Periselectivity in the Cycloaddition Reactions of Pentafulvenes with 3-Oxidopyrylium Betaines: Effect of Substituent on the C-6 Carbon

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Received 28 November 2007; revised 10 March 2008

Abstract: Periselectvity in cycloaddition reactions of pentafulvenes with 3-oxidopyrylium betaines is examined. The results of our studies show that depending on the substituent on the C-6 carbon, the reaction may proceed either through the [6+3] or the [3+2] pathway. The results of our investigations with various pentafulvenes are discussed.

Key words: pentafulvenes, oxidopyrylium betaines, cycloaddition, periselectivity

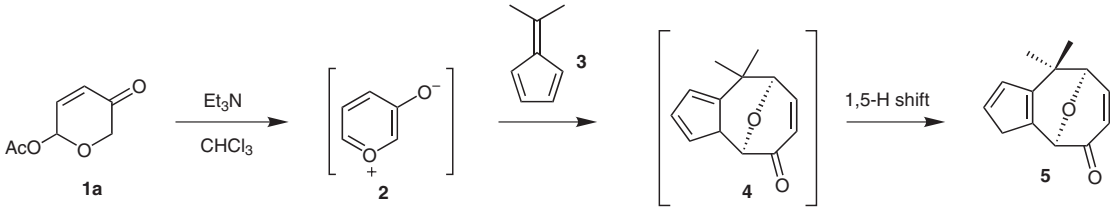
The rich and fascinating chemistry presented through cycloaddition reactions,[1] where products are simple sum of reactants is a corner stone in synthesis. The advent of fulvenes as convincing frames expanded its credibility and scope in cycloaddition reactions. Fulvenes belong to the category of nonfunctionalized C=C bonds. They represent an interesting class of organic compounds with a unique π-electron system and are superior models of cyclic cross-conjugated systems.[2] Based on their dipole moments as well as on their reactivity patterns, they would occupy an intermediate position between the open chain olefinic and aromatic targets in a number of synthetic studies.

Pentafulvenes stand out among the various types of fulvenes and are the most widely studied.[3] They have been identified as a well-known construction unit for many fused ring systems through intra and intermolecular cycloaddition reactions. They perform flexibly as a 2π-, 4π- or 6π-moiety in cycloadditions depending on the competing partner.[4] The periselectivity of these reactions is controlled by the substituents on the fulvene and the other substrate.

Investigations from our own laboratory have unraveled the interesting reactivity profile of fulvenes in cycloaddition reactions.[5] Our recent investigations have shown that pentafulvenes undergo facile [6+3] cycloaddition with 3-oxidopyrylium betaines,[6] leading to the formation of 5/8 fused cyclooctanoids (Scheme 1).[7] The product is formed by a [6+3] cycloaddition followed by a 1,5-H shift. In order to study the generality of the [6+3] cycloaddition, we utilized pentafulvenes with various alkyl, aryl, as well as cycloalkyl substituents at the exocyclic position. The normal [6+3] cycloaddition followed by 1,5-H shift was observed in all the examples studied.

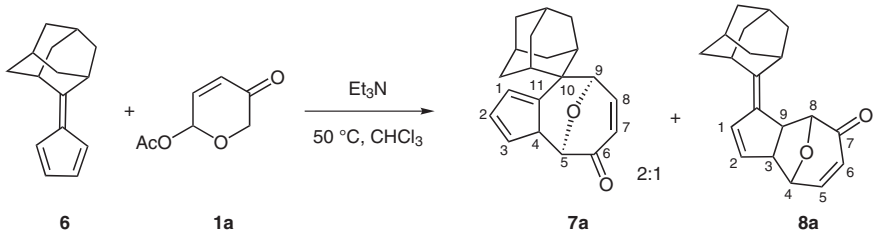
The outcome of a cycloaddition reaction was generally dictated by the specific nonbonded interactions in the transition state. Introduction of a sterically encumbered group as a controlling factor has lot more pronounced effect in this scenario, as its presence modifies the nonbonding interactions and subsequently will influence the preference for alternate cycloaddition pathways. Encouraged by this, we decided to take the benefit out from the cycloaddition chemistry of 6,6-adamantylidenefulvene (**6**) with 3-oxidopyrylium betaines. The selection of fulvene **6** was based on the excellent steric and rigid features and also in view of its limited attention in cycloaddition chemistry.

We then performed the reaction of adamantylidenefulvene (**6**) with 3-oxdiopyrylium betaine under the same reported conditions. The reaction afforded the [6+3] adduct **7a** along with a novel [3+2] adduct **8a**. Interestingly, compared to fulvenes studied earlier,[7] 1,5-H shift was not observed in the [6+3] adduct **7a**. The reaction is shown in Scheme 2.



Scheme 1

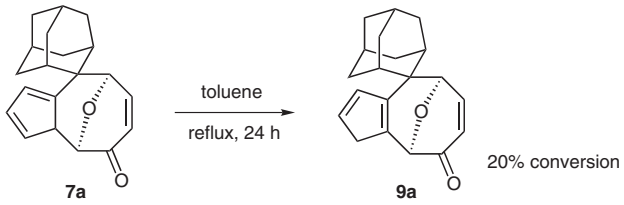
SYNTHESIS 2008, No. 12, pp 1955–1959
Advanced online publication: 16.05.2008
DOI: 10.1055/s-2008-1067093; Art ID: Z27607SS



Scheme 2

The structures of the products were assigned by detailed spectral analysis. IR spectrum of **7a** showed the characteristic carbonyl absorption at 1694 cm^{-1}. In the ^1H NMR spectrum, the bridgehead proton H-5 appeared as a doublet at δ = 4.75 with a coupling constant of J = 8.3 Hz and the solo ring junction hydrogen H-4 resonated as a doublet with the same coupling constant. This finding was a strong evidence for the proposed structure **7a**. In the ^{13}C NMR spectrum, the carbonyl carbon resonated at δ = 191.8 and the bridgehead carbons at C-5 and C-9 appeared at δ = 81.6 and 72.1, respectively. The spectral assignment was well supported by proton–proton COSY analysis.

When the adduct **7a** was heated in toluene under reflux conditions, 1,5-H shift leading to the isomer **9a** was observed, but in low yields (Scheme 3). The product was characterized by spectral analysis.



Scheme 3

In the [3+2] adduct **8a**, the carbonyl absorption was detected at 1704 cm^{-1}. ^1H NMR located the protons of the 7/5 ring junction as a triplet at δ = 3.82 for H-9 and a complex multiplet in the region δ = 3.99–3.92 for H-3. In the ^{13}C NMR spectrum, the carbonyl group was found to resonate at δ = 194.2. The relative stereochemistry at the 7/5 ring junction was obtained from NOE studies. A *trans* stereochemistry was assigned for the ring junction protons H-3 and H-9, on the basis of the lack of enhancement in the H-3 signal when the molecule was irradiated at the resonance frequency of H-9 (Figure 1). The observed magnification in the signal intensities of H-8 and adamantylidene proton H-12 provided positive evidence for the structure of **8a.**

Similar reactivity was observed with **6** and various 2-substituted 3-oxidopyrylium betaines affording a mixture of [6+3] and [3+2] adducts and the results are summarized in Table 1. The [6+3] adducts were found to be the major products in all the examples studied. The results obtained shows that the above cycloaddition reaction is sensitive to the steric bulk of the adamantyl substituent. Steric inhibition of the 1,5-H shift in the [6+3] cycloadduct is a notable feature in these reactions.

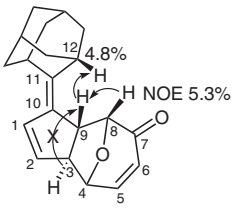
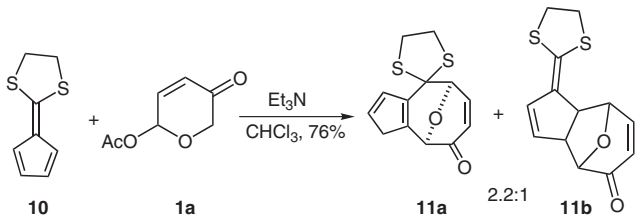


Figure 1 NOE enhancements in **8a**

Our next attempt was to study the reactivity profile of 6,6-dithiodimethylenefulvene (**10**) with oxidopyrylium betaine. The fulvene **10** underwent smooth reaction with the betaine at room temperature affording a mixture of [6+3] and [3+2] adducts **11a** and **11b**, respectively, in 76% yield (Scheme 4).



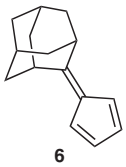
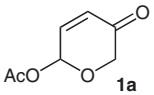
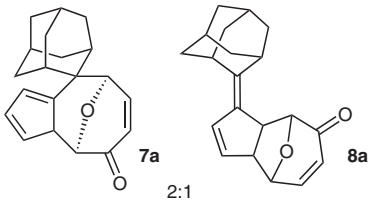
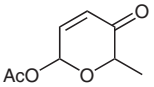
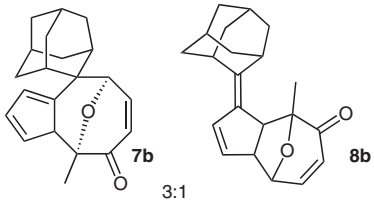
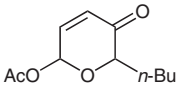
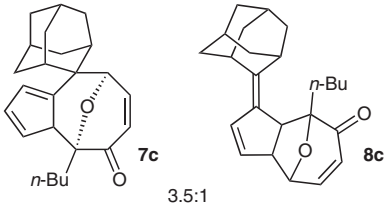
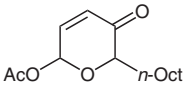
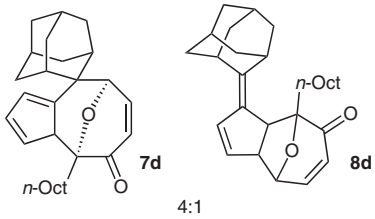
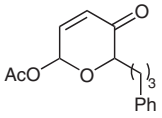
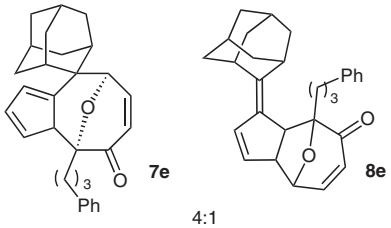
Scheme 4

The products were characterized by detailed spectral analysis (^1H, ^{13}C NMR and IR spectra). In both isomers ^1H NMR located methylene protons attached to the sulfur atoms as a multiplet in the region δ = 3.60–3.20. The structures were further confirmed by mass spectra, which showed molecular ion peaks with in the approved limits.

The formation of [3+2] adduct was reasoned to be due to the decrease in the electron density of fulvene **10** caused by the hyperconjugation of empty *d* orbital of sulfur and olefin π-electrons.[8]

In conclusion, we have shown that the steric and electronic features of substituents at the exocyclic position of fulvenes strongly affect their cycloaddition reaction with 3-oxidopyrylium betaines. The cycloaddition of alkyl, aryl and cycloalkyl substituted fulvenes with 3-oxidopyrylium betaines led to the regioselective formation of [6+3] adduct followed by 1,5-H shift, while 6,6-adamantylidenefulvene (**6**) with a bulky substituent at the exocyclic position afforded the product without 1, 5-H shift, along

Table 1 Cycloaddition of 6,6-Adamantylidenefulvene (**6**)[a]

Entry	Fulvene	Pyranulose acetate	Product	Yield (%)
1	 **6**	 **1a**	 **7a** 2:1 **8a**	74
2	 **1b**	 **7b** 3:1 **8b**		73
3	 **1c**	 **7c** 3.5:1 **8c**		65
4	 **1d**	 **7d** 4:1 **8d**		64
5	 **1e**	 **7e** 4:1 **8e**		52

[a] Reactions conditions: **6** (1.0 equiv), pyranulose acetate **1** (1.2 equiv), Et_3N (1.2 equiv), $CHCl_3$, 50 °C, 6 h.

with a novel [3+2] adduct. Another exciting reactivity was shown by 6,6-dithiodimethylenefulvene (**10**) having less electron density at the exocyclic position when compared to a typical fulvene, as it produced a mixture of [6+3] adduct followed by 1,5-H shift and the [3+2] adduct.

All reactions were conducted in oven-dried glassware. Solvents used for the experiments were distilled and dried as specified. Pyranulose acetates and fulvenes were prepared as per the literature procedures. All other reagents were purchased from local supplier. All reactions were monitored by TLC (Silica gel 60 F_{254}, 0.25 mm, Merck); visualization was effected with UV and/or by developing in an I_2 chamber or with basic $KMnO_4$. Chromatography refers to open column chromatography on silica gel (100–200 mesh). Melting points were recorded on a Büchi melting point apparatus and are uncorrected. NMR spectra were recorded at 300 (^{1}H) and 75 (^{13}C) MHz, respectively, on a Bruker Avance DPX-300 MHz spectrometer. Chemical shifts are reported in δ (ppm) relative to TMS (^{1}H) or $CDCl_3$ (^{13}C) as internal standards. IR spectra were recorded on Bomem MB series FT-IR spectrometer; absorptions are reported in cm^{-1}. Elemental analyses were performed on a Perkin Elmer 2400 Elemental analyzer.

Compounds 7a and 8a; Typical Procedure

6,6-Adamantylidenefulvene (**6**; 100 mg, 0.50 mmol), pyranulose acetate **1a** (94 mg, 0.60 mmol) and anhyd Et_3N (0.08 mL, 0.60 mmol) were taken in anhyd $CHCl_3$ and stirred at 50 °C in a Schlenk tube for 6 h under N_2. The solvent was removed under reduced pressure and the residue on chromatography on a silica gel (60–120 mesh) column using 10% EtOAc–hexane mixture as eluent afforded the products **7a** and **8a** in 2:1 ratio as pale yellow viscous liquids (74%, combined yield).

7a

Yield: 49%; pale yellow viscous liquid; $R_f = 0.52$ (70:30 hexane–EtOAc).

IR (KBr): 2917, 2857, 1694, 1455, 1380, 1263, 1152, 1073, 1020, 830 cm^{-1}.

^1H NMR: δ = 6.86 (dd, *J* = 4.4, 10.4 Hz, 1 H), 6.46 (dd, *J* = 1.2, 3.7 Hz, 1 H), 6.26–6.22 (m, 2 H), 5.88 (d, *J* = 10.4 Hz, 1 H), 5.24 (d, *J* = 4.3 Hz, 1 H), 4.75 (d, *J* = 8.3 Hz, 1 H), 3.48 (d, *J* = 8.3 Hz, 1 H), 2.54–2.50 (m, 1 H), 2.39–2.33 (m, 2 H), 2.13–1.61 (m, 11 H).

^{13}C NMR: δ = 191.8, 147.8, 147.1, 133.5, 130.6, 129.8, 128.3, 81.6, 72.1, 52.3, 50.2, 38.9, 34.7, 34.6, 33.5, 32.8, 32.7, 32.0, 27.9, 27.6.

HRMS (EI): *m*/*z* calcd for $C_{20}H_{22}O_2$ (M^+): 294.1620; found: 294.1624.

8a

Yield: 25%; pale yellow viscous liquid; R_f = 0.50 (70:30 hexane–EtOAc).

IR (KBr): 2912, 2846, 1704, 1451, 1401, 1260, 1097, 845 cm^{-1}.

^1H NMR: δ = 6.85 (dd, *J* = 4.6, 9.9 Hz, 1 H), 6.32 (dd, *J* = 1.2, 5.7 Hz, 1 H), 5.93 (dd, *J* = 1.0, 9.9 Hz, 1 H), 5.55 (dd, *J* = 2.4, 5.7 Hz, 1 H), 4.90 (dd, *J* = 4.6, 7.2 Hz, 1 H), 4.60 (d, *J* = 8.5 Hz, 1 H), 3.99–3.92 (m, 1 H), 3.82 (t, *J* = 8.5 Hz, 1 H), 2.75 (s, 1 H), 2.52 (s, 1 H), 1.42–2.10 (m, 12 H).

^{13}C NMR: δ = 194.2, 151.6, 148.0, 144.7, 133.9, 130.3, 127.9, 84.9, 75.7, 55.3, 46.9, 40.1, 39.8, 38.7, 37.5, 37.4, 36.9, 35.1, 28.7, 28.2.

HRMS (EI): *m*/*z* calcd for $C_{20}H_{22}O_2$ (M^+): 294.1620; found: 294.1623.

7b and **8b**

Total yield: 73%; ratio **7b/8b** = 3:1.

7b

Yield: 55%; pale yellow viscous liquid.

IR (KBr): 2917, 1692, 1457, 1372, 1259, 1094, 1021 cm^{-1}.

^1H NMR: δ = 6.83 (dd, *J* = 4.3, 10.3 Hz, 1 H), 6.46–6.43 (m, 1 H), 6.21–6.16 (m, 2 H), 5.83 (d, *J* = 10.3 Hz, 1 H), 5.24 (d, *J* = 4.3 Hz, 1 H), 3.09 (s, 1 H), 2.54–2.37 (m, 4 H), 2.10–1.77 (m, 10 H), 1.58 (s, 3 H).

^{13}C NMR: δ = 193.6, 147.7, 133.5, 130.9, 129.4, 127.9, 124.0, 85.3, 72.9, 56.7, 46.9, 39.3, 38.9, 34.7, 34.6, 33.5, 32.8, 32.0, 27.9, 27.6, 23.8.

HRMS (EI): *m*/*z* calcd for $C_{21}H_{24}O_2$ (M^+): 308.1776; found: 308.1773.

8b

Yield: 18%; pale yellow viscous liquid.

IR (KBr): 2923, 2846, 1693, 1454, 1377, 1259, 1097, 1037 cm^{-1}.

^1H NMR: δ = 6.76 (dd, *J* = 4.6, 9.8 Hz, 1 H), 6.25 (dd, *J* = 1.2, 5.8 Hz, 1 H), 5.85 (d, *J* = 9.8 Hz, 1 H), 5.43 (dd, *J* = 2.5, 5.8 Hz, 1 H), 4.81 (dd, *J* = 4.6, 7.5 Hz, 1 H), 4.05–4.00 (m, 1 H), 3.40 (d, *J* = 8.3 Hz, 1 H), 2.81–2.77 (m, 2 H), 2.28–1.95 (m, 12 H), 1.54 (s, 3 H).

^{13}C NMR: δ = 194.8, 150.6, 148.9, 145.2, 135.1, 131.3, 128.7, 87.9, 78.3, 57.1, 51.4, 44.9, 41.2, 40.6, 39.6, 37.7, 37.1, 36.8, 35.6, 29.9, 22.8.

HRMS (EI): *m*/*z* calcd for $C_{21}H_{24}O_2$ (M^+): 308.1776; found: 308.1779.

7c and **8c**

Total yield: 65%; ratio **7c/8c** = 3.5:1.

7c

Yield: 50%; pale yellow viscous liquid.

IR (KBr): 2919, 2868, 1694, 1455, 1380, 1352, 1262, 1190, 1074, 758 cm^{-1}.

^1H NMR: δ = 6.83 (dd, *J* = 4.4, 10.3 Hz, 1 H), 6.46–6.44 (m, 1 H), 6.20–6.17 (m, 2 H), 5.84 (d, *J* = 10.3 Hz, 1 H), 5.27 (d, *J* = 4.4 Hz, 1 H), 3.12 (s, 1 H), 2.54–2.50 (m, 1 H), 2.20–2.16 (m, 2 H), 2.09–1.54 (m, 11 H), 1.37–1.22 (m 6 H), 0.91 (t, *J* = 7.0 Hz, 3 H).

^{13}C NMR: δ = 193.2, 147.5, 147.2, 133.4, 131.1, 129.4, 128.6, 88.2, 72.7, 55.2, 51.6, 39.1, 36.9, 34.7, 33.7, 33.5, 32.9, 32.0, 28.2, 27.9, 27.6, 25.4, 23.2, 14.1.

HRMS (EI): *m*/*z* calcd for $C_{24}H_{30}O_2$ (M^+): 350.2246; found: 350.2252.

8c

Yield: 15%; pale yellow viscous liquid.

IR (KBr): 2916, 2856, 1699, 1463, 1411, 1268, 1090, 855 cm^{-1}.

^1H NMR: δ = 6.86 (dd, *J* = 4.7, 9.8 Hz, 1 H), 6.31 (dd, *J* = 1.25, 5.8 Hz, 1 H), 5.94 (d, *J* = 9.8 Hz, 1 H), 5.48 (dd, *J* = 2.4, 5.8 Hz, 1 H), 4.92 (dd, *J* = 4.7, 7.5 Hz, 1 H), 4.09–4.04 (m, 1 H), 3.52 (d, *J* = 8.3 Hz, 1 H), 2.75 (s, 1 H), 2.61–2.54 (m, 2 H), 2.07–1.60 (m, 11 H), 1.34–1.29 (m, 6 H), 0.90–0.88 (m, 3 H).

^{13}C NMR: δ = 195.6, 154.2, 151.9, 133.5, 131.6, 130.7, 128.3, 93.6, 74.7, 56.5, 49.4, 39.7, 37.6, 37.4, 36.7, 35.8, 35.3, 34.2, 29.9, 28.4, 27.0, 26.3, 23.4, 14.4.

HRMS (EI): *m*/*z* calcd for $C_{24}H_{30}O_2$ (M^+): 350.2246; found: 350.2267.

7d and **8d**

Total yield: 54%; ratio **7d/8d** = 4:1.

7d

Yield: 43%; pale yellow viscous liquid.

IR (KBr): 2923, 2851, 1693, 1462, 1374, 1259, 1158, 1037, 793 cm^{-1}.

^1H NMR: δ = 6.83 (dd, *J* = 4.4, 10.2 Hz, 1 H), 6.47–6.45 (m, 1 H), 6.20–6.16 (m, 2 H), 5.84 (d, *J* = 10.3 Hz, 1 H), 5.27 (d, *J* = 4.4 Hz, 1 H), 3.11 (s, 1 H), 2.54–2.33 (m, 3 H), 2.11–1.79 (m, 11 H), 1.33–1.26 (m, 14 H), 0.88–0.85 (m, 3 H).

^{13}C NMR: δ = 193.3, 150.3, 147.5, 133.5, 131.1, 129.4, 128.6, 88.2, 72.7, 55.2, 51.6, 38.9, 37.3, 34.7, 33.5, 32.9, 32.0, 31.6, 30.1, 29.6, 29.5, 29.4, 28.2, 28.0, 27.6, 23.2, 22.7, 14.2.

HRMS (EI): *m*/*z* calcd for $C_{28}H_{38}O_2$ (M^+): 406.2872; found: 406.2878.

8d

Yield: 11%; pale yellow viscous liquid.

IR (KBr): 2923, 1695, 1456, 1399, 1127, 754 cm^{-1}.

^1H NMR: δ = 6.85 (dd, *J* = 4.7, 9.8 Hz, 1 H), 6.31 (dd, *J* = 1.3, 5.8 Hz, 1 H), 5.94 (d, *J* = 9.8 Hz, 1 H), 5.48 (dd, *J* = 2.4, 5.8 Hz, 1 H), 4.92 (dd, *J* = 4.7, 7.6 Hz, 1 H), 4.11–4.04 (m, 1 H), 3.52 (d, *J* = 8.2 Hz, 1 H), 2.74–2.70 (m, 2 H), 2.07–1.93 (m, 12 H), 1.31–1.25 (m, 14 H), 0.90–0.88 (m, 3 H).

^{13}C NMR: δ = 195.4, 152.6, 151.3, 135.7, 132.3, 131.9, 124.9, 89.5, 77.2, 54.9, 46.9, 39.3, 37.8, 36.7, 35.8, 35.4, 34.2, 31.9, 27.3, 26.9, 29.7, 29.4, 29.3, 29.2, 29.1, 27.5, 22.7, 14.1.

HRMS (EI): *m*/*z* calcd for $C_{28}H_{38}O_2$ (M^+): 406.2872; found: 406.2863.

7e and **8e**

Total yield: 52%; ratio **7e/8e** = 4:1.

7e

Yield: 42%; pale yellow viscous liquid.

IR (KBr): 2919, 2857, 1689, 1455, 1380, 1262, 1073, 746 cm^{-1}.

^{1}H NMR: δ = 7.26–7.15 (m, 5 H), 6.82 (dd, *J* = 4.4, 10.2 Hz, 1 H), 6.46–6.44 (m, 1 H), 6.19–6.15 (m, 2 H), 5.83 (d, *J* = 10.2 Hz, 1 H), 5.26 (d, *J* = 4.3 Hz, 1 H), 3.11 (s, 1 H), 2.76–2.39 (m, 9 H), 2.05–1.68 (m, 11 H).

^{13}C NMR: δ = 193.1, 147.5, 147.1, 142.3, 133.5, 131.1, 129.5, 128.6, 128.5, 128.3, 125.8, 88.1, 72.7, 55.2, 51.6, 39.3, 38.9, 36.9, 36.4, 34.7, 33.5, 32.9, 32.0, 30.3, 28.0, 27.7, 25.3.

HRMS (EI): *m*/*z* calcd for $C_{29}H_{32}O_2$ (M^+): 412.2402; found: 412.2406.

8e

Yield: 10%; pale yellow viscous liquid.

IR (KBr): 2921, 2850, 1689, 1492, 1453, 1380, 1259, 1045 cm^{-1}.

^{1}H NMR: δ = 7.30–7.13 (m, 5 H), 6.82 (dd, *J* = 4.7, 9.8 Hz, 1 H), 6.29 (dd, *J* = 1.2, 5.8 Hz, 1 H), 5.92 (d, *J* = 9.8 Hz, 1 H), 5.45 (dd, *J* = 2.5, 5.8 Hz, 1 H), 4.89 (dd, *J* = 4.7, 7.5 Hz, 1 H), 4.07–4.01 (m, 1 H), 3.48 (d, *J* = 8.3 Hz, 1 H), 2.85–2.80 (m, 1 H), 2.72–2.68 (m, 1 H), 2.16–1.94 (m, 18 H).

^{13}C NMR: δ = 196.4, 151.6, 149.3, 142.3, 134.7, 133.9, 132.0, 130.1, 129.5, 128.6, 126.7, 89.0, 77.8, 55.5, 47.4, 39.9, 36.8, 36.1, 35.9, 35.0, 34.2, 33.4, 31.9, 29.7, 28.2, 27.5, 26.9.

HRMS (EI): *m*/*z* calcd for $C_{29}H_{32}O_2$ (M^+): 412.2402; found: 412.2438.

11a and **11b**

Total yield: 76%; ratio **11a/11b** = 4:1.

11a

Yield: 53%; pale yellow viscous liquid.

IR (KBr): 2929, 2855, 1693, 1450, 1389, 1292, 1053, 1003 cm^{-1}.

^{1}H NMR: δ = 7.14 (dd, *J* = 4.2, 10.4 Hz, 1 H), 6.58 (d, *J* = 5.2 Hz, 1 H), 6.43 (d, *J* = 5.2 Hz, 1 H), 5.95 (d, *J* = 10.4 Hz, 1 H), 4.80 (s, 1 H), 3.56–3.49 (m, 3 H), 3.39–3.27 (m, 2 H), 3.18–2.93 (m, 2 H).

^{13}C NMR: δ = 193.4, 145.9, 133.9, 133.4, 129.0, 131.1, 123.9, 77.3, 76.8, 63.7, 42.0, 40.9, 39.6.

HRMS (EI): *m*/*z* calcd for $C_{13}H_{12}O_2S_2$ (M^+): 264.0279; found: 264.0254.

11b

Yield: 23%; pale yellow viscous liquid.

IR (KBr): 2934, 2851, 1699, 1456, 1379, 1285, 1053, 1009 cm^{-1}.

^{1}H NMR: δ = 6.90 (dd, *J* = 4.6, 9.9 Hz, 1 H), 6.13 (d, *J* = 5.1 Hz, 1 H), 5.98 (d, *J* = 9.9 Hz, 1 H), 5.65–5.63 (m, 1 H), 4.93–4.89 (m, 1 H), 4.79 (d, *J* = 8.2 Hz, 1 H), 3.96–3.85 (m, 2 H), 3.47–3.36 (m, 4 H).

^{13}C NMR: δ = 192.3, 151.0, 142.4, 135.9, 132.4, 130.4, 128.3, 83.9, 76.0, 56.6, 50.9, 38.8, 38.5.

HRMS (EI): *m*/*z* calcd for $C_{13}H_{12}O_2S_2$ (M^+): 264.0279; found: 264.0271.

Isomerization of 7a to 9a

Compound **7a** was heated in toluene under reflux for 36 h. After column chromatography, product **9a** was obtained in 20% yield.

^{1}H NMR: δ = 6.80 (dd, *J* = 4.4, 10.3 Hz, 1 H), 6.30–6.25 (m, 2 H), 5.87 (d, *J* = 10.3 Hz, 1 H), 5.17 (d, *J* = 4.4 Hz, 1 H), 4.63 (s, 1 H), 3.12–2.92 (m, 2 H), 2.40–1.64 (m, 14 H).

Acknowledgment

The authors thank the Council of Scientific and Industrial Research (CSIR), New Delhi for financial assistance (Task Force Project-CMM-005 on Specialty Chemicals). K.S.K. thanks CSIR, New Delhi for a Senior Research Fellowship. We thank Dr. R. Luxmi Varma, Scientist, Chemical Sciences Division, Ms. S. Viji, and Ms. Saumini Mathew for the NMR and high-resolution mass spectra.

References

(1) *Comprehensive Organic Synthesis*, Vol. 5; Trost, B. M.; Fleming, I., Eds.; Pergamon: Oxford, **1991**.
(2) Krygowski, T. M.; Ciesielski, A. M. *Chem. Pap.* **1995**, *49*, 128.
(3) Yates, P. *Advances in Alicyclic Chemistry*, Vol. 2; Academic Press: New York, **1968**.
(4) (a) Hong, B.-C.; Chen, F.-L.; Chen, S.-H.; Liao, J.-H.; Lee, G.-H. *Org. Lett.* **2005**, *7*, 557; and references cited therein. (b) Zhang, X.; Khan, S. I.; Foote, C. S. *J. Org. Chem.* **1995**, *60*, 4102.
(5) (a) Anas, S.; Sajisha, V. S.; Mohanlal, S.; Radhakrishnan, K. V. *Synlett* **2006**, 2399. (b) Nair, V.; Nair, A. G.; Rahdakrishnan, K. V.; Nandakumar, M. V.; Rath, N. P. *Synlett* **1997**, 767. (c) Nair, V.; Anilkumar, G.; Radhakrishnan, K. V.; Nandakumar, M. V.; Kumar, S. *Tetrahedron* **1997**, *53*, 15903. (d) Nair, V.; Jayan, C. N.; Radhakrishnan, K. V.; Anilkumar, G.; Rath, N. P. *Tetrahedron* **2001**, *57*, 5807.
(6) (a) Hendrickson, J. B.; Farina, J. S. *J. Org. Chem.* **1980**, *45*, 3359. (b) Sammes, P. G.; Street, L. J. *J. Chem. Soc., Perkin Trans. 1* **1983**, 2729.
(7) (a) Radhakrishnan, K. V.; Krishnan, S. K.; Bhadbhade, M. M.; Bhosekar, G. V. *Tetrahedron Lett.* **2005**, *46*, 4785. (b) Krishnan, S. K.; Sajisha, S.; Anas, S.; Suresh, C. H.; Bhadbhade, M. M.; Bhosekar, G. V.; Radhakrishnan, K. V. *Tetrahedron* **2006**, *62*, 5952. (c) Krishnan, K. S.; Suresh, E.; Mathew, S.; Radhakrishnan, K. V. *Synthesis* **2006**, 1811. (d) Krishnan, K. S.; Smitha, M.; Suresh, E.; Radhakrishnan, K. V. *Tetrahedron* **2006**, *62*, 12345.
(8) Hong, B.-C.; Sun, S.-S.; Tsai, Y.-C. *J. Org. Chem.* **1997**, *62*, 7717.