C; IR (Chloroform): ν 3021, 1788, 1765, 1652, 1212 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.42 (s, 3H), 3.72 (s, 2H), 4.91 (d, J=3.1 Hz, 1H), 5.08–5.13 (m, 1H), 5.76 (br s, 1H), 7.07 (d, J=8 Hz, 2H), 7.17 (d, J= 8 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.2, 157.6, 155.1, 137.2, 132.3, 129.0 (2C), 126.5 (2C), 118.0, 94.6, 31.6, 15.3; MS (ESI): *m/z* 232 (M^+); Anal. Calcd for $C_{13}H_{12}O_2S$: C, 67.24; H, 5.17; S, 13.79; Found C, 67.13, H, 4.95; S, 13.68%.

4.2.9. 4-(2-Iodo-3,4,5-trimethoxybenzyl)-5-methylene-2(5*H*)-furanone (1i). Pinkish brown solid; Yield: 2.34 g, 57%; Mp: 109 °C; IR (Chloroform): ν 3016, 1788, 1764, 1562, 1228 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.80 (s, 2H), 3.81 (s, 6H), 3.84 (s, 3H), 4.99 (d, J=3.1 Hz, 1H), 5.12–5.15 (m, 1H), 5.65 (br s, 1H), 6.63 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.2, 156.6, 155.0, 153.7 (2C), 153.3, 141.0, 134.4, 118.2, 109.2, 94.5, 60.7, 60.5, 55.9, 37.8; MS (ESI): *m/z* 403 $(MH)^+$, 420 $(M+H_2O)$; Anal. Calcd for $C_{15}H_{15}O_5I$: C, 44.77; H, 3.73; Found C, 44.52; H, 3.64%.

4.2.10. 4-[4-(Allyloxy)-3-methoxybenzyl]-5-methylene-2(5*H*)-furanone (1j). Viscous oil; Yield: 1.23 g, 48%; IR (Chloroform): ν 3015, 1788, 1765, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.71 (br s, 2H), 3.83 (s, 3H), 4.54–4.59 (m, 2H), 4.91 (d, J=2.9 Hz, 1H), 5.12–5.16 (m, 1H), 5.21–5.42 (m, 2H), 5.79 (br s, 1H), 5.95–6.14 (m, 1H), 6.61–6.75 (m, 2H), 6.81 (d, J=8.7 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.2, 157.8, 155.2, 149.5, 147.0, 132.9, 128.3, 120.5, 117.9, 117.5, 113.6, 112.1, 94.2, 69.5, 55.6, 31.8; MS (ESI): *m/z* 272 (M^+), 231, 203, 137, 77; Anal. Calcd for $C_{16}H_{16}O_4$: C, 70.58; H, 5.88; Found: C, 70.63; H, 5.77%.

4.2.11. 4-[3-(Allyloxy)-4-methoxybenzyl]-5-methylene-2(5*H*)-furanone (1k). Pale yellow gum; yield: 1.58 g, 57%; IR (Chloroform): ν 3015, 1788, 1765, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.74 (br s, 2H), 3.88 (s, 3H), 4.61 (d, J=6.0 Hz, 2H), 4.95 (d, J=2.5 Hz, 1H), 5.20 (d, J=2.5 Hz, 1H), 5.28–5.42 (m, 2H), 5.83 (s, 1H), 5.88–6.18 (m, 1H), 6.70–6.88 (m, 3H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.4, 158.0, 155.5, 149.0, 148.3, 133.2, 128.2, 121.4, 118.2, 117.6, 114.7, 112.4, 94.4, 70.0, 55.9, 32.0; MS (ESI): *m/z* 273 (M+1), 291 $(MH^+ + H_2O)$; Anal. Calcd for $C_{16}H_{16}O_4$: C, 70.58; H, 5.88; Found: C, 70.61; H, 5.97%.

4.2.12. 5-Methylene-4-(1-naphthylmethyl)-2(5*H*)-furanone (1l). Pinkish white solid; Yield: 1.61 g, 67%; Mp: 115 °C; IR (Chloroform): ν 2926, 1768, 1719, 1220 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 4.24 (s, 2H), 5.13 (d, J=2.7 Hz, 1H), 5.25–5.30 (m, 1H), 5.57 (br s, 1H), 7.30–7.56 (m, 4H), 7.80–7.95 (m, 3H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.4, 157.6, 155.2, 133.7, 131.7, 131.2, 128.8, 128.2, 127.2, 126.4, 125.8, 125.3, 123.2, 118.5, 94.5, 29.9; MS (ESI): *m/z* 237 $(MH)^+$, 254 $(M+H_2O)$; Anal. Calcd for $C_{16}H_{12}O_2$: C, 81.35; H, 5.08.; Found C, 81.47; H, 5.10%.

4.2.13. 4-[(2-Methoxy-1-naphthyl)methyl]-5-methylene-2(5*H*)-furanone (1m). Pale yellow solid; Yield: 1.66 g, 61%; Mp: 135 °C; IR (Chloroform): ν 3020, 1770, 1768, 1530, 1212 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.97 (s, 3H), 4.24 (s, 2H), 5.22 (d, J=2.9 Hz, 1H), 5.24–5.28 (m, 1H), 5.46 (br s, 1H), 7.30–7.53 (m, 3H), 7.68 (d, J=8.0 Hz, 1H), 7.79–7.91 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.8, 158.0, 155.6, 154.4, 132.4, 129.2, 128.9, 128.5, 126.8, 123.4, 122.2, 117.6, 116.5, 112.6, 94.0, 56.1, 21.9; MS (ESI): *m/z* 266 $(M)^+$, 251, 236, 221, 171, 77; Anal. Calcd for $C_{17}H_{14}O_3$: C, 63.90; H, 5.26; Found: C, 63.93; H, 5.27%.

4.2.14. 4-[(4-Methoxy-1-naphthyl)methyl]-5-methylene-2(5*H*)-furanone (1n). Pale yellow solid; Yield: 1.68 g, 62%; Mp: 82 °C; IR (Chloroform): ν 3019, 1787, 1765, 1653, 1216 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 4.00 (s, 3H), 4.09 (s, 2H), 5.07 (d, J=2.7 Hz, 1H), 5.21–5.23 (m, 1H), 5.55 (br s, 1H), 6.76 (d, J=7.8 Hz, 1H), 7.24 (d, J=7.8 Hz, 1H); 7.46 –7.55 (m, 2H), 7.64–7.73 (m, 1H), 8.31–8.38 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.3, 158.1, 155.2, 155.0, 131.9, 127.2, 126.7, 125.8, 125.0, 123.5, 123.0, 122.6, 118.2, 103.0, 94.2, 55.2, 29.3; MS (ESI): *m/z* 266 $(M)^+$; Anal. Calcd for $C_{17}H_{14}O_3$: C, 63.90; H, 5.26; Found: C, 64.13; H, 5.32%.

4.2.15. 4-(4,8-Dimethoxy-naphthalen-1-ylmethyl)-5-methylene-2(5*H*)-furanone (1o). Pale yellow solid; Yield: 1.57 g, 52%; Mp: 129 °C; IR (Chloroform): ν 2926, 1765, 1744, 1500, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.76 (s, 3H), 4.01 (s, 3H), 4.28 (s, 2H), 5.09 (d, J=2.5 Hz, 1H), 5.23–5.26 (m, 1H), 5.34 (br s, 1H), 6.77 (d, J=7.8 Hz, 1H), 6.84 (d, J=7.8 Hz, 1H), 7.17 (d, J=7.8 Hz, 1H), 7.40 (t, J=8.2 Hz, 1H), 7.95 (d, J=8.2 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 169.2, 161.4, 156.0, 154.7, 129.0 (2C), 128.0, 125.3, 124.3, 123.3, 116.0, 114.9, 106.4, 103.7, 93.3, 55.3, 54.9, 34.5; MS (ESI): *m/z* 297 $(MH)^+$; Anal. Calcd for $C_{18}H_{16}O_4$: C, 72.97; H, 5.40; Found: C, 73.18; H, 5.29%.

4.2.16. 4-[(2,7-Dimethoxy-1-naphthyl)methyl]-5-methylene-2(5*H*)-furanone (1p). Pale yellow solid; Yield: 1.75 g, 58%; Mp: 85 °C; IR (Chloroform): ν 3019, 1768, 1605, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.85 (s, 3H), 3.93 (s, 3H), 4.16 (unresolved doublet, 2H), 5.19–5.27 (m, 2H), 5.53 (br s, 1H), 6.88 (d, J=2.0 Hz, 1H),

7.03 (dd, $J=8.0$, 2.0 Hz, 1H), 7.15 (d, $J=8.0$ Hz, 1H), 7.74 (t, $J=8.0$ Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 168.8, 158.5, 158.1, 155.7, 155.0, 133.8, 130.1, 129.0, 124.4, 117.6, 115.7, 115.5, 110.0, 101.3, 94.1, 56.0, 55.0, 22.1; MS (ESI): *m/z* 296 $(M)^+$, 268, 253, 237, 216, 201, 185, 165, 105, 77; Anal. Calcd for $C_{18}H_{16}O_4$: C, 72.97; H, 5.40; Found: C, 72.83; H, 5.51%.

4.2.17. 4-[(6-Methoxy-2-naphthyl)methyl]-5-methylene-2(5*H*)-furanone (1q). Pale yellow solid; Yield: 1.55 g, 57%; Mp: 122 °C; IR (Chloroform): ν 3019, 1778, 1765, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$ + acetone-d_6): δ 3.92 (br s, 5H), 4.96 (d, $J=2.9$ Hz, 1H), 5.15–5.21 (m, 1H), 5.85 (br s, 1H), 7.10–7.28 (m, 3H), 7.57 (br s, 1H), 7.69 (t, $J=8.0$ Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 167.6, 157.6, 157.2, 155.0, 133.1, 130.6, 128.4 (2C), 126.7, 126.6 (2C), 118.6, 117.7, 105.1, 93.9, 54.5, 31.8; MS (ESI): *m/z* 266 $(M)^+$, 251, 177, 91; Anal. Calcd for $C_{17}H_{14}O_3$: C, 63.90; H, 5.26; Found: C, 63.76; H, 5.13%.

4.2.18. 4-[(1,4-Dimethoxy-2-naphthyl)methyl]-5-methylene-2(5*H*)-furanone (1r). Pale yellow solid; Yield: 1.93 g, 64%; Mp: 87 °C; IR (Chloroform): ν 2920, 1768, 1717, 1672, 1221 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ 3.88 (s, 3H), 3.96 (s, 3H), 4.01 (br s, 2H), 5.12 (d, $J=2.9$ Hz, 1H), 5.20–5.25 (m, 1H), 5.88 (br s, 1H), 7.49–7.65 (m, 3H), 8.04 (dd, $J=8.0$, 2.0 Hz, 1H), 8.26 (dd, $J=8.0$, 2.0 Hz, 1H); MS (ESI): *m/z* 296 (M+); Anal. Calcd for $C_{18}H_{16}O_4$: C, 72.97; H, 5.40; Found: C, 72.93; H, 5.38%.

4.2.19. Mixed anhydride 8a. Pale brown solid; Yield: 0.58 g, 17%; Mp: 65–67 °C, IR (Chloroform): ν 3019, 1778, 1717, 1662, 1515, 1263, 1216, 757 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): 1.73 (s, 3H), 1.98 (s, 3H), 3.50 (q, $J=4.0$ Hz, 2H), 3.81 (s, 3H), 3.83 (s, 6H), 5.69 (s, 1H), 6.38 (s, 2H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 199.0, 168.5, 167.6, 153.2 (2C), 137.2, 131.2, 130.1, 118.4, 106.1, 105.5, 60.5, 55.9 (2C), 33.4, 23.4, 21.1; MS (ESI): *m/z* 354 $(M+H_2O)^+$, 337 $(MH)^+$; Anal. Calcd for $C_{17}H_{20}O_7$: C, 60.71; H, 5.99; Found: C, 60.61; H, 6.07%.

4.2.20. 4-Butyl-4-hydroxy-2-(3,4,5-trimethoxybenzyl)-cyclopent-2-enone. A solution of furanone **1d** (0.20 g, 0.72 mmol) in dry tetrahydrofuran (2 mL) was added dropwise into a solution of *n*-butyllithium (0.90 mmol) in dry tetrahydrofuran (15 mL) at −78 °C over 30 min. 3,4,5-Trimethoxybenzaldehyde (0.142 g, 0.72 mmol) in dry tetrahydrofuran (5 mL) was added dropwise to the brick red colored reaction mixture and the reaction was allowed to stir at 0 °C for 1 h. It was then quenched with saturated ammonium chloride (10 mL). The reaction mixture was extracted with ethyl acetate (2×15 mL), organic layer was washed with water (20 mL) followed by brine (15 mL) and dried over sodium sulfate. After evaporation, the residue was chromatographed over silica gel with petroleum ether–ethyl acetate as an eluent to afford the title compound.

Pale yellow thick oil; Yield: 0.11 g, 45%; IR (Chloroform): ν 3500, 2940, 1720, 1580, 1220 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 0.86 (t, $J=6.0$ Hz, 3H), 1.18–1.30 (m, 2H), 1.50–1.80 (m, 2H), 2.43 (d, $J=20.0$ Hz, 1H), 2.57 (d, $J=20.0$ Hz, 1H), 3.35 (s, 2H), 3.78 (s, 3H), 3.80 (s, 6H), 6.36 (s, 2H), 6.87 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 205.8, 160.1, 153.2 (2C), 145.2, 136.2, 133.7, 128.5, 106.0 (2C), 60.9, 56.0 (2C), 49.3, 40.2, 31.2, 26.4, 22.9, 13.9; MS (ESI): *m/z* 335 $(MH)^+$, 352 $(M+H_2O)$; Anal. Calcd for $C_{19}H_{26}O_5$: C, 68.26; H, 7.78; Found: C, 68.31; H, 7.54%.

4.3. A typical procedure for the synthesis of 5-methylene-3,4-dibenzyl (substituted)-2(5*H*)-furanones

A solution of furanone **1** (0.72 mmol) in dry tetrahydrofuran (2 mL) was added dropwise into a solution of lithium diisopropylamide (0.90 mmol) in dry tetrahydrofuran (7 mL) at −78 °C over 10 min and stirred further for 20 min. Aldehyde (0.72 mmol) in dry tetrahydrofuran (10 mL) was added dropwise to the brick red reaction mixture, the reaction was allowed to stir at same temperature for 1 h and then it was quenched with saturated ammonium chloride (5 mL) containing acetic acid (2 mL). The reaction mixture was extracted with ethyl acetate (2× 15 mL), organic layer was washed with water (15 mL), dilute sodium bicarbonate solution (15 mL) followed by brine (10 mL) and dried over sodium sulfate. After evaporation, the residue was chromatographed on silica gel with petroleum ether-ethyl acetate as an eluent to collect the title compounds (yield ranges from 35 to 66%).

4.3.1. 3-[Hydroxy-5-methylene-4-(3,4,5-trimethoxybenzyl)-(3,4,5-trimethoxyphenyl)methyl]-2(5*H*)-furanone (11a). Pale yellow gum; Yield: 0.16 g, 48%; IR (Chloroform): ν 3515, 1766, 1713, 1655, 1223 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.71 (s, 6H), 3.74 (s, 6H), 3.75–3.95 (m including s at 3.79, 8H), 4.92 (d, $J=$ 2.9 Hz, 1H), 5.22 (d, $J=2.9$ Hz, 1H), 5.68 (br s, 1H), 6.24 (s, 2H), 6.59 (s, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.0, 154.7 (2C), 153.3 (4C), 148.6, 136.9, 136.5, 132.1, 131.3, 105.3 (2C), 102.9 (2C), 96.0, 68.6, 60.6 (2C), 55.9 (4C), 30.5; MS (ESI): *m/z* 472 (M^+); Anal. Calcd for $C_{25}H_{28}O_9$: C, 63.55; H, 5.93; Found: C, 63.47; H, 6.05%.

4.3.2. 3-[Hydroxy-(3-hydroxy-4-methoxyphenyl)-methyl]-5-methylene-4-(3,4,5-trime-thoxybenzyl)-2(5*H*)-furanone (11b). Thick yellow gum; Yield: 0.17 g, 55%; IR (Chloroform): ν 3540, 3019. 1765, 1592, 1508, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.73 (s, 6H), 3.80 (s, 3H), 3.86 (s, 3H), 3.89 (s, 2H), 4.91 (d, $J=$ 2.9 Hz, 1H), 5.19 (d, $J=2.9$ Hz, 1H), 5.65 (br s, 1H), 5.74 (br s, 1H), 6.27 (s, 2H), 6.76 (d, $J=8.0$ Hz, 1H), 6.87 (d, $J=$ 8.0 Hz, 1H), 6.89 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+$ CCl_4): δ 169.0, 154.8, 153.5 (2C), 148.7, 145.9, 143.9, 134.3, 132.1, 131.3, 129.6, 117.8, 112.5, 110.7, 107.1, 105.7, 96.1, 68.5, 60.7, 56.2, 56.0, 55.9, 30.7; MS (ESI): *m/z* 428 $(MH)^+$; Anal. Calcd for $C_{23}H_{24}O_8$: C, 64.48; H, 5.60; Found: C, 64.54; H, 5.62%.

4.3.3. 3-[Hydroxy-(7-methoxybenzo[1,3]dioxol-5-yl)-methyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11c). Thick yellow gum; Yield: 0.17 g, 52%; IR (Chloroform): ν 3438, 1763, 1637, 1508, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.75 (s, 6H), 3.81 (s, 3H), 3.82 (s, 3H), 3.90 (br s, 2H), 4.94 (d, $J=2.9$ Hz, 1H), 5.22 (d, $J=2.9$ Hz, 1H), 5.64 (s, 1H), 5.94 (s, 2H), 6.27

(s, 2H), 6.50 (br s, 1H), 6.59 (br s, 1H); MS (ESI): *m/z* 456 (M^+), 473 ($M+NH_3$), Anal. Calcd for $C_{24}H_{24}O_9$: C, 61.11; H, 5.55; Found: C, 61.28; H, 5.67%.

4.3.4. 3-(Hydroxy-benzo[1,3]dioxol-5-yl-methyl)-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11d). Thick pale yellow gum; Yield: 0.18 g, 60%; IR (Chloroform): ν 3498, 3018, 1763, 1592, 1505, 1216 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.74 (s, 6H), 3.80 (s, 3H), 3.90 (s, 2H), 4.93 (d, $J=2.9$ Hz, 1H), 5.21 (d, $J=2.9$ Hz, 1H), 5.65 (br s, 1H), 5.93 (s, 2H), 6.27 (s, 2H), 6.72 (d, $J=8.0$ Hz, 1H), 6.76–6.89 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.0, 154.7(2C), 153.4(2C), 148.0, 147.4, 134.9, 132.0, 131.1 (2C), 119.6, 108.2, 106.0, 105.4 (2C), 101.1, 96.3, 68.7, 60.8, 56.0 (2C), 26.8; MS (ESI): *m/z* 426 (M+), 443 (M-1+H_2O); Anal. Calcd for $C_{23}H_{22}O_8$: C, 64.78; H, 5.16; Found: C, 64.70; H, 5.23%.

4.3.5. 3-[Hydroxy-(4-methoxy-3-nitrophenyl)methyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11e). Thick tan gum; Yield: 0.16 g, 49%; IR (Chloroform): ν 3515, 3015, 1766, 1713, 1655, 1592, 1492, 1223 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.75 (s, 6H), 3.80 (s, 3H), 3.85 (s, 2H), 3.93 (s, 3H), 5.02 (d, $J=2.9$ Hz, 1H), 5.29 (d, $J=2.9$ Hz, 1H), 5.71 (br s, 1H), 6.28 (s, 2H), 6.98 (d, $J=8.0$ Hz, 1H), 7.48 (dd, $J=8.0$, 2.0 Hz, 1H), 7.76 (d, $J=2.0$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 168.7, 159.7, 154.9, 153.7 (2C), 152.6, 149.6, 137.6, 133.3, 131.7, 131.5, 130.2, 123.2, 113.7, 105.7 (2C), 96.8, 67.4, 60.8, 56.6, 56.2 (2C), 30.7; MS (ESI): *m/z* 457 $(M)^+$, 475 ($M+H_2O$); Anal. Calcd for $C_{23}H_{23}NO_9$: C, 60.39; H, 5.32; N, 3.06; Found: C, 60.41; H, 5.38; N, 3.13%.

4.3.6. 3-[Hydroxy-(2-methoxynaphthalen-1-yl)methyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11f). Thick pale yellow gum; Yield: 0.17 g, 52%; IR (Chloroform): ν 3421, 3019, 1760, 1595, 1508, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.33–3.65 (m, 2H), 3.61 (s, 6H), 3.76 (s, 3H), 3.87 (s, 3H), 4.84 (d, $J=2.9$ Hz, 1H), 5.18 (d, $J=2.9$ Hz, 1H), 5.88 (s, 2H), 6.68 (s, 1H), 7.15 (d, $J=9.2$ Hz, 1H), 7.30–7.52 (m, 2H), 7.77 (dd, $J=9.2$, 2.4 Hz, 2H), 8.06 (d, $J=8.3$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.2, 158.5, 154.9, 153.2, 150.0, 146.9, 137.1, 131.7, 130.8 (2C), 129.4, 128.7, 127.1, 123.7 (2C), 123.0, 113.3, 109.2, 105.3 (2C), 96.1, 63.8, 60.6, 56.4, 56.0 (2C), 30.1; MS (ESI): *m/z* 462 $(M)^+$, 444 (M-H_2O); Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.62; Found: C, 70.27; H, 5.72%.

4.3.7. 3-[Hydroxy-(4-methoxynaphthalen-1-yl)methyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11g). Brownish yellow gum; Yield: 0.25 g, 75%; IR (Chloroform): ν 3426, 3015, 2939, 1764, 1594, 1592, 1239 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.54 s, 6H), 3.66 (br s, 2H), 3.72 (s, 3H), 3.97 (s, 3H), 4.94 (d, $J=2.9$ Hz, 1H), 5.25 (d, $J=2.9$ Hz, 1H), 6.03 (s, 2H), 6.37 (s, 1H), 6.67 (d, $J=8.0$ Hz, 1H), 7.30–7.60 (m, 3H), 8.00 (dd, 1H, $J=8.0$, 2.0 Hz, 1H), 8.28 (dd, $J=8.0$, 2.0 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.7, 155.7, 154.7, 153.0 (2C), 150.0, 136.4, 131.7, 131.3, 130.8, 127.6, 127.0 (2C), 125.1, 124.0, 123.0, 122.6, 105.0 (2C), 102.4, 96.3, 65.2, 60.6, 55.6, 55.3 (2C), 30.6; MS (ESI): *m/z* 480 ($M+H_2O$), 463 $(MH)^+$; Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.62; Found: C, 69.93; H, 5.49%.

4.3.8. 3-[(2,7-Dimethoxynaphthalen-1-yl)-hydroxymethyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11h). Pale yellow gum; Yield: 0.20 g, 57%; IR (Chloroform): ν 3418, 3015, 2900, 1778, 1615, 1212 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.57 (s, 6H), 3.74 (s, 2H), 3.84 (s, 9H), 4.81 (d, $J=2.9$ Hz, 1H), 4.89 (br s, 1H), 5.16 (d, $J=2.9$ Hz, 1H), 5.84 (s, 2H), 6.67 (br s, 1H), 6.95 (dd, $J=2.0$, 6.6 Hz, 2H), 7.40 (d, $J=2.0$ Hz, 1H), 7.65 (t, $J=7.0$ Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.7, 158.6, 155.2, 154.5, 152.9 (2C), 147.3, 136.2, 133.2, 131.7, 131.4, 130.4, 130.1, 124.7, 119.5, 116.4, 110.2, 104.4 (2C), 101.6, 95.6, 63.8, 60.6, 56.1, 55.7 (2C), 55.2, 30.0; MS (ESI): *m/z* 492 $(M)^+$; Anal. Calcd for $C_{28}H_{28}O_8$: C, 68.29; H, 5.69; Found: C, 68.08; H, 5.81%.

4.3.9. 3-[(4,8-Dimethoxy-naphthalen-1-yl)-hydroxymethyl]-5-methylene-4-(3, 4, 5-trimethoxybenzyl)-2(5*H*)-furanone (11i). Brownish yellow solid; Yield: 0.19 g, 55%; Mp: 197 °C; IR (Chloroform): ν 3400, 3018, 2938, 1772, 1599, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.33 (d, $J=14.0$ Hz, 1H), 3.48 (d, $J=14.0$ Hz, 1H), 3.67 (s, 6H), 3.78 (s, 3H), 3.87 (s, 3H), 3.96 (s, 3H), 4.82 (d, $J=2.9$ Hz, 1H), 5.12 (d, $J=2.9$ Hz, 1H), 6.23 (s, 2H), 6.69 (d, $J=8.3$ Hz, 1H), 6.75–6.92 (m, 2H), 7.36 (t, $J=8.3$ Hz, 1H), 7.61 (d, $J=8.3$ Hz, 1H), 7.91 (d, $J=8.3$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.1, 154.8, 153.5 (2C), 148.7, 143.8, 143.3 (2C), 141.8, 140.9, 139.4, 132.0, 131.3, 126.9, 126.8, 125.0, 124.8, 123.8, 119.9 (2C), 105.6 (2C), 96.2, 69.2, 60.7, 56.0 (2C), 36.8; MS (ESI): *m/z* 474 (M-H_2O)$^+$; Anal. Calcd for $C_{28}H_{28}O_8$: C, 68.29; H, 5.69; Found: C, 68.30; H, 5.74%.

4.3.10. 3-[Hydroxy-(6-methoxynaphthalen-2-yl)-methyl]-5-methylene-4-(3,4,5-trimethoxybenzyl)-2(5*H*)-furanone (11j). Yellow solid; Yield: 0.19 g, 57%; MP: 82 °C; IR (Chloroform): ν 3435, 3018, 1764, 1594, 1506, 1216 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.55 (s, 6H), 3.75 (s, 3H), 3.80–3.85 (m, 2H), 3.90 (s, 3H), 4.90 (d, $J=2.9$ Hz, 1H), 5.19 (d, $J=2.9$ Hz, 1H), 5.88 (s, 1H), 6.18 (s, 2H), 7.04–7.15 (m, 2H), 7.43 (d, $J=8.0$ Hz, 1H), 7.58–7.70 (m, 3H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.1, 159.6, 158.0, 154.7, 153.3(2C), 148.9, 137.0, 136.0, 134.2, 132.0, 131.2, 129.4, 128.6, 127.4, 124.7, 124.4, 119.2, 105.5, 105.4, 96.1, 68.9, 60.7, 55.8 (2C), 55.2, 30.8; MS (ESI): *m/z* 462 $(M)^+$; Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.67; Found: C, 70.23; H, 5.55%.

4.3.11. 3-(Benzo[1,3]dioxol-5-yl-hydroxymethyl)-4-benzo[1,3]dioxol-5-ylmethyl-5-methylene-2(5*H*)-furanone (13). Thick gum; Yield: 0.14 g, 52%; IR (Chloroform): ν 3446, 2935, 1743, 1593, 1240, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.80 (d, $J=14.0$ Hz, 1H), 3.90 (d, $J=14.0$ Hz, 1H), 4.92 (d, $J=2.0$ Hz, 1H), 5.22 (d, $J=2.0$ Hz, 1H), 5.65 (s, 1H), 5.95 (br s, 2H), 6.56 (d, $J=8.0$ Hz, 2H), 6.72–6.83 (m, 4H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 172.2, 154.1, 149.2 (2C), 147.8, 136.3, 131.8, 120.7, 118.6, 115.1 (2C), 108.2, 107.3, 107.1, 105.9, 100.2 (2C), 95.2, 94.7, 67.3, 29.3; MS (ESI): *m/z* 381 $(MH)^+$, 399 (MH+18); Anal. Calcd for $C_{21}H_{16}O_7$: C, 55.26; H, 4.21; Found: C, 55.31; H, 4.23%.

4.3.12. 4-Benzo[1,3]dioxol-5-ylmethyl-3-[hydroxy-(3,4,5-trimethoxyphenyl)-methyl]-5-methylene-2(5*H*)-furanone (15). Pale yellow gum; Yield: 0.17 g, 55%; IR (Chloroform): ν 3446, 3018, 1755, 1708, 1217, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.74 (s, 3H), 3.79 (s, 3H), 3.81 (m, 2H), 3.84 (s, 3H), 4.88 (d, $J=2.0$ Hz, 1H), 5.18 (d, $J=2.0$ Hz, 1H), 5.68 (br s, 1H), 5.92 (s, 2H), 6.52–6.69 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.92, 154.4, 153.0 (2C), 148.8, 146.7, 146.6, 136.2, 130.7, 130.3, 120.9, 115.7, 108.3, 108.1, 103.4, 102.6, 100.8, 96.3, 68.6, 60.5, 55.6 (2C), 29.7; MS (ESI): *m/z* 426 (M^+), 443 (M-1+H_2O); Anal. Calcd for $C_{23}H_{22}O_8$: C, 64.78; H, 5.16; Found: C, 64.83; H, 5.21%.

4.3.13. 3-[Hydroxy-(3,4,5-trimethoxyphenyl)-methyl]-4-(6-methoxynaphthalen-2-yl-methyl)-5-methylene-2(5*H*)-furanone (17). Thick yellow foam; Yield: 0.18 g, 53%; IR (Chloroform): ν 3401, 3019, 1773, 1653, 1507, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.58 (s, 6H), 3.77 (s, 3H), 3.85 (s, 3H), 4.03 (d, $J=14.0$ Hz, 1H), 4.16 (d, $J=14.0$ Hz, 1H), 4.92 (d, $J=2.9$ Hz, 1H), 5.19 (d, $J=2.9$ Hz, 1H), 5.70 (br s, 1H), 6.53 (s, 2H), 6.55 (d, $J=8.0$ Hz, 1H), 7.05–7.18 (m, 2H), 7.38 (br s, 1H), 7.56 (d, $J=8.0$ Hz, 1H), 7.62 (d, $J=8.0$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.0, 157.8, 155.0, 153.3 (2C), 148.8, 137.6, 136.6, 136.4, 133.4, 131.7, 131.3, 128.9, 127.3, 126.7, 126.5, 119.2, 105.7, 104.1, 103.4, 96.1, 69.1, 60.6, 56.0, 55.9, 55.2, 30.3; MS (ESI): *m/z* 480 (M+H_2O), 462 $(M)^+$; Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.67; Found: C, 70.19; H, 5.64%.

4.4. A typical procedure for the synthesis of cyclic naphthalene lignan analogues

Hydroxy lignans (2 mmol) were taken in dry dichloromethane (15 mL) under nitrogen atmosphere and cooled to 0 °C. Trifluoroacetic acid (0.23 mL, 3 mmol) was added dropwise within 5 min. The reaction mixture became dark blue in color. It was allowed to stir at room temperature and the reaction was monitored by thin layer chromatography. After completion of reaction (1–4 h), the mixture was diluted with water (15 mL) and extracted with dichloromethane (2×20 mL). The organic layer was washed with dilute sodium bicarbonate solution (20 mL) followed by water (20 mL) and brine (25 mL) and dried over anhydrous sodium sulfate. After removal of solvent the residue was chromatographed on silica gel with petroleum ether–acetone (8:2) as an eluent to collect the cyclized products (yield ranges from 60 to 90%).

4.4.1. 3-Methylene-6,7,8-trimethoxy-9-(3,4,5-trimethoxyphenyl)-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12a). Yellow brownish solid; Yield: 0.70 g, 78%; Mp: 56 °C; IR (Chloroform): ν 2920, 1768, 1717, 1450, 1221, 1150 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.50 (s, 3H), 3.65–4.50 (m including s at 3.77, 3.82 and 3.91, 17H), 4.87 (d, $J=2.4$ Hz, 1H), 5.15 (d, $J=2.4$ Hz, 1H), 5.20 (br s, 1H), 6.41 (s, 2H), 6.63 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 169.0, 153.0 (2C), 152.7 (4C), 137.1, 134.1, 130.9, 128.7, 123.5 (2C), 105.3, 104.9 (2C), 96.2, 72.8, 60.3 (2C), 55.6 (4C), 32.6; MS (ESI): *m/z* 455 $(MH)^+$; Anal. Calcd for C_{25} $H_{26}O_8$: C, 66.07; H, 5.72; Found: C, 66.32; H, 5.79%.

4.4.2. 9-(3-Hydroxy-4-methoxyphenyl)-3-methylene-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12b). Yellow brownish solid; Mp: 87 °C; Yield: 0.61 g, 74%; IR (Chloroform): ν 3408, 3019, 1766, 1653, 1423, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.47 (s, 3H), 3.69–4.05 (m including s at 3.81, 3.84 and 3.90, 11H), 4.86 (d, $J=2.4$ Hz, 1H), 5.14 (br s, 2H), 5.55 (br s, 1H), 6.52 (d, $J=2.0$ Hz, 1H), 6.61 (s, 1H), 6.75 (d, $J=8.3$ Hz, 1H), 6.92 (dd, $J=8.3$, 2.0 Hz, 1H); MS (ESI): *m/z* 411 $(MH)^+$; Anal. Calcd for $C_{23}H_{22}O_7$: C, 56.09; H, 5.36; Found: C, 57.21; H, 5.30%.

4.4.3. 9-Benzo[1,3]-dioxol-5-yl-3-methylene-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12c). Yellow gum; Yield: 0.74 g, 91%; IR (Chloroform): ν 3018, 1762, 1592, 1216, 758 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3+CCl_4$): δ 3.40 (s, 3H), 3.64–3.87 (m including s at 3.72 and 3.80, 8H), 4.77 (br s, 1H), 5.04 (br s, 2H), 5.79 (br s, 2H), 6.53 (br s, 2H), 6.56–6.64 (dd, $J=8.0$, 2.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3+CCl_4$): δ 167.7, 153.6, 153.0, 151.7, 147.5, 146.7, 146.2, 141.5, 136.4, 131.0, 126.6, 123.2, 121.5, 108.6, 108.0, 106.8, 100.8, 92.9, 60.6, 60.2, 55.9, 37.6, 26.6; MS (ESI): *m/z* 409 $(MH)^+$; Anal. Calcd for $C_{23}H_{20}O_7$: C, 67.64; H, 4.90; Found: C, 67.78; H, 5.12%.

4.4.4. 3-Methylene-9-(2-methoxynaphthalen-1-yl)-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12d). Pale yellow crystalline solid; Yield: 0.54 g, 61%; Mp: 219 °C; IR (Chloroform): ν 3019, 1775, 1600, 1515, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3+CCl_4$): δ 2.67 (br s, 3H), 3.46 (br s, 3H), 3.71 (s, 3H), 3.86 (br s, 5H), 4.84 (br s, 1H), 5.08 (br s, 1H), 5.99 (br s, 1H), 6.58 (s, 1H), 7.07 (d, $J=8.0$ Hz, 1H), 7.37–7.42 (m, 1H), 7.66–7.74 (m, 3H); 8.63 (d, $J=8.0$ Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.7, 158.7, 157.8, 155.2, 153.7, 151.7, 151.2, 148.3, 132.9, 129.0 (2C), 128.0, 126.4, 123.7, 123.4, 123.1, 116.5, 114.3, 111.4, 106.1, 93.0, 60.3, 59.0, 56.7, 55.5, 30.0, 26.8; MS (ESI): *m/z* 463 $(MH+H_2O)^+$; Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.97; H, 5.40; Found: C, 72.68; H, 5.35%.

4.4.5. 9-(4-Methoxynaphthalen-1-yl)-3-methylene-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12e). Pale yellow crystalline solid; Yield: 0.72 g, 81%; Mp: 113–115 °C; IR (Chloroform): ν 3018, 1780, 1594, 1507, 1216 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3+CCl_4$): δ 2.89 (s, 3H), 3.77 (s, 3H), 3.90–3.95 (m including s at 3.92 and 3.93, 7H), 4.13 (dd, $J=18.0$, 1.9 Hz, 1H) 4.88 (d, $J=2.9$ Hz, 1H), 5.11 (d, $J=2.9$ Hz, 1H), 5.94 (bt, $J=1.9$ Hz, 1H), 6.63 (d, $J=8.0$ Hz, 1H), 6.67 (s, 1H), 6.87 (d, $J=8.0$ Hz, 1H), 7.53 (t, $J=8.0$ Hz, 1H), 7.68 (t, $J=8.0$, 2.0 Hz, 1H), 8.30 (d, $J=8.0$ Hz, 1H), 8.61–8.64 (m, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 167.5, 154.1, 154.0 (2C), 152.9, 151.8, 146.1, 141.8, 132.4, 131.9, 126.5, 125.8, 125.5 (2C), 124.2 (2C), 122.1, 106.8, 103.4 (2C), 92.3, 60.5, 59.4, 56.0, 55.3, 32.8, 26.8; MS (ESI): *m/z* 445 $(MH)^+$; Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.97; H, 5.40; Found: C, 72.91; H, 5.57%.

4.4.6. 9-(4,8-Dimethoxynaphthalen-1-yl)-3-methylene-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12f). Yellow crystalline solid; Yield: 0.60 g, 63%; Mp: 119 °C; IR (Chloroform): ν 2925, 1772, 1635, 1460, 1220 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3+CCl_4$): δ 3.00 (s, 3H), 3.76 (s, 3H), 3.84 (dd, $J=18.0$, 3.0 Hz, 1H), 3.88

(s, 3H), 3.90 (s, 3H), 4.05 (dd, J=18.0, 3.0 Hz, 1H), 4.10 (s, 3H), 4.81 (d, J=2.9 Hz, 1H), 5.07 (d, J=2.9 Hz, 1H), 6.57 (d, J=8.0 Hz, 1H), 6.62 (s, 1H), 6.70 (d, J=8.0 Hz, 1H), 7.10 (d, J=8.0 Hz, 1H), 7.35 (t, J=2.9 Hz, 1H), 7.39 (t, J=8.0 Hz, 1H), 7.91 (d, J=8.0 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 167.3, 158.5, 154.0, 153.8, 152.5, 151.8, 144.5, 141.5, 133.0, 132.7, 127.6, 126.7, 125.8, 125.4, 124.9 (2C), 114.8, 108.0, 106.3, 103.7, 91.4, 60.5, 59.6, 56.2, 55.8, 55.3, 34.4, 26.4; MS (ESI): m/z 475 $(MH)^+$; Anal. Calcd for $C_{28}H_{26}O_7$: C, 70.88; H, 5.48; Found: C, 70.86; H, 5.52%.

4.4.7. 9-(6-Methoxynaphthalen-2-yl)-3-methylene-6,7,8-trimethoxy-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (12g). Yellow crystalline solid; Yield: 0.79 g, 89%; Mp 118 °C; IR (Chloroform): ν 3019, 1772, 1605, 1465, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.33 (s, 3H), 3.75–4.12 (m including s at 3.80, 3.87 and 3.91, 11 H), 4.87 (d, J=2.7 Hz, 1H), 5.12 (d, J=2.7 Hz, 1H), 5.35 (t, J=3.9 Hz, 1H), 6.67 (s, 1H), 7.08 (dd, J=8.0, 2.0 Hz, 2H), 7.31 (dd, J=8.6, 1.9 Hz, 1H), 7.55 (d, J=1.9 Hz, 1H), 7.63 (dd, J=8.6, 2.0 Hz, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 167.6, 157.6, 153.9, 153.1, 152.0, 146.6, 141.6, 137.8, 133.5, 131.3, 129.3, 128.9, 127.1, 126.9, 126.7, 123.5, 118.7 (2C), 106.8, 105.6, 92.7, 60.6, 60.2, 56.0, 55.2, 38.1, 26.8; MS (ESI): m/z 445 $(MH)^+$; Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.97; H, 5.40; Found: C, 72.89; H, 5.60%.

4.4.8. 5-Benzo-[1,3]dioxol-5-yl-8-methylene-5,9-dihydro-8*H*-furo[3′,4′:6,7]naphtha[2,3-*d*][1,3]dioxol-6-one (14). Off-white crystalline solid; Yield: 0.59 g, 82%; Mp: 117–119 °C; IR (Chloroform): ν 2898, 1786, 1764, 1652, 1490 cm^{-1}; ^{1}H NMR ($CDCl_3+CCl_4$): δ 3.76 (dd, J=22.0, 6.0 Hz, 1H), 3.93 (dd, J=22.0, 6.0 Hz, 1H), 4.84 (t, J=6.0 Hz, 1H), 4.90 (d, J=2.5 Hz, 1H), 5.18 (d, J=2.5 Hz, 1H), 5.89 (s, 2H), 5.92 (d, J=10.0 Hz, 2H), 6.08 (d, J=2.8 Hz, 1H), 6.51 (s, 1H), 6.59 (s, 1H), 6.72 (br s, 3H); MS (ESI): m/z 363 (M+1); Anal. Calcd for $C_{21}H_{14}O_6$: C, 69.61; H, 3.85; Found: C, 69.41; H, 3.93%.

4.4.9. 8-Methylene-5-(3,4,5-trimethoxyphenyl)-5,9-dihydro-8*H*-furo[3′,4′:6,7]naphtha[2,3-*d*] [1,3]dioxol-6-one (16). Off-white crystalline solid; Yield: 0.69 g, 85%; Mp: 102–104 °C; IR (Chloroform): ν 3019, 1788, 1763, 1607, 1490, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3+CCl_4$): δ 3.79 (s, 9H), 3.82–3.88 (m, 2H), 4.88 (t, J=4.0 Hz, 1H), 4.91 (d, J=4.0 Hz, 1H), 5.18 (d, J=4.0 Hz, 1H), 5.96 (br s, 2H), 6.35 (s, 2H), 6.63 (s, 1H), 6.75 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 168.6, 153.2 (2C), 146.9, 138.3, 131.2, 128.7 (2C), 123.2, 115.7, 108.9, 107.6, 107.5, 105.3, 105.1(2C), 93.2, 60.4, 55.7 (2C), 42.5, 26.5; MS (ESI): m/z 409 $(MH)^+$; Anal. Calcd for $C_{23}H_{20}O_7$ C, 67.64; H, 4.94; Found: C, 67.83; H, 5.23%.

4.4.10. 3-Methoxy-8-methylene-11-(3,4,5-trimethoxyphenyl)-7,11-dihydro-7*H*-9-oxa-cyclopenta[*b*]phenanthren-10-one (18). Pale yellow crystalline solid; Yield: 0.76 g, 86%; Mp: 135 °C; IR (Chloroform): ν 3019, 1764, 1589, 1215, 757 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3+CCl_4$): δ 3.72 (s, 6H), 3.78 (s, 3H), 3.93 (s, 3H), 3.98 (dd, J=18.0, 2.0 Hz, 1H), 4.04 (dd, J=2.0, 18.0 Hz, 1H), 4.96 (d, J=2.9 Hz, 1H), 5.21 (d, J=2.9 Hz, 1H), 5.69 (d, J=2.0 Hz, 1H), 6.47 (s, 2H), 7.13 (dd, J=8.0, 2.0 Hz, 1H), 7.17 (d, J=2.0 Hz, 1H), 7.44 (d, J=8.0 Hz, 1H), 7.77 (d, J=8.0 Hz, 1H), 7.83 (d, J=8.0 Hz, 1H); MS (ESI): m/z 445 $(MH)^+$; Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.97; H, 5.40; Found: C, 73.12; H, 5.26%.

4.4.11. 6,7,8-Trimethoxy-3-methylene-9-(1-methyl-1*H*-indol-3-yl)-4,9-dihydro-3*H*-naphtho[2,3-*c*]furan-1-one (19). White crystalline solid; Yield: 0.53 g, 64%; Mp 128–130 °C; IR (Chloroform): ν 3019, 1767, 1658, 1537, 1215 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3+CCl_4$): δ 3.40 (s, 3H), 3.63–4.19 (m including s at 3.72, 3.80 and 3.92, 11H), 4.83 (d, J=2.9 Hz, 1H), 5.09 (d, J=2.9 Hz, 1H), 5.50 (t, J=2.9 Hz, 1H), 6.66 (s, 1H), 6.96 (t, J=8.0 Hz, 1H), 6.98 (s, 1H), 7.12 (t, J=8.0 Hz, 1H), 7.17–7.23 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3+CCl_4$): δ 167.9, 153.7, 152.8, 152.2, 146.3, 141.6, 136.9, 131.2, 127.7, 126.6, 123.6, 121.3, 121.2, 119.3, 118.9, 115.1, 109.1(2C), 106.9, 92.3, 60.6, 60.2, 56.0, 32.5, 26.8; MS (ESI): m/z 416 $(M-1)^+$; Anal. Calcd for $C_{25}H_{23}NO_5$: C, 71.93; H, 5.55; N, 3.36; Found: C, 72.10; H, 5.51; N, 3.43%.

4.5. 3-Acetyl-4-(2,6-dimethylphenyl)-but-3-enoic acid (21)

To a well-stirred mixture of 2,6-dimethyl benzaldehyde **20** (1.00 g, 7.42 mmol) and ethyl levulinate (3.22 g, 22.2 mmol) in methanol (250 mL), aqueous sodium hydroxide solution (0.32 g, 22.2 mmol) was added dropwise at −10 °C. After complete addition, reaction mixture was stirred at same temperature for 4–5 h and the reaction was monitored by thin layer chromatography. After completion of reaction, methanol was removed under vacuum, reaction mixture was diluted with water (100 mL) and washed with ethyl acetate (2×50 mL) and aqueous layer was acidified with conc. HCl. The yellow oil separated was extracted with ethyl acetate (3×20 mL) and it was repeatedly washed with water to remove traces of levulinic acid, followed by brine, dried over sodium sulfate and evaporated to yield acid **21** as an oil which crystallized on standing.

White crystalline solid; Yield: 1.34 g, 78%; Mp: 97 °C; IR (Chloroform): ν 3020, 1712, 1670, 1466, 1215 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ 1.72 (s, 3H), 2.21 (s, 6H), 3.50 (s, 2H), 7.05–7.15 (m, 4H), 7.97 (br s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 201.4, 177.2, 139.5, 136.5, 135.1 (2C), 135.0, 127.9, 127.5 (2C), 39.5, 28.9, 20.1 (2C); MS: 232 $(M)^+$; Anal calcd for $C_{14}H_{16}O_3$: C, 72.41; H, 6.89; Found: C, 72.52; H, 6.91%.

4.6. 3-Acetyl-4-(2,6-dimethylphenyl)-but-3-enoic acid methyl ester (22)

Acid **21** (0.80 g, 3.44 mmol) was dissolved in distilled methanol (15 mL) and the solution was cooled to 0 °C. To this solution, diazomethane in ether (50 mL) prepared from nitrosomethylurea (1.77 g, 17.2 mmol) was added slowly with constant stirring. After being stirred for 1 h, solvent was evaporated under vacuum and the crude ester was purified by column chromatography using 10% acetone in petroleum ether as an eluent to afford pure ester.

Yellow oil; Yield: 0.75 g, 88%; IR (Chloroform): ν 3019, 1775, 1715, 1466, 1215 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 1.38 (s, 3H), 1.88 (s, 6H), 3.13 (s, 2H), 3.36 (s, 3H), 6.67–6.78 (m, 4H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 201.2, 171.9, 139.0, 137.3, 135.8 (2C), 135.2, 128.0, 127.7 (2C), 51.9, 39.6, 29.1, 20.3 (2C); MS (ESI): *m/z* 246 $(M)^+$; Anal Calcd for $C_{15}H_{18}O_3$: C, 72.58; H, 7.25; Found: C, 72.60; H, 7.19%.

4.7. 3-(2,6-Dimethylbenzyl)-4-oxo-pentanoic acid methyl ester (23)

Ester **22** (0.72 g, 2.92 mmol) was dissolved in distilled methanol (15 mL) in two-necked round bottom flask, purged with nitrogen gas and charged with 10% Pd/C (10 mg). Then the reaction was flushed with hydrogen gas and stirred for 1 h under H_2 gas (balloon). Reaction mixture was then filtered through Whatman filter paper, filtrate was evaporated to dryness and the residue was purified by column chromatography using 5% acetone in pet ether as an eluent to afford pure ester **23**.

Yellow oil; Yield: 0.60 g, 83%; IR (Chloroform): ν 3022, 1771, 1714, 1585, 756 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 2.17 (s, 3H), 2.32 (s, 6H), 2.67–2.98 (m, 4H), 3.28–3.50 (m, 1H), 3.59 (s, 3H), 7.02 (br s, 3H); MS (ESI): *m/z* 249 (M+1); Anal. Calcd for $C_{15}H_{20}O_3$: C, 72.58; H, 8.06; Found: C, 72.67; H, 8.17%.

4.8. 4-(2,6-Dimethylbenzyl)-5,5-dimethyl-dihydro-2(3*H*)-furanone[14] (24)

To a suspension of activated magnesium metal (0.02 g, 0.79 mmol) in dry THF (5 mL) was added iodomethane (0.14 g, 0.10 mmol) dropwise over 10 min at room temperature. To the resultant solution of methyl magnesium iodide, suspension of $CeCl_3$ (0.24 g, 1.01 mmol) in dry THF (2 mL) was added followed by ester **23** (0.20 g, 0.8 mmol) in dry THF (1 mL) over a period of 10 min at 0 °C. The reaction mixture was stirred at same temperature for 4 h after which the reaction was quenched with dilute HCl (50%, 2 mL). The resulting suspension was stirred for another 10 min and then extracted with ethyl acetate (2× 25 mL). Organic layer was washed with water (15 mL), brine (15 mL) and dried over sodium sulfate. Evaporation of the solvent gave crude lactone, which was purified on silica gel column using 10% acetone in pet ether as an eluent to afford the pure lactone **24**.

White crystalline solid; Yield: 0.09 g, 48%; Mp: 132–133 °C (lit.[14] 132–133 °C); IR (Chloroform): ν 3019, 2978, 1761, 1522, 1474, 1215, 1121, 929, 669 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 1.44 (s, 3H), 1.58 (s, 3H), 2.25–2.50 (m including s at 2.33, 9H), 2.63–2.85 (m, 2H), 7.04 (br s, 3H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 175.3, 135.9 (2C), 135.6, 128.7 (2C), 126.4, 86.5, 45.8, 34.4, 28.5, 26.9, 21.6, 20.2 (2C); MS (ESI): *m/z* 233 $(MH)^+$; Anal. Calcd for $C_{15}H_{20}O_2$: C, 77.58; H, 8.62; Found: C, 77.49; H, 8.92%.

Acknowledgements

We thank Dabur Research Foundation, Ghaziabad, India for biological activity of some of the compounds. We also thank the Department of Science and Technology, New Delhi for the financial support. V.A.M. thanks CSIR, New Delhi for the award of senior research fellowship.

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18. Some of the new chemical entities described in this manuscript were screened for anticancer and antifungal activity and have exhibited potential cytotoxicity as well as antifungal activity. The results will be published elsewhere.