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Synthesis and some transformations of new 9-furylnaphtho[2,3-*b*]furan derivatives

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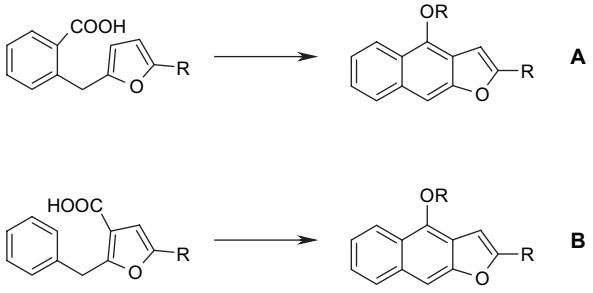
Abstract—The synthesis of a number of naphtho[2,3-*b*]furan derivatives, containing a furyl substituent in position 9 by intramolecular cyclization of 2-carboxy and 2-formylbis(5-alkylfur-2-yl)methanes is described. The reactivity of the title compounds in formylation, acetylation, nitration, and oxidation reactions has been investigated. It was shown that nitration of 2-methyl-9-(5-methyl-2-furyl)naphtho-[2,3-*b*]furan-4-yl acetate leads to oxidative furan ring opening rather than to electrophilic substitution.

1. Introduction

Among natural compounds, representatives incorporating the naphthofuran framework are quite common. Thus, maturin and maturinin were isolated from the roots of *Cacalia decomposita*.[1a] Later, another group of authors[1b] isolated the natural analogs of the naphthofurans from the roots of *Senecio Canescens*, namely 13-hydroxydehydroxycacalohastine, 13-acetoxydehydrocacalohastine along with the sesquiterpenoid naphthofuran derivative. In their recent communication, some Japanese authors have reported[1c] that a number of the above-mentioned naturally occurring naphthofuran derivatives like maturin and 14-methoxydehydrocacalohastine were also isolated from *Trichilia cuneata*. The synthesis of naphthofuran derivatives attracts our attention because of a fairly wide spectrum of biological activity.[2] For example, nitro derivatives of naphthofurans possess pronounced mutagenic activity,[2b,c,f,g,m–o] that is of interest for medicinal chemistry. It should also be noted that furonaphthoquinones, a class of naturally occurring biologically active compounds,[3] can be synthesized directly from naphthofuran derivatives.[4]

A number of methods for construction of the naphthofuran framework are known. Thus, authors[5] have demonstrated some pathways to annulate furan ring directly onto the naphthalene nucleus. For example, Narasimhan and Mali[5a] have proposed a convenient method based on cyclization of 2-methoxy-3-(2-methoxyvinyl)naphthalene, synthesized from 2-methoxy-3-naphthaldehyde. It is also reported that under the action of lithium iodide cyclobuta[*a*]naphthalene derivatives undergo a transformation into naphthofurans.[5b] The reaction of α-chloro-α-phenylthioketones with 2-naphthol, catalyzed by Lewis acids, also leads to the formation of naphthofurans.[5c] Photolysis or thermolysis of cyclopropa[*b*]naphthalene derivatives give naphthofurans with low yields.[5d] In the paper of Royer et al.,[5e] a route to naphthofuran derivatives starting from methyl 3-hydroxy-2-naphthoate is disclosed.

However, the two most widespread and popular synthetic approaches for the synthesis of the naphthofuran nucleus are based on intramolecular cyclization of the corresponding carboxy 2-benzylfurans (Scheme 1). Cyclization of the



Scheme 1.

Keywords: Furan; Cyclization; 9-Furylnaphtho[2,3-*b*]furan.
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ortho-carboxy group in the benzene part of the molecule onto the β-position of the furan ring[4] (path A) and β-carboxyfuran cyclization onto the *ortho*-position of the aromatic ring[3b,6] (path B) eventually leads to the formation of the naphthofuran framework. For our synthesis of new naphthofuran derivatives with potential biological activity, the reaction in pathway A (Scheme 1) was employed.

2. Results and discussion

2.1. Synthesis of derivatives of 9-furylnaphtho-[2,3-*b*]furan

In this article, we disclose our results on the synthesis and transformations of the 9-furylsubstituted naphthofurans **4** and **7**. Preliminary results were reported earlier.[7] It is known that the furan cycle can easily undergo different kinds of transformations[8] and therefore it is a very attractive substituent for the introduction into naphthofuran ring system.

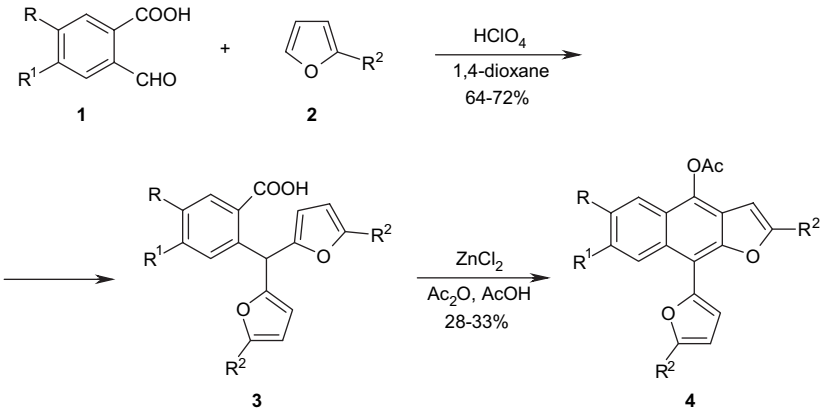
The synthesis of 4-acetoxy-9-furylnaphthofurans **4** was accomplished according to the known procedure.[4a,b] As key starting compounds, we used *ortho*-carboxybenzylfurans **3**, that are readily available via the reported condensation of derivatives of 2-formylbenzoic acid **1** and 2-alkylfuran **2** in the presence of catalytic amounts of 70% perchloric acid in dry 1,4-dioxane at 65–70 °C (Scheme 2).[9]

Benzaldehydes **6**, which served as precursors for the 4-unsubstituted 9-furylnaphthofurans **7**, were obtained by reduction of benzoic acids **3** into alcohols **4** with subsequent mild oxidation (Scheme 3). The last cyclization catalyzed by hydrogen chloride in ethanol furnished the desired naphthofurans (Table 1).

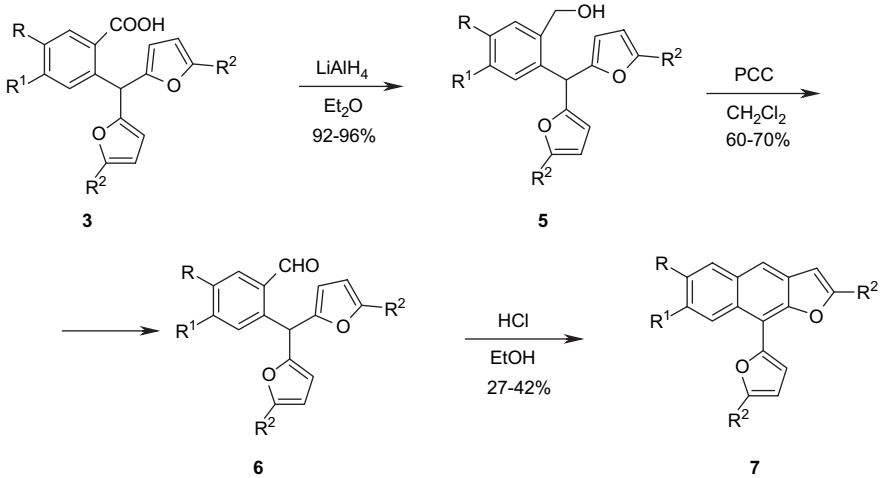
The structure and spatial orientation of compound **7a** was unambiguously proved by X-ray crystallography (Fig. 1). In a monocrystal of compound **7a**, two independent mole-

Table 1. Naphthofuran synthesis via cyclization of compounds **3** and **6**

4–7	R	R^1	R^2	Yield, %			
				4	**5**	**6**	**7**
a	H	H	Me	31	92	70	37
b	Cl	H	Me	30.5	96	61	42
c	Br	H	Me	33	93	60	39
d	Br	H	Et	28	93	67	27
e	Br	H	*t*-Bu	32	—	—	—
f	H	Cl	Me	31	—	—	—



Scheme 2.



Scheme 3.

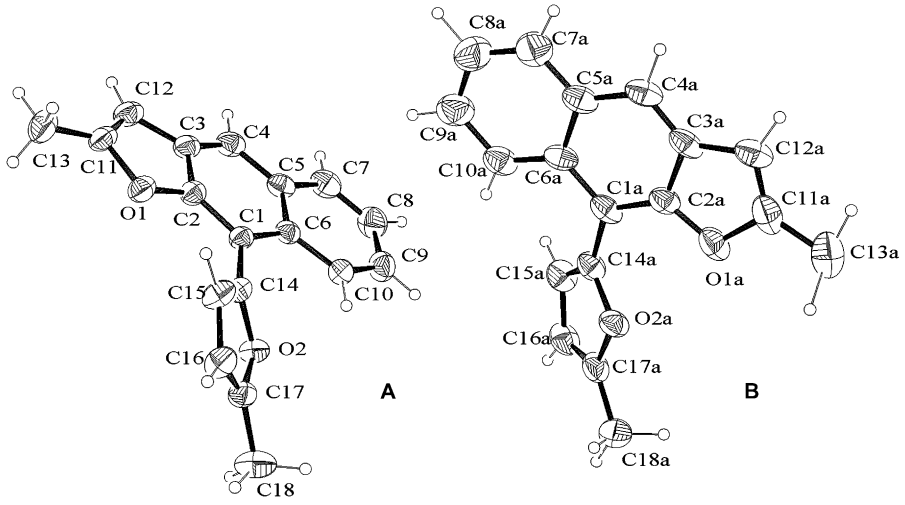


Figure 1. The X-ray crystal structure of two conformationally independent molecules of naphthofuran **7a**.

cules were detected with different orientation of the furan ring with regard to the naphthofuran framework.

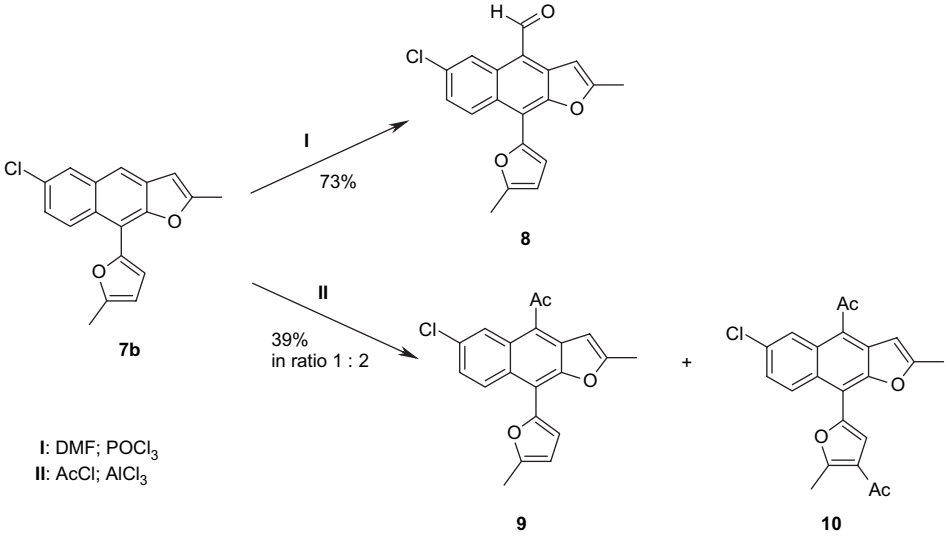
In both molecules, the naphthofuran fragment is planar (plane 1). In molecule **B**, the furan cycle O2a–C14a–C15a–C16a–C17a is rotated to 40.7° relative to the plane 1 with oxygen atoms faced as 'one toward the other'. In molecule **A**, furan O2–C14–C15–C16–C17 is rotated to 41.3° relative to the plane 1 with oxygen atoms 'one against the other'.

2.2. Reactions of 9-furylnaphtho[2,3-*b*]furans

Literature reports on the reactivity of naphthofuran derivatives are scarce. As mentioned above, naphthofuran derivatives are rather widespread in nature and some natural and synthetic naphthofurans possess biological activity. Therefore, the search for new transformations of naphthofurans and screening of the obtained compounds for biological activity evaluation is of great importance. Aiming at further functionalization of the naphthofuran nucleus, we attempted an introduction of different reactive groups into compounds **4** and **7**.

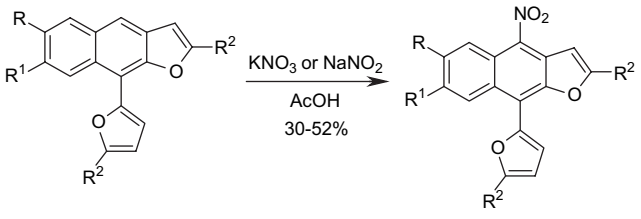
Having taken into account the free activated position 4 in naphthofurans **7**, we investigated some electrophilic reactions of the title compounds. Formylation of compound **7b** using Vilsmeier reaction conditions selectively gave rise to aldehyde **8** (73% yield). In turn, acylation of the same compound with acetyl chloride in the presence of $AlCl_3$ gave monoacetylated **9** and bisacetylated products **10** in the ratio of 1:2 and 39% overall yield (Scheme 4). The disappearance of the signal at 6.3 ppm in ^{1}H NMR spectrum of compound **10** was attributed to the presence of the acetyl group in the 4-position of the furan substituent.

Nitration of 9-furylnaphthofurans **7a**,**b** with potassium nitrate in glacial acetic acid gave rise to new nitro derivatives of naphthofurans **11a**,**b**. As expected, nitration took place at position 4 of the naphthofuran framework (Scheme 5). Unexpectedly, the same nitro compound **11b** was obtained in the attempted nitrosation of compound **7b** with sodium



Scheme 4.

nitrite and acetic acid. To the best of our knowledge, the nitration of the electron-rich aromatic and heterocyclic systems under similar conditions is well documented.[10] It was shown that this reaction starts with single electron transfer from the substrate to the nitrogen oxides or nitrosonium cation with formation of the radical cation of the substrate. The intermediate radical cation can react further with nitrite-anion or nitrogen dioxide with the formation of the radical or cationic complex with subsequent aromatization into the nitro compound. The distinct reaction pathway depends on the spin density distribution in the initially formed radical cation and this study is under investigation.

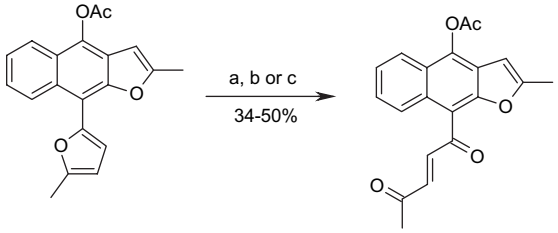


7a,b **11a,b**

a: R = H, R^1 = H, R^2 = Me
b: R = Cl, R^1 = H, R^2 = Me

Scheme 5.

Nitration of 4-acetoxynaphthofuran **4a**, in which the 4-position susceptible to the electrophilic attack is already occupied, with potassium nitrate in glacial acetic acid gave compound **12** rather than any nitro compound (Scheme 6). The structure of the compound was confirmed by the existence of 1H doublets at δ 7.02 and 7.70 ppm in the NMR spectrum with spin–spin splitting constant of J=15.9 Hz, which is typical for vicinal olefinic protons in trans orientation. Compound **12** resulting from the oxidative ring opening of the furan ring in the 9-position of the naphthofuran was also obtained from an alternative synthesis (Scheme 6). For this purpose, the PCC or MMPP, common oxidants for the synthesis of 1,4-unsaturated diketones from the furan derivatives, were used.[11]

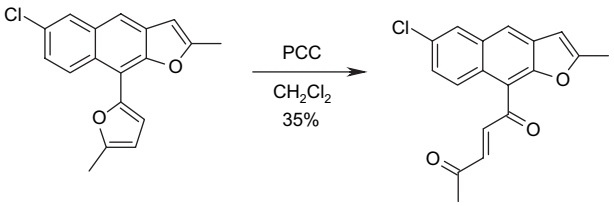


4a **12**

a: KNO_3 / AcOH
b: MMPP / benzene
c: PCC / CH_2Cl_2

Scheme 6.

The furan ring opening was also observed in the case of the 4-unsubstituted naphthofurans **7**. It was shown that treatment of compound **7b** with pyridinium chlorochromate in methylene chloride gave corresponding unsaturated diketone **13** with 36% yield (Scheme 7).



7b **13**

Scheme 7.

3. Conclusion

The elaborated synthetic pathways allow broadening the range of available naphthofuran derivatives. The structure and spatial orientation of the molecules in the single crystal of 2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan (**7a**) were studied by X-ray crystallography. Electrophilic substitution reactions onto the 4-position of the naphthofuran framework were studied as well as oxidative furan ring-opening reactions. Further research on reactivity of the obtained compounds is in progress.

4. Experimental

4.1. General

Melting points are uncorrected. ^{1}H NMR spectra were recorded in $CDCl_3$ on a Bruker AC 200 spectrometer at 200 MHz. Chemical shifts are reported in parts per million relatively to the tetramethylsilane as an internal standard and coupling constants (J) are given in absolute values in Hertz to the nearest 0.1 Hz. ^{13}C NMR spectra were recorded on a Bruker AM300 (50.32 MHz) at ambient temperature in $CDC1_3$. Mass spectra were recorded on a Kratos MS-30 instrument with 70 eV electron impact ionization at 200 °C. IR spectra were recorded on InfraLUM FT-02. Column chromatography was carried out using silica gel KSK (50–160 mkm) manufactured by LTD Sorbpolymer. Single crystal suitable for X-ray crystallography was grown from hexane.

4.1.1. General procedure for the preparation of naphthofurans 4. A mixture of **3** (1.0 mmol), acetic acid (2 mL), acetic anhydride (2 mL), and $ZnCl_2$ (2–4 mg) as catalyst was refluxed until completion of the reaction (monitored with TLC). The reaction mixture was poured into water (10 mL), neutralized with $NaHCO_3$, and extracted with CH_2Cl_2 (3×10 mL). The organic layer was separated, dried over Na_2SO_4, treated with active charcoal, and filtered off. The solvent was removed in rotatory evaporator, and the residue was purified on silica gel column with hexane–CH_2Cl_2 (4:1) as an eluent. The solvent was removed in rotatory evaporator and the residue was recrystallized from CH_2Cl_2–hexane.

4.1.1.1. 2-Methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]-furan-4-yl acetate (4a). Yield 100 mg, 31% as colorless crystals; mp 145–147 °C; IR (KBr): 1753, 1366, 1224, 1195, 1159, 1068, 1008, 948, 780, 753, 726 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.50 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.27 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.40 (s,

1H, 3-H), 6.88 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.47–7.54 (m, 2H, 6-H, 7-H), 7.95–8.00 (m, 1H, 5-H), 8.54–8.59 (m, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 13.9, 14.5, 20.8, 99.9, 107.5, 108.3, 113.0, 120.8, 122.5, 123.6, 124.5, 125.5, 126.3, 128.9, 136.5, 146.3, 151.5, 152.5, 158.5, 168.9. MS: *m/z* (%) 320 (M^+, 10), 278 (100), 235 (19), 189 (14), 178 (20). Anal. Calcd for $C_{20}H_{16}O_4$: C, 74.99; H, 5.03. Found: C, 75.05; H, 5.10.

4.1.1.2. 6-Chloro-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan-4-yl acetate (4b). Yield 110 mg, 30.5% as colorless crystals; mp 140–143 °C; IR (KBr): 1751, 1195, 1008, 905, 860, 795, 775, 730, 563 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.50 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 2.55 (s, 3H, CH_3), 6.27 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.38 (s, 1H, 3-H), 6.89 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.42 (dd, J=2.1, 9.3 Hz, 1H, 7-H), 7.94 (d, J=2.1 Hz, 1H, 5-H), 8.54 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 13.9, 14.5, 20.8, 100.1, 107.6, 108.6, 113.5, 119.7, 123.5, 124.4, 126.2, 126.9, 128.3, 130.6, 135.5, 145.9, 151.3, 152.8, 159.1, 168.6. MS: *m/z* (%) 354/356 (M^+, 10/3), 312/314 (100/33), 277 (44), 269 (15), 189 (10), 178 (14), 149 (13). Anal. Calcd for $C_{20}H_{15}ClO_4$: C, 67.71; H, 4.26. Found: C, 67.78; H, 4.20.

4.1.1.3. 6-Bromo-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan-4-yl acetate (4c). Yield 130 mg, 33% as colorless crystals; mp 148–150 °C; IR (KBr): 1755, 1597, 1555, 1395, 1350, 1334, 1220, 1194, 1081, 1004, 902, 792, 778, 563 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.49 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 2.55 (s, 3H, CH_3), 6.27 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.38 (s, 1H, 3-H), 6.89 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.54 (dd, J=2.1, 9.3 Hz, 1H, 7-H), 8.11 (d, J=2.1 Hz, 1H, 5-H), 8.47 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.0, 14.5, 20.9, 100.1, 107.7, 108.7, 113.5, 118.9, 123.0, 123.5, 124.9, 127.1, 128.4, 128.7, 135.4, 145.9, 151.3, 152.8, 159.2, 168.7. MS: *m/z* (%) 398/400 (M^+, 17/17), 356/358 (100/98), 277 (42), 234 (18), 219 (12), 178 (13), 149 (11). Anal. Calcd for $C_{19}H_{15}BrO_4$: C, 60.17; H, 3.79. Found: C, 60.20; H, 3.72.

4.1.1.4. 6-Bromo-2-ethyl-9-(5-ethyl-2-furyl)naphtho-[2,3-*b*]furan-4-yl acetate (4d). Yield 120 mg, 28%; mp 84–86 °C; IR (KBr): 1756, 1587, 1545, 1389, 1344, 1354, 1193, 1100, 1035, 903, 758 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.34–1.50 (m, 6H, CH_2CH_3), 2.56 (s, 3H, COCH_3), 2.79–2.92 (m, 4H, CH_2CH$_3$), 6.27 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.38 (s, 1H, 3-H), 6.92 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.54 (dd, J=2.1, 9.3 Hz, 1H, 7-H), 8.11 (d, J=2.1 Hz, 1H, 5-H), 8.51 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 11.5, 12.35, 20.9, 21.7, 22.1, 98.4, 106.1, 108.8, 113.2, 118.8, 123.0, 123.3, 124.9, 127.0, 128.4, 128.6, 135.6, 145.9, 151.2, 158.3, 164.5, 168.6. MS: *m/z* (%) 426/428 (M^+, 14/14), 384/386 (100/93), 370/372 (56/53), 290 (10), 233 (14), 189 (16), 149 (15). Anal. Calcd for $C_{22}H_{19}BrO_4$: C, 61.84; H, 4.48. Found: C, 61.89; H, 4.42.

4.1.1.5. 6-Bromo-2-(*tert*-butyl)-9-[5-(*tert*-butyl)-2-furyl]naphtho[2,3-*b*]furan-4-yl acetate (4e). Yield 155 mg, 32% as colorless crystals; mp 101–103 °C; IR (KBr): 1759, 1586, 1365, 1194, 1161, 1117, 1025, 906, 810, 793 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.43 (s, 18H, CH_3), 2.57 (s, 3H, COCH_3), 6.25 (d, J=3.2 Hz, 1H, 4-H_{Fur}), 6.35 (s, 1H, 3-H), 6.91 (d, J=3.2 Hz, 1H, 3-H_{Fur}), 7.53 (dd, J=1.9, 9.3 Hz, 1H, 7-H), 8.09 (d, J=1.9 Hz, 1H, 5-H), 8.60 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 20.9, 28.8 (3C), 29.3 (3C), 33.0, 33.4, 96.3, 104.0, 109.0, 112.8, 118.7, 123.0, 123.4, 124.9, 126.7, 128.3, 128.5, 129.7, 135.6, 146.0, 151.0, 164.6, 168.7. MS: *m/z* (%) 482/484 (M^+, 11/10), 440/442 (67/62), 425/427 (100/98). Anal. Calcd for $C_{26}H_{27}BrO_4$: C, 64.93; H, 6.26. Found: C, 65.01; H, 6.20.

4.1.1.6. 7-Chloro-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan-4-yl acetate (4f). Yield 110 mg, 31% as colorless crystals; mp 166–168 °C; IR (KBr): 1751, 1616, 1541, 1396, 1356, 1342, 1220, 1186, 1118, 1067, 1008, 949, 977, 884, 813, 783, 739 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.51 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.29 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.38 (s, 1H, 3-H), 6.91 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.41 (dd, J=1.9, 9.0 Hz, 1H, 6-H), 7.90 (d, J=9.0 Hz, 1H, 5-H), 8.62 (d, J=1.9 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 13.9, 14.5, 20.8, 100.0, 107.6, 107.9, 113.4, 122.1, 122.6, 122.8, 125.2, 125.4, 129.3, 131.5, 136.6, 145.7, 152.0, 152.8, 158.8, 168.5. MS: *m/z* (%) 354/356 (M^+, 8/3), 312/314 (100/31), 277 (15), 269 (18), 178 (19), 149 (11). Anal. Calcd for $C_{20}H_{15}ClO_4$: C, 67.71; H, 4.26. Found: C, 67.75; H, 4.22.

4.1.2. General procedure for the preparation of alcohols 5. To a stirred suspension of benzoic acid **3** (50.0 mmol) in anhydrous Et_2O (150 mL), $LiAlH_4$ (100.0 mmol) was added portionwise under cooling (−3 to 0 °C). The reaction was monitored by TLC analysis, and after 5 h the mixture was carefully poured into ice water and neutralized with 6 M hydrochloric acid. The product was extracted with Et_2O (3×100 mL), dried with Na_2SO_4, treated with active charcoal, and filtered off. The solvent was removed in rotatory evaporator and the residue was recrystallized from hexane.

4.1.2.1. 2-Di(5-methyl-2-furyl)methylphenylmethanol (5a). Yield 13 g, 92% as colorless crystals; mp 65–67 °C; IR (KBr): 3296, 1612, 1562, 1450, 1218, 1022, 1002, 951, 778 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.61 (br s, 1H, O*H*), 2.26 (s, 6H, CH_3), 4.75 (s, 2H, CH_2), 5.74 (s, 1H, C*H*), 5.85 (d, J=3.2 Hz, 2H, 3-H_{Fur}), 5.89 (d, J=3.2 Hz, 2H, 4-H_{Fur}), 7.19–7.31 (m, 3H, H_{Ar}), 7.40–7.45 (m, 1H, H_{Ar}). Anal. Calcd for $C_{18}H_{18}O_3$: C, 76.57; H, 6.43. Found: C, 76.50; H, 6.49.

4.1.2.2. 5-Chloro-2-di(5-methyl-2-furyl)methylphenylmethanol (5b). Yield 15.5 g, 98% as colorless crystals; mp 71–72 °C; IR (KBr): 3252, 1616, 1561, 1477, 1407, 1216, 1087, 1049, 1020, 880, 778 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.70 (br s, 1H, O*H*), 2.25 (s, 6H, CH_3), 4.72 (s, 2H, CH_2), 5.62 (s, 1H, C*H*), 5.84 (d, J=3.2 Hz, 2H, 3-H_{Fur}), 5.89 (d, J=3.2 Hz, 2H, 4-H_{Fur}), 7.10 (d, J=8.3 Hz, 1H, H_{Ar}), 7.25 (dd, J=1.8, 8.3 Hz, 1H, H_{Ar}), 7.46 (d, J=1.8 Hz, 1H, H_{Ar}). Anal. Calcd for $C_{18}H_{17}ClO_3$: C, 68.25; H, 5.41. Found: C, 68.31; H, 5.39.

4.1.2.3. 5-Bromo-2-di(5-methyl-2-furyl)methylphenylmethanol (5c). Yield 16.8 g, 93% as colorless crystals; mp 75–76 °C; IR (KBr): 3252, 1717, 1589, 1558, 1473, 1451, 1047, 1020, 864, 777 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.66 (br s, 1H, O*H*), 2.25 (s, 6H, CH_3), 4.72 (s, 2H, CH_2), 5.61 (s, 1H, C*H*), 5.85 (d, J=3.2 Hz, 2H, 3-H_{Fur}), 5.88 (d, J=3.2 Hz, 2H, 4-H_{Fur}), 7.05 (d, J=8.3 Hz, 1H, H_{Ar}), 7.39

(dd, J=2.1, 8.3 Hz, 1H, H_{Ar}), 7.60 (d, J=2.1 Hz, 1H, H_{Ar}). Anal. Calcd for $C_{18}H_{17}BrO_3$: C, 59.85; H, 4.74. Found: C, 59.91; H, 4.69.

4.1.2.4. 5-Bromo-2-di(5-ethyl-2-furyl)methylphenylmethanol (5d). Yield 18 g, 93% as colorless crystals; mp 85–87 °C; IR (KBr): 3266, 1556, 1473, 1401, 1365, 1181, 1047, 1011, 863, 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.19 (t, J=7.6 Hz, 6H, CH_2CH_3), 1.68 (br s, 1H, O*H*), 2.58 (q, J=7.6 Hz, 2H, CH_2CH_3), 4.71 (s, 2H, CH_2), 5.61 (s, 1H, CH), 5.85 (d, J=3.1 Hz, 2H, 3-H_{Fur}), 5.89 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 7.00 (d, J=8.3 Hz, 1H, H_{Ar}), 7.38 (dd, J=1.9, 8.3 Hz, 1H, H_{Ar}), 7.60 (d, J=1.9 Hz, 1H, H_{Ar}). Anal. Calcd for $C_{20}H_{21}BrO_3$: C, 61.71; H, 5.44. Found: C, 61.78; H, 5.39.

4.1.3. General procedure for the preparation of benzaldehydes 6. A solution of alcohol **5** (35.5 mmol) in dry CH_2Cl_2 (100 mL) was added dropwise to the suspension of pyridinium chlorochromate (70.0 mmol) in dry CH_2Cl_2 (100 mL). The mixture was stirred for 6 h at rt. At the end of the reaction (TLC monitoring), the precipitate was filtered off and washed with hot CH_2Cl_2 (3×100 mL). The filtrate was concentrated in rotatory evaporator, and the oily residue was purified chromatographically on silica gel column with hexane–CH_2Cl_2 (10:1) mixture as eluent. The fraction containing desired benzaldehyde was concentrated to the volume of 20 mL and left to crystallize overnight.

4.1.3.1. 2-Di(5-methyl-2-furyl)methylbenzaldehyde (6a). Yield 7 g, 70% as colorless crystals; mp 63–65 °C; IR (KBr): 1695, 1572, 1213, 1019, 949, 871, 780, 753, 717, 678 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.25 (s, 6H, CH_3), 5.87 (s, 4H, H_{Fur}), 6.46 (s, 1H, C*H*), 7.31–7.33 (m, 1H, H_{Ar}), 7.42–7.54 (m, 1H, H_{Ar}), 7.85–7.88 (m, 1H, H_{Ar}), 10.27 (s, 1H, C*H*O). Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.13; H, 5.75. Found: C, 77.20; H, 5.58.

4.1.3.2. 5-Chloro-2-di(5-methyl-2-furyl)methylbenzaldehyde (6b). Yield 6.8 g, 61% as colorless crystals; mp 75–77 °C; IR (KBr): 1693, 1563, 1475, 1404, 1227, 1191, 1109, 1022, 967, 900, 785, 721 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.25 (s, 6H, CH_3), 5.89 (s, 4H, H_{Fur}), 6.34 (s, 1H, C*H*), 7.26 (d, J=8.3 Hz, 1H, H_{Ar}), 7.49 (dd, J=2.1, 8.3 Hz, 1H, H_{Ar}), 7.84 (d, J=2.1 Hz, 1H, H_{Ar}), 10.23 (s, 1H, C*H*O). Anal. Calcd for $C_{18}H_{15}ClO_3$: C, 68.69; H, 4.80. Found: C, 68.73; H, 4.85.

4.1.3.3. 5-Bromo-2-di(5-methyl-2-furyl)methylbenzaldehyde (6c). Yield 7.6 g, 60% as colorless crystals; mp 85–87 °C; IR (KBr): 1699, 1562, 1476, 1278, 1232, 1187, 1020, 881, 782, 713 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.25 (s, 6H, CH_3), 5.89 (s, 4H, H_{Fur}), 6.32 (s, 1H, C*H*), 7.19 (d, J=8.3 Hz, 1H, H_{Ar}), 7.64 (dd, J=2.1, 8.3 Hz, 1H, H_{Ar}), 7.98 (d, J=2.1 Hz, 1H, H_{Ar}), 10.22 (s, 1H, C*H*O). Anal. Calcd for $C_{18}H_{15}BrO_3$: C, 60.19; H, 4.21. Found: C, 60.25; H, 4.18.

4.1.3.4. 5-Bromo-2-di(5-ethyl-2-furyl)methylbenzaldehyde (6d). Yield 9.2 g, 67% as colorless oil; IR (KBr): 1693, 1605, 1560, 1462, 1377, 1183, 1014, 883, 789 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.17–1.22 (m, 6H, CH_2CH_3), 2.56–2.63 (m, 4H, CH_2CH_3), 5.90 (s, 4H, H_{Fur}), 6.32 (s, 1H, C*H*), 7.16 (d, J=8.3 Hz, 1H, H_{Ar}), 7.63 (dd, J=2.1, 8.3 Hz, 1H, H_{Ar}), 7.99 (d, J=2.1 Hz, 1H, H_{Ar}), 10.22 (s, 1H, C*H*O). Anal. Calcd for $C_{18}H_{15}BrO_3$: C, 62.03; H, 4.94. Found: C, 62.08; H, 4.89.

4.1.4. General procedure for the preparation of naphthofurans 7. A solution of **6** (1 g) in EtOH (12 mL) was treated with ethanolic HCl solution (2 mL) prepared by saturation of 200 g of ethanol with 100 g of gaseous HCl. The mixture was kept at 50 °C for 1 h (TLC monitoring). The reaction mixture was poured into water (100 mL), neutralized with $NaHCO_3$, and extracted with CH_2Cl_2 (3×50 mL). The organic layer was separated, dried with Na_2SO_4, treated with active charcoal, and filtered off. The solvent was removed under reduced pressure, and the oily residue was purified on silica gel column eluting with hexane–benzene (3:1). The residue was recrystallized from hexane–benzene.

WARNING: Care should be taken when handling benzene as a solvent due to its carcinogenic properties.

4.1.4.1. 2-Methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan (7a). Yield 350 mg, 37% as colorless crystals; mp 59–61 °C; IR (KBr): 1619, 1604, 1540, 1399, 1331, 1250, 1216, 1152, 1094, 1022, 943, 894, 879, 793, 752 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.52 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.28 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.50 (s, 1H, 3-H), 6.93 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.39–7.52 (m, 2H, 6-H, 7-H), 7.89 (s, 1H, 4-H), 7.90–7.95 (m, 1H, 5-H), 8.57–8.61 (m, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.0, 14.5, 102.4, 107.5, 109.4, 113.0, 118.0, 123.9, 125.0, 126.1, 128.4 (2C), 130.1, 131.0, 146.9, 151.3, 152.4, 158.3. MS: m/z (%) 262 (M^+, 100), 219 (66), 191 (12), 190 (23), 189 (33), 149 (19). Anal. Calcd for $C_{18}H_{14}O_2$: C, 82.42; H, 5.38. Found: C, 82.49; H, 5.43.

4.1.4.2. Crystal data of compound 7a. $C_{18}H_{14}O_2$, monoclinic, space group $P2(1)/c$; a=9.569(2) Å, b=34.400(7) Å, c=8.457(2) Å, α=90° β=95.90(3)° γ=90°, V=2769.1(10) $Å^3$, Z=8, D_{calcd}=1.258 mg/m^3, $F(000)$=1104; 5138 reflections collected, 4842 unique (R_{int}=0.0325); final R indices (4842 observed collections $I>2\sigma I$): R_1=0.0366, wR_2=0.0976; final R indices (all data): R_1=0.1419, wR_2=0.1132. Crystallographic data (excluding structure factors) for the structure in this article have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication number CCDC 295796. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44 1223 336033 or e-mail: deposit@ccdc.cam.ac.uc]. Each request should be accompanied by the complete citation of this paper.

4.1.4.3. 6-Chloro-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan (7b). Yield 400 mg, 42% as colorless crystals; mp 94–96 °C; IR (KBr): 1600, 1539, 1396, 1241, 1153, 1024, 943, 919, 880, 784 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.51 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.29 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.50 (s, 1H, 3-H), 6.95 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.40 (dd, J=2.1, 9.3 Hz, 1H, 7-H), 7.78 (s, 1H, 4-H), 7.89 (d, J=2.1 Hz, 1H, 5-H), 8.55 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.1, 14.5, 102.4, 107.6, 109.7, 113.3, 116.9, 125.6, 126.3, 126.6, 127.9, 129.6, 131.0, 131.7, 146.5, 151.0, 152.6, 158.9. MS: m/z (%) 296/298 (M^+, 100/35), 253/255 (49/19), 219 (21), 218 (38), 190 (28),

189 (61), 149 (10). Anal. Calcd for $C_{18}H_{13}ClO_2$: C, 72.85; H, 4.42. Found: C, 72.80; H, 4.48.

4.1.4.4. 6-Bromo-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan (7c). Yield 370 mg, 39% as colorless crystals; mp 119–121 °C; IR (KBr): 1622, 1593, 1396, 1241, 1150, 1018, 960, 909, 868, 806, 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.50 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.28 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.50 (s, 1H, 3-H), 6.95 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.50 (dd, J=2.1, 9.3 Hz, 1H, 7-H), 7.77 (s, 1H, 4-H), 8.06 (d, J=2.1 Hz, 1H, 5-H), 8.48 (d, J=9.3 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.0, 14.6, 102.5, 107.7, 109.7, 113.4, 116.9, 117.8, 126.5, 128.1 (2C), 130.0, 131.0, 132.2, 146.5, 150.0, 152.6, 158.9. MS: *m*/*z* (%) 340/342 (M^+, 94/100), 297/299 (45/28), 262 (14), 233 (14), 219 (27), 218 (35), 190 (32), 189 (56), 149 (28). Anal. Calcd for $C_{18}H_{13}BrO_2$: C, 63.36; H, 3.84. Found: C, 63.42; H, 3.80.

4.1.4.5. 6-Bromo-2-methyl-9-(5-ethyl-2-furyl)naphtho[2,3-*b*]furan (7d). Yield 260 mg, 27% as colorless crystals; mp 58–60 °C; IR (KBr): 1613, 1592, 1526, 1442, 1396, 1212, 1139, 1037, 915, 894, 808, 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.35–1.42 (m, 6H, CH_2CH_3), 2.81–2.92 (m, 4H, CH_2CH_3), 6.28 (d, J=3.2 Hz, 1H, 4-H_{Fur}), 6.50 (s, 1H, 3-H), 6.98 (d, J=3.2 Hz, 1H, 3-H_{Fur}), 7.52 (dd, J=1.9, 9.3 Hz, 1H, 7-H), 7.77 (s, 1H, 4-H), 8.06 (d, J=1.9 Hz, 1H, 5-H), 8.54 (d, J=9.3 Hz, 1H, 8-H);^{13}C NMR δ 11.6, 12.4, 21.8, 22.1, 100.8, 106.1, 109.9, 113.2, 116.9, 117.8, 126.4, 128.0, 128.1, 130.0, 130.8, 132.2, 146.5, 150.9, 158.1, 164.3. MS: *m*/*z* (%) 368/370 (M^+, 67/69), 353/355 (100/96), 297/299 (15/18), 290 (13), 262 (13), 246 (17), 231 (25), 218 (31), 203 (17), 202 (23), 190 (14), 189 (39), 176 (12), 170 (16). Anal. Calcd for $C_{20}H_{17}BrO_2$: C, 65.06; H, 4.64. Found: C, 65.02; H, 4.68.

4.1.5. Formylation and acylation of naphthofuran 7b.

4.1.5.1. 6-Chloro-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan-4-carbaldehyde (8). To a cooled (−1 to 0 °C) solution of **7b** (500 mg, 1.7 mmol) in DMF (8 mL), $POCl_3$ (8 mL) was added dropwise. The mixture was stirred for 5 h at rt. At the end of the reaction (TLC monitoring), the mixture was carefully poured into crash ice. The precipitate obtained was filtered off, washed with water, and air-dried. The recrystallization from diethyl ether with charcoal afforded compound **8** as yellow crystals (400 mg, 73%). Mp=179–181 °C; IR (KBr): 1668, 1572, 1513, 1429, 1242, 1048, 1032, 893, 809, 785 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.51 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 6.28 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 7.04 (s, 1H, 3-H), 7.07 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.36 (dd, J=1.6, 9.2 Hz, 1H, 7-H), 8.57 (d, J=9.2 Hz, 1H, 8-H), 8.98 (d, J=1.6 Hz, 1H, 5-H), 10.68 (s, 1H, C*H*O); ^{13}C NMR δ 14.0, 14.6, 101.8, 108.3, 115.9, 116.7, 117.8, 122.2, 125.5, 125.9, 128.5, 130.7, 133.2, 135.5, 145.6, 149.7, 154.1, 162.6, 188.6. MS: *m*/*z* (%) 324/326 (M^+, 100/33), 295/297 (17/7), 253/255 (22/10), 218 (10), 202 (11), 189 (27). Anal. Calcd for $C_{19}H_{13}ClO_3$: C, 70.27; H, 4.03. Found: C, 70.32; H, 4.08.

4.1.5.2. 1-[6-Chloro-2-methyl-9-(5-methyl-2-furyl)naphtho[2,3-*b*]furan-4-yl]-1-ethanone (9), 1-[5-(4-acetyl-6-chloro-2-methylnaphtho[2,3-*b*]furan-9-yl)-2-methyl-3-furyl]-1-ethanone (10). To the cooled (−7 to 0 °C) stirred suspension of $AlCl_3$ (670 mg, 50.5 mmol) in dry CH_2Cl_2 the solution of acetyl chloride (400 mg, 50.5 mmol) in dry CH_2Cl_2 was added and kept for 20 min. Then solution of **7b** (500 mg, 1.7 mmol) in dry CH_2Cl_2 was added. The mixture was stirred for 2 h at rt. At the end of the reaction (TLC monitoring), the mixture was poured into water and neutralized with $NaHCO_3$. The emulsion was extracted with CH_2Cl_2, combined organic layers were treated with Na_2SO_4 and charcoal. The solvent was evaporated under reduced pressure. The residue was separated by column chromatography using silica gel (5–40 mkm) and benzene–hexane=2:1 as eluent to give products **9** (75 mg) and **10** (170 mg) in ratio 1:2 in total 39% yield.

WARNING: Care should be taken when handling benzene as a solvent due to its carcinogenic properties.

Compound **9** was isolated as yellow crystals with mp 122–124 °C; IR (KBr): 1668, 1596, 1529, 1424, 1384, 1357, 1248, 1143, 1034, 933, 791 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.51 (s, 3H, CH_3), 2.55 (s, 3H, CH_3), 2.78 (s, 3H, CH_3), 6.29 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 6.63 (s, 1H, 3-H), 7.00 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.43 (dd, J=1.8, 9.2 Hz, 1H, 7-H), 8.28 (d, J=1.8 Hz, 1H, 5-H), 8.60 (d, J=9.2 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) 14.0, 14.6, 32.3, 102.5, 107.9, 112.9, 115.0, 124.0, 126.0, 126.5, 126.9, 128.3, 128.4, 130.0, 131.8, 145.6, 150.1, 153.5, 160.7, 202.1. MS: *m*/*z* (%) 338/340 (M^+, 52/27), 323/325 (100/42), 296/298 (39/19), 261 (23), 205 (13), 203 (10), 190 (26). Anal. Calcd for $C_{20}H_{15}ClO_3$: C, 70.91; H, 4.46. Found: C, 70.95; H, 4.41.

Compound **10** was isolated as colorless crystals with mp 188–190 °C; IR (KBr): 1672, 1573, 1556, 1406, 1374, 1154, 943, 926, 811, 687, 640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.97 (s, 3H, CH_3), 2.44 (s, 3H, CH_3), 2.70 (s, 3H, CH_3), 6.64 (s, 1H, 3-H), 7.42 (dd, J=2.0, 9.0 Hz, 1H, 7-H), 7.70 (d, J=9.2 Hz, 1H, 5-H), 8.01 (d, J=2.0 Hz, 1H, 8-H), 8.50 (s, 1H, H_{Fur}); ^{13}C NMR δ 13.7, 15.9, 28.4, 31.2, 106.9, 109.3, 117.3, 121.7, 121.7, 126.7, 127.4, 127.5, 128.4, 130.8, 131.8, 148.0, 151.1, 153.8, 166.2, 193.2, 193.4. MS: *m*/*z* (%) 380/382 (M^+, 98/33), 365/367 (100/35), 337/339 (14/3), 320 (10). Anal. Calcd for $C_{22}H_{17}ClO_4$: C, 69.39; H, 4.50. Found: C, 69.45; H, 4.42.

4.1.6. Nitrosation and nitration of naphthofurans 7.

4.1.6.1. 2-Methyl-9-(5-methyl-2-furyl)-4-nitronaphtho[2,3-*b*]furan (11a). To a stirred suspension of KNO_3 (580 mg, 5.7 mmol) in glacial acetic acid (10 mL), a solution of **7a** (1 g, 3.8 mmol) in 20 mL acetic acid was added. The mixture was kept at 50 °C for 0.5 h (TLC monitoring). The mixture was poured into water (100 mL), neutralized with $NaHCO_3$ and precipitate filtered off and recrystallized from ethanol. Compound **11a** (350 mg, 30%) was obtained as yellow crystals with mp 157–159 °C; IR (KBr): 1539, 1508, 891, 786, 760, 687, 575 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.53 (s, 3H, CH_3), 2.61 (s, 3H, CH_3), 6.33 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 7.05 (s, 1H, 3-H), 7.10 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.56–7.60 (m, 1H, H_{Ar}), 7.66–7.70 (m, 1H, H_{Ar}), 8.71–8.79 (m, 2H, H_{Ar}); ^{13}C NMR δ 14.1, 14.7, 103.3, 108.3, 116.2, 116.5, 123.1, 124.2, 126.0 (2C), 127.0 (2C), 127.8, 127.9, 128.3, 145.1, 154.4, 162.8. MS: *m*/*z* (%) 307 (M^+, 54), 278 (27), 277 (100), 235 (14), 234 (56), 203 (15), 189 (35), 178 (16), 149 (30). Anal. Calcd for $C_{18}H_{13}NO_4$: C, 70.35; H, 4.26. Found: C, 70.40; H, 4.21.

4.1.6.2. 6-Chloro-2-methyl-9-(5-methyl-2-furyl)-4-nitronaphtho[2,3-*b*]furan (11b). Nitronaphthofuran **11b** was synthesized similar to **11a** starting from naphthofuran **7b** (yield: 430 mg, 33%) as yellow crystals with mp 211–213 °C; IR (KBr): 1596, 1539, 1494, 1319, 1233, 898, 791 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.53 (s, 3H, CH_3), 2.59 (s, 3H, CH_3), 6.33 (d, J=3.1 Hz, 1H, 4-H_{Fur}), 7.04 (s, 1H, 3-H), 7.11 (d, J=3.1 Hz, 1H, 3-H_{Fur}), 7.47 (dd, J=2.1, 9.2 Hz, 1H, 7-H_{Ar}), 8.66 (d, J=9.2 Hz, 1H, 5-H_{Ar}), 8.82 (d, J=2.1 Hz, 1H, 8-H_{Ar}); ^{13}C NMR δ 14.0, 14.7, 103.6, 108.5, 116.5, 117.1, 122.2, 125.1, 126.1, 126.8, 128.7 (2C), 129.3 (2C), 134.6, 144.9, 154.8, 163.5. MS: *m*/*z* (%) 341/343 (M^+, 100/36), 311/313 (75/36), 295/297 (25/11), 189 (14). Anal. Calcd for $C_{18}H_{12}ClNO_4$: C, 63.26; H, 3.54. Found: C, 63.31; H, 3.50.

4.1.6.3. 6-Chloro-2-methyl-9-(5-methyl-2-furyl)-4-nitronaphtho[2,3-*b*]furan (11b) by nitration with $NaNO_2$. To a stirred solution of **7b** (500 mg, 1.7 mmol) in glacial acetic acid (10 mL), $NaNO_2$ (160 mg, 2.3 mmol) was added. The mixture was kept at rt for 0.5 h (TLC monitoring). The reaction mixture was poured into water (100 mL), neutralized with $NaHCO_3$, and filtered off. The residue was recrystallized from acetone. Compound **11b** (300 mg, 52%) was obtained as yellow crystals with mp 211–213 °C.

4.1.7. Oxidation of naphthofurans.

4.1.7.1. 2-Methyl-9-[(*E*)-4-oxo-2-pentenoyl]naphtho[2,3-*b*]furan-4-yl acetate (12) (oxidation with nitric acid). To a stirred suspension of KNO_3 (470 mg, 4.7 mmol) in glacial acetic acid (10 mL), the solution of **4a** (1 g, 3.1 mmol) in 20 mL acetic acid was added. The mixture was kept at 50 °C for 1 h (TLC monitoring). The mixture was poured into water (100 mL), neutralized with $NaHCO_3$, and the precipitate was filtered off. The residue was recrystallized from ethanol. Compound **12** (520 mg, 50%) was obtained as yellow crystals with mp 188–190 °C; IR (KBr): 1764, 1683, 1659, 1582, 1508, 1375, 1247, 1170, 1122, 1006, 971, 868, 807, 769, 728, 563 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.43 (s, 3H, CH_3), 2.52 (s, 3H, CH_3), 2.56 (s, 3H, CH_3), 6.43 (s, 1H, 3-H), 7.02 (d, J=15.9 Hz, 1H, *H*C=CH), 7.50–7.61 (m, 2H, 6-H, 7-H), 7.70 (d, J=15.9 Hz, 1H, HC=C*H*), 8.00–8.03 (m, 1H, 5-H), 8.46–8.49 (m, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.4, 20.8, 28.4, 100.1, 114.6, 121.2, 122.5, 123.7, 125.2, 125.3, 127.5, 129.1, 137.9, 139.1, 140.5, 153.9, 158.8, 168.2, 191.0, 198.4. MS: *m*/*z* (%) 336 (M^+, 26), 295 (38), 294 (100), 252 (17), 251 (85), 225 (72), 197 (20), 169 (27). Anal. Calcd for $C_{20}H_{16}O_5$: C, 71.42; H, 4.79. Found: C, 71.48; H, 4.83.

4.1.7.2. 2-Methyl-9-[(*E*)-4-oxo-2-pentenoyl]naphtho[2,3-*b*]furan-4-yl acetate (12) (oxidation with PCC). A solution of naphthofuran **4a** (1 g, 3.1 mmol) in dry CH_2Cl_2 (20 mL) was added dropwise to the suspension of pyridinium chlorochromate (4 g, 18.8 mmol) in dry CH_2Cl_2 (20 mL). The mixture was stirred for 60 h at rt. At the end of the reaction (TLC monitoring), the precipitate was filtered off and washed with hot CH_2Cl_2 (3×50 mL). The filtrate was concentrated in rotatory evaporator, and the oily residue was purified chromatographically on silica gel eluting with hexane–benzene (3:1). The eluate was concentrated to the volume of 10 mL and left to crystallize overnight. Compound **12** (520 mg, 50%) was obtained as yellow crystals.

WARNING: Care should be taken when handling benzene as a solvent due to its carcinogenic properties.

4.1.7.3. 2-Methyl-9-[(*E*)-4-oxo-2-pentenoyl]naphtho[2,3-*b*]furan-4-yl acetate (12) oxidation by MMPP. To a solution of naphthofuran **4a** (1 g, 3.1 mmol) in dry benzene (50 mL), MMPP (15.3 g, 31.0 mmol) was added. The mixture refluxed for 5 h. At the end of the reaction (TLC monitoring), the phthalic acid was filtered off and washed with hot benzene. The benzene extracts were combined and washed with hot water. Then benzene solution concentrated in vacuum. The product was recrystallized from the hexane–benzene mixture. Compound **12** (360 mg, 34%) was obtained as yellow crystals.

WARNING: Care should be taken when handling benzene as a solvent due to its carcinogenic properties.

4.1.7.4. (*E*)-1-(6-Chloro-2-methylnaphtho[2,3-*b*]-furan-9-yl)-2-pentene-1,4-dione (13). A solution of naphthofuran **7b** (1 g, 3.4 mmol) in dry CH_2Cl_2 (20 mL) was added dropwise to the suspension of pyridinium chlorochromate (3.6 g, 16.8 mmol) in dry CH_2Cl_2 (20 mL). The mixture was stirred for 60 h at rt. At the end of the reaction (TLC monitoring), the precipitate was filtered off and washed with hot CH_2Cl_2 (3×50 mL). The filtrate was concentrated in vacuum, and the oily residue was purified chromatographically on silica gel eluting with hexane–benzene (3:1). The eluate was concentrated to the volume of 10 mL and left to crystallize overnight. Compound **13** (370 mg, 35%) was obtained as yellow crystals with mp 124–126 °C; IR (KBr): 1694, 1661, 1492, 1400, 1337, 1285, 1241, 1094, 918, 886, 791 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.44 (s, 3H, CH_3), 2.54 (s, 3H, CH_3), 6.54 (s, 1H, 3-H), 6.98 (d, J=15.9 Hz, 1H, *H*C=CH), 7.45 (dd, J=2.0, 9.2 Hz, 1H, 7-H), 7.69 (d, J=15.9 Hz, 1H, HC=C*H*), 7.90 (d, J=2.0 Hz, 1H, 5-H), 7.97 (s, 1H, 4-H), 9.37 (d, J=9.2 Hz, 1H, 8-H); ^{13}C NMR ($CDCl_3$) δ 14.5, 28.5, 102.4, 115.8, 122.1, 126.4, 126.8, 126.9, 127.7, 130.5, 131.2, 131.3, 138.0, 139.0, 153.2, 159.5, 191.5, 198.5. MS: *m*/*z* (%) 312/314 (M^+, 67/25), 269/271 (76/25), 243/245 (100/27), 187/189 (40/13), 152 (74). Anal. Calcd for $C_{18}H_{13}ClO_3$: C, 69.13; H, 4.19. Found: C, 69.20; H, 4.15.

WARNING: Care should be taken when handling benzene as a solvent due to its carcinogenic properties.

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