Sulfinyl Homo- and Hetero-Dienes from Sulfenic Acids: An Approach Towards Six-membered Nitrogen Heterocycles in Enantiomerically Pure Form

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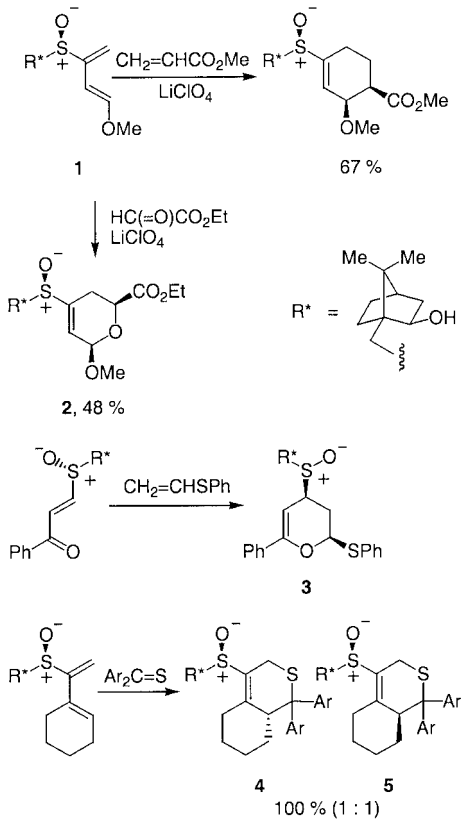
Abstract: Two different synthetic pathways are presented that provide access to enantiopure sulfinyl hydrazones; in both addition of sulfenic acid/unsaturation represents the crucial step of the procedure. The obtained results are discussed in terms of regioselectivity in the formation of α- and/or β-sulfinyl α,β-unsaturated products when sulfenic acids are reacted with substrates showing carbonyl conjugated triple bonds, and/or their derivatives. Despite its structural limitations, (R_S,*E*,*E*)-2-[(1*S*)-isoborneol-10-sulfinyl]-2-butenal dimethylhydrazone (**6**) behaves as 1-azabuta-1,3-diene in hetero Diels–Alder reaction with *N*-methylmaleimide, giving a unique cycloadduct with complete *endo* and facial selectivities.

Key words: 1-aza-1,3-dienes, chiral auxiliaries, stereoselective synthesis, sulfenic acids, sulfoxides

Cyclic structures represent a relevant portion of the skeleton of several natural substances. Six-membered rings are building blocks in carbohydrates, alkaloids, terpenes, steroids, and a tremendous number of other biomolecules. Their widespread presence in nature represents the main reason for the interest generated by reactions such as the Diels–Alder (DA) cycloaddition which supplies a straightforward and stereocontrolled access to six-membered cyclic molecules.

The development of an efficient and original methodology to generate a diene skeleton, bearing an enantiopure sulfinyl group,[1] directed our research towards DA reactions of such substrates with commonly used dienophiles, with the aim of testing the efficiency – as chiral auxiliary – of the sulfoxide substituent directly linked to a diene carbon, and possibly obtaining functionalized six-membered rings in enatiomerically pure form. The high degree of stereochemical control observed in the cycloadditions of diene **1** with methyl acrylate in the presence of $LiClO_4$ (Scheme 1)[2] prompted us to involve several different sulfinyl dienes in catalyzed and uncatalyzed homo-DA reactions.[3] We were also interested in investigating the reactivity of our sulfinyl dienes in hetero-DA (HDA) cycloadditions, which give an easy access to very useful heterocyclic molecules. Pyranoid[4] and thiopyranoid[5] derivatives **2**–**5** were synthesized following the approaches shown in Scheme 1. The most common heterodienophiles such as glyoxylates for pyranoid and thioketones for thiopyranoid systems cycloadded to suitable sulfinyl dienes with a satisfying stereochemical control and/or easy separation of the diastereomeric cycloadducts by chromatography. On the other hand, the facile access to high yields of enantiomerically pure β-sulfinyl α,β-unsaturated carbonyl compounds suggested their use as heterodienes in inverse electron-demanding DA reactions, giving an alternative access to enantiopure pyranoid systems (see, for instance, the synthesis of **3** in Scheme 1).[6]



Scheme 1

In this paper we discuss the effectiveness of the synthetic pathways **a** and **b** (Scheme 2) towards enantiopure sulfinyl α,β-unsaturated dimethylhydrazones, obtained by addition of suitable sulfenic acids to alkynyl hydrazones (pathway **a**) or alternatively by addition of sulfenic acids to alkynyl carbonyl compounds and subsequent derivatization of the obtained α,β-unsaturated carbonyl compounds with H_2NNMe_2 (pathway **b**). This study seemed to be a useful framework to analyze the influence that the substitution features of the triple bond in the acceptor

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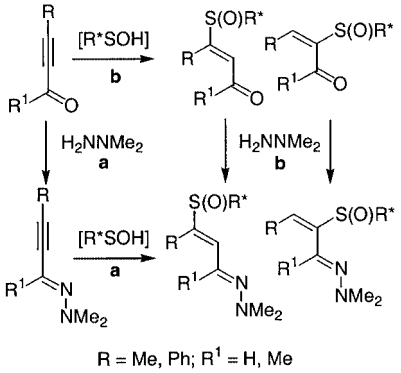
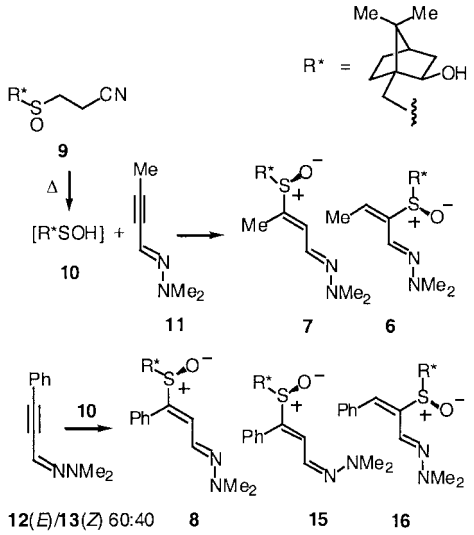
molecules exert on the sulfenic acid addition. We also report the use of (R_S,*E*,*E*)-2-butenal dimethylhydrazones **6** and **7** and 2- and 3-[(1*S*)-isoborneol-10-sulfinyl] substituted, as 1-azabuta-1,3-dienes in stereoselective HDA reactions for access to hydrogenated pyridine derivatives. The introduction into the azadiene moiety of an electron-donating group, such as NMe_2, has proven to be effective in activating this system towards the normal electron-demanding DA reaction with electron-deficient dienophiles.[7] Several applications of such 1-azabuta-1,3-dienes in racemic form were directed to the synthesis of alkaloids[8] whereas few examples of enantiopure 1-azabuta-1,3-dienes are reported in the literature[9] and only one of these heterodienes[9a] has been involved successfully in stereoselective DA cycloadditions.



Scheme 2

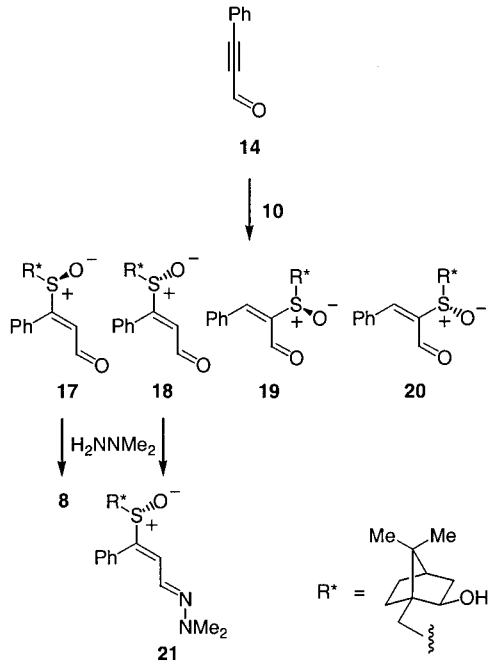
3-[(1*S*)-Isoborneol-10-sulfinyl]propanenitriles (sulfur epimeric mixture **9**)[2] were choosen as suitable precursors of sulfenic acid **10** which was obtained by their thermolysis in toluene (Scheme 3). Isoborneolsulfenic acid **10** was generated in situ and reacted, (i) with 2-butynal dimethylhydrazone (**11**), prepared from crotonaldehyde following the literature procedure,[10] and (ii) with a 60:40 mixture of (*E*)- and (*Z*)-3-phenyl-2-propynal dimethylhydrazones (**12**) and (**13**).[11] Compounds **12** and **13** were prepared from phenylpropargyl aldehyde (**14**) and 1,1-dimethylhydrazine and are separable by column chromatography. The addition of **10** to the triple bond of hydrazone **11** afforded a mixture of regioisomeric sulfinyl hydrazones **7** and **6** in a total yield of 14% and in a 66:34 ratio. Thermolysis of **9** in the presence of the mixture of **12** and **13** led to the formation of sulfinyl hydrazones **8**, **15**, and **16** in 16% total yield and in a 42:28:30 ratio (Scheme 3). The results of this last reaction, in terms of regioselectivity, are comparable with those obtained in the addition of sulfenic acid **10** to dimethylhydrazone **11**. Both reactions occurred with complete stereoselectivity, affording (R_S)-sulfinyl hydrazones in all cases. The sulfur configuration was assigned on the basis of the stereochemical outcome previously observed in the addition of **10** with different alkynes.[1,2] Hydrazones **6**–**8**, **15**, and **16** were all easily separated by column chromatography, obtained in enantiomerically pure form, and fully characterized.



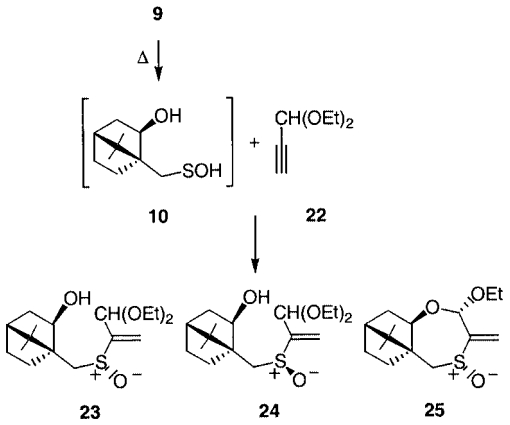
Scheme 3

The synthetic approach, shown as pathway **a** in Scheme 2 and followed at first, suffered the limitation of the desired compounds being formed in low yields, and this restriction induced us to cover pathway **b** whose key step consisted of the addition of a sulfenic acid to a carbonyl compound, positively corroborated by our previous studies.[6] Thermolysis of cyanoethylsulfinylisoborneols **9** in the presence of phenylpropargyl aldehyde (**14**) afforded 3-[(1*S*)-isoborneol-10-sulfinyl]-3-phenyl-2-propenals **17** and **18** and 2-[(1*S*)-isoborneol-10-sulfinyl-3-phenyl-2-propenals **19** and **20** in a 43:40:11:6 ratio and 73% total yield (Scheme 4). Despite the observed loss of stereoselectivity, since the two sulfur epimers **17** and **18** were obtained in almost the same percentages, and an analogous ratio was measured between **19** and **20**, the addition of sulfenic acid **10** to aldehyde **14** showed an increased regioselectivity (83:17) and a much better total yield. The sulfur configuration in the sulfinyl aldehydes **17**–**20** was attributed as mentioned above. (R_S)- and (S_S)-3-sulfinyl-2-propenals **17** and **18** were reacted separately with 1,1-dimethylhydrazine. The reaction of **17** with H_2NNMe_2 led to the formation of a compound which was isolated in 92% yield and identified as dimethylhydrazone **8** (see Scheme 3), whereas the epimeric dimethylhydrazone **21** was obtained from sulfinyl propenal **18** and 1,1-dimethylhydrazine in 86% yield.

We also investigated the addition of sulfenic acid **10** to the propiolaldehyde diethyl acetal (**22**) which would lead to isoborneolsulfinyl 2-propenal dimethylhydrazones, after removal of the acetal protection and reaction of the sulfinyl aldehyde with 1,1-dimethylhydrazyne. Thermolysis of **9** in the presence of acetal **22** (Scheme 5) afforded epimeric sulfinyl acetals **23** and **24**, together with the condensed tricyclic compound **25**, in 65% total yield and 47:30:23 ratio, respectively. A complete regioselectivity was observed in this reaction, in favour of 2-sulfinyl-3,3-diethoxypropenes.[12]



Scheme 4



Scheme 5

The tetrahydro-1,4-oxathiepin ring in **25** originates from the acetal exchange between ethoxy and isoborneol hydroxy moieties, and represents a further example of unexpected and undesired products that we have seldom obtained using the isoborneol sulfinyl group as chiral auxiliary, i.e. fused oxathia heterocycles **26**–**28** (Figure 1).[6,13] Their structures are easily recognizable on the basis of their NMR data. In particular the resonance of the geminal proton to isoborneol oxygen atom is clearly indicative of cyclization involving the hydroxy group. In all the synthesized isoborneol sulfoxides **6**–**8**, **15**–**21**, **23**, **24**, **29**, **31**, **32** this H-2′ resonance appears as a doublet of doublets, sometimes further spin-spin coupled with the hydroxy proton, in the range 4.0–4.2 ppm. The same resonance is clearly shielded (3.71 ppm) in tricyclic derivative **25** where the corresponding proton is identified as H-1, and analogous trend was observed in structurally related compounds such as **26**,[13a] **27**,[6] and **28**.[13b] At the same time the C-2′ resonance is observed in the range 76.4–77.2 for sulfoxides **6**, **8**, **15**, **18**, **20**, **21**, **23**, **24**, **31, 32** but it is deshielded to 85.1 ppm in compound **25**, where the corresponding carbon nucleus is identified as C-1. The assignment of the absolute configuration of **25**, as shown in Scheme 5, is based on the observed formation of only one tricyclic diastereomer among the products of the reaction under study. This experimental result suggests a thermodynamic control of the heterocyclization which follows the addition of **10** onto the triple bond of **22**.

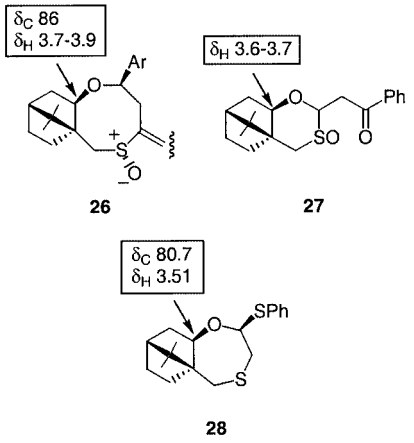
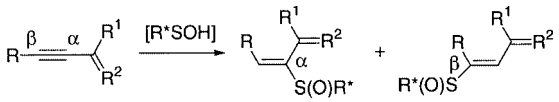


Figure 1

The addition of sulfenic acids to substrates showing carbonyl conjugated triple bonds, and/or their derivatives, has a synthetic validity in the preparation of sulfinyl substituted α,β-unsaturated compounds, which in turn can be involved in a variety of significant reactions. Therefore, we were concerned in an analysis of the formation of α- and/or β-sulfinyl α,β-unsaturated products (Table 1) and a valuation of the results in terms of regioselectivity of this addition. The data reported in Table 1 deserve some comments. The addition of sulfenic acid **10** to alkynyl ketones occurred with complete regioselectivity in favor of the corresponding β-sulfinyl substituted products (entries 7–9), owing to the mesomerism of the acceptor moiety involving the carbonyl group. Furthermore, the results of the addition of **10** to 3-butyn-2-one and its 4-phenyl derivative **30** (entries 7 and 9) clearly pointed out the negligible role that substituent R plays on regioselectivity. The reduced polarization induced by the hydrazone function in substrates **11** and **12** turned into a 7:3 ratio between β- and α-sulfinyl substituted final products (entries 3 and 4). Finally the thermolysis of precursors of **10** in the presence of substrate **22** (entry 1) led just to the α-sulfinyl substituted products, and these results, if compared with the ones in entries 7–9, are in accordance with the electron-withdrawing inductive effect exerted by the acetal function over the carbon atoms of the triple bond.

Table 1 Regioselectivity in the Addition of (1*S*)-Isoborneol-10-sulfenic Acid (**10**) to Alkynyl Conjugated Carbonyl Compounds and their Derivatives

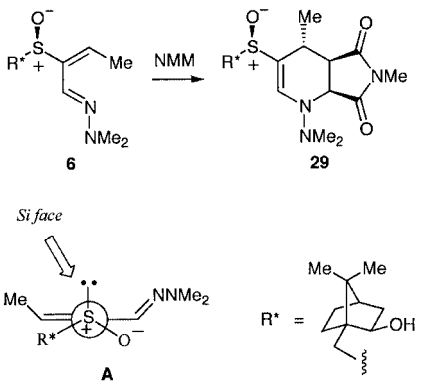


Entry	Substrate[a]	R	R^1	R^2	%Products	
					α-Sulfinyl	β-Sulfinyl
1	Propiolaldehyde diethyl acetal (**22**)	H	H	$(OEt)_2$	100 (**23**+**24**)	
2	2-Ethynyl-2-phenyl-1,3-dithiane	H	Ph	$S(CH_2)_3S$	50	50
3	2-Butynal dimethylhydrazone (**11**)	Me	H	$NNMe_2$	34 (**6**)	66 (**7**)
4	(*E*)-3-Phenyl-2-propynal dimethylhydrazone (**12**)	Ph	H	$NNMe_2$	30 (**16**)	70 (**8**)
5	Phenylpropargyl aldehyde (**14**)	Ph	H	O	17 (**19** + **20**)	83 (**17** + **18**)
6	Ethyl propiolate	H	OEt	O	11	89
7	3-Butyn-2-one	H	Me	O		100
8	1-Phenyl-2-propyn-1-one	H	Ph	O		100
9	4-Phenyl-3-butyn-2-one (**30**)	Ph	Me	O		100 (**31** + **32**)

[a] The experiments of entries 2 and 6–8 are described in ref.[6]

As a part of our study on stereoselective DA reactions involving sulfinyl butadienes,[2–6] we decided to investigate the reactivity of sulfinyl hydrazones **6** and **7** as 1-azabuta-1,3-dienes[7,10] in cycloadditions with *N*-methylmaleimide (NMM). Cycloaddition of **7** with NMM failed, although several conditions were adopted, as the reaction of **6** with NMM, performed in refluxing 1,2-dichloroethane for 96 h, led to (4*R*,4a*R*,7a*S*,R_S)-4,6-dimethyl-1-dimethylamino-3-[(1*S*)-isoborneol-10-sulfinyl]-4,4a,6,7a-tetrahydro-1*H*-pyrrolo[3,4-*b*]pyridine-5,7-dione (**29**) as the only HDA cycloadduct of the reaction among four possible diastereoisomers. The absolute configuration of the new formed stereocentres in cycloadduct **29** was assigned taking into account the *endo* approach of the dienophile onto the *Si* face of diene **6** in its **A** conformation around the S–C bond (Scheme 6).[2,6] The steric requirements of hydrazones **6** and **7**, showing a trisubstituted carbon–carbon double bond, account for the obtained results together with the position of the sulfinyl group which plays a fundamental role in the lack of reactivity of hydrazone **7**.

In conclusion, this work represents a further contribution to the employment of the addition of enantiopure sulfenic acids to alkenes or alkynes as a direct and easy methodology for the introduction of a stereogenic sulfur atom into a suitably unsaturated substrate. We have extensively demonstrated[1–6,14] that the structural features of the sulfenic acids as well as the electronic nature of the unsaturated acceptors play a relevant role in the results of this reaction in terms of total yield and regioselectivity, and that there is a great possibility of modulation of the starting products. In this work, in particular, we draw up two different synthetic pathways for the obtainment of enantiopure sulfinyl hydrazones, in both of which the addition sulfenic acid/unsaturation represents the crucial step, and give an example of applicability of this chemistry. The addition of enantiopure sulfenic acids to enynes or suitably substituted alkynes gives an easy access to homo- and hetero-sulfinyldienes which we have involved in various stereoselective uncatalyzed and catalyzed DA reactions, obtaining in most of the cases a very good control of *endo*/*exo* and facial selectivities exerted by the sulfinyl group.[2,3a–c,4,6,14,15] Despite its structural limitations, sulfinyl *N*,*N*-dimethylhydrazone **6** behaves as 1-azabuta-1,3-diene in HDA reaction with NMM, giving a unique product of cycloaddition with complete *endo* and facial selectivities.



Scheme 6

All reactions were monitored by TLC on commercially available precoated plates (silica gel 60 F 254) and the products were visualized with acidic vanillin solution. Silica gel 60, 230–400 mesh, was used for column chromatography. Petrol refers to light petroleum, bp 30–40 °C. Melting points were measured on a microscopic apparatus and are uncorrected. Optical rotations were measured in $CHCl_3$ solutions whose concentrations are expressed in g/100 mL. ^1H and ^{13}C NMR spectra were recorded at 300 MHz and 75 MHz respectively (unless otherwise specified) in $CDCl_3$ solutions with TMS as internal standard. The assignments are supported by Attached Proton Test (APT) and homodecoupling experiments. Protons and carbon nuclei, marked with (′), pertain to the isoborneol moiety in compounds **6**–**8**, **15**–**21**, **23**, **29**, **31**, **32**. Carbon nuclei, marked with (″), pertain to the phenyl group in compounds **8**, **12**, **13**, **15**, **18**, **20**, **21**, **31**, **32**. IR spectra were taken for neat oils or nujol mulls with a FT spectrophotometer. Mass spectra were measured by FAB (*m*-nitrobenzyl alcohol as matrix).

Thermolysis of (1*S*)-10-[(2-Cyanoethyl)sulfinyl]isoborneols 9 in the Presence of 2-Butynal Dimethylhydrazone (11)[10]; Typical Procedure

Sulfoxides **9** (mixture of sulfur epimers,[2] 0.46 g, 1.8 mmol) in toluene (5 mL) containing hydrazone **11** (0.30 g, 2.7 mmol) were maintained at reflux temperature. When the reaction appeared complete by TLC (after ca 4 h) the solvent was removed under reduced pressure. The column chromatography of the crude product mixture, eluted with petroleum ether containing 40–60% EtOAc, afforded the regioisomeric hydrazones **7** and **6** (in a 66:34 ratio, 14% total yield); The minor isomer was the first to elute followed by the major isomer.

(R_S,*E*,*E*)-2-[(1*S*)-isoborneol-10-sulfinyl]-2-butenal dimethylhydrazone (6)

Minor regioisomer; oil; $[\alpha]_D^{25}$ +98.1 (*c* 1.4).

^1H NMR: δ = 7.14 (d, 1 H, $J_{1,3}$ = 1.0 Hz, H-1), 6.35 (dq, 1 H, $J_{3,4}$ = 7.4 Hz, H-3), 4.17 (m, 1 H, H-2′), 3.24 and 2.85 (AB system, 2 H, $J_{10'A,10'B}$ = 12.9 Hz, H_2-10′), 2.92 (s, 6 H, NMe_2), 2.01 (d, 3 H, H_3-4), 1.7–1.1 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.06 (s, 3 H, H_3-8′), 0.80 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 139.05 (C-2), 125.55 (C-1), 124.02 (C-3), 76.88 (C-2′), 56.33 (C-10′), 51.79 (C-1′), 48.01 (C-7′), 45.16 (C-4,4′), 42.18 (NMe_2), 38.38 (C-3′), 30.61 and 27.17 (C-5′,6′), 20.38 and 19.88 (C-8′,9′).

MS: *m/z* (%) = 313 (55) (M + 1), 111 (100), 69 (26), 55 (32), 43 (23).

Anal. Calcd for $C_{16}H_{28}N_2O_2S$: C, 61.50; H, 9.03; N, 8.97. Found: C, 61.54; H, 8.68; N, 8.89.

(R_S,*E*,*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-2-butenal Dimethylhydrazone (7)

Major regioisomer; oil.

IR (nujol): 3397 (OH), 1541, 1291, 1077, 1033 (SO) cm^{-1}.

^1H NMR: δ = 6.93 (d, 1 H, $J_{1,2}$ = 9.2 Hz, H-1), 6.78 (dq, 1 H, $J_{2,4}$ = 1.3 Hz, H-2), 4.13 (m, 1 H, H-2′), 3.31 and 2.24 (AB system, 2 H, $J_{10'A,10'B}$ = 13.0 Hz, H_2-10′), 3.02 (s, 6 H, NMe_2), 2.09 (d, 3 H, H_3-4), 1.8–1.2 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.08 (s, 3 H, H_3-8′), 0.80 (s, 3 H, H_3-9′).

MS: *m/z* (%) = 313 (29) (M + 1), 69 (95), 55 (100), 43 (71).

Anal. Calcd for $C_{16}H_{28}N_2O_2S$: C, 61.50; H, 9.03; N, 8.97. Found: C, 61.65; H, 8.97; N, 9.04.

Reaction of Phenylpropargyl Aldehyde (14) with 1,1-Dimethylhydrazine; Typical Procedure

To a solution of **14** (1.50 g, 11.5 mmol) in Et_2O (10 mL) kept at 0 °C under stirring, 1,1-dimethylhydrazine (1.38 g, 23.0 mmol) in Et_2O (3 mL) was added dropwise. After allowing the mixture to warm to the r.t., water (5 mL) was added, the crude mixture was extracted with Et_2O (3 × 10 mL), and the organic layers collected and dried over Na_2SO_4. After removing the solvent under reduced pressure, the column chromatography of the crude product mixture, eluted with $CHCl_3$, afforded the stereoisomeric hydrazones **12** and **13** (in 60:40 ratio, 90% total yield). The minor isomer was the first to elute followed by the major isomer.

(*Z*)-3-Phenyl-2-propynal Dimethylhydrazone (13)[11a]

Minor stereoisomer; oil.

IR (neat oil): 2864, 2195, 1533, 1488, 1442, 1356, 1291, 1131, 1064, 847, 757, 691 cm^{-1}.

^1H NMR: δ = 7.5–7.3 (m, 5 H, Ph), 6.47 (s, 1 H, H-1), 3.01 (s, 6 H, NMe_2).

^{13}C NMR: δ = 131.48 (C-2″,6″), 128.28 (C-3″,5″), 128.03 (C-4″), 123.31 (C-1″), 112.50 (C-1), 89.13 (C-3), 87.09 (C-2), 42.35 (NMe_2).

Anal. Calcd for $C_{11}H_{12}N_2$: C, 76.71; H, 7.02; N, 16.26. Found: C, 76.65; H, 7.04; N, 15.54.

(*E*)-3-Phenyl-2-propynal Dimethylhydrazone (12)

Major stereoisomer; oil.

IR (neat oil): 2864, 2182, 1537, 1487, 1442, 1368, 1284, 1129, 1039, 834, 756, 690 cm^{-1}.

^1H NMR: δ = 7.4–7.3 (m, 5 H, Ph), 6.63 (s, 1 H, H-1), 3.17 (s, 6 H, NMe_2).

^{13}C NMR: δ = 130.98 (C-2″,6″), 128.64 (C-4″), 128.34 (C-3″,5″), 122.55 (C-1″), 115.49 (C-1), 96.41 (C-3), 84.45 (C-2), 45.80 (NMe_2).

Anal. Calcd for $C_{11}H_{12}N_2$: C, 76.71; H, 7.02; N, 16.26. Found: C, 76.35; H, 7.03; N, 15.86.

Thermolysis of (1*S*)-10-[(2-Cyanoethyl)sulfinyl]isoborneols 9 in the Presence of (*E*)- and (*Z*)-3-Phenyl-2-propynal Dimethylhydrazones (12/13, 60:40); Typical Procedure

Sulfoxides **9** (mixture of sulfur epimers,[2] 0.49 g, 1.9 mmol) in toluene (5 mL) containing the mixture **12**/**13** (60:40) as obtained following the previous procedure (0.50 g, 2.9 mmol) were maintained at reflux temperature. When the reaction appeared complete by TLC (ca 4 h) the solvent was removed under reduced pressure. The column chromatography of the crude product mixture, eluted with petroleum ether containing 40–60% EtOAc, afforded sulfinyl hydrazones **8**, **15**, and **16** (in a 42:28:30 ratio, 16% total yield), which eluted in the order given.

(R_S,*E*,*E*)-3-[(1*S*)-isoborneol-10-sulfinyl]-3-phenyl-2-propenal dimethylhydrazone (8)

Low melting solid; $[\alpha]_D^{22}$ –116.9 (*c* 7.0).

IR (nujol): 3416 (OH), 1537, 1292, 1077 (SO), 757, 699 cm^{-1}.

^1H NMR: δ = 7.5–7.3 (m, 5 H, Ph), 7.06 (d, 1 H, $J_{1,2}$ = 9.4 Hz, H-1), 6.95 (d, 1 H, H-2), 4.12 (dd, 1 H, $J_{2',3'}$ = 8.0, 3.8 Hz, H-2′), 2.96 and 2.23 (AB system, 2 H, $J_{10'A,10'B}$ = 13.2 Hz, H_2-10′), 2.95 (s, 6 H, NMe_2), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 0.98 (s, 3 H, H_3-8′), 0.63 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 140.62 (C-3), 132.58 (C-1″), 130.46 (C-1), 129.34 (C-3″,5″), 129.31 (C-2″,6″), 129.09 (C-4″), 126.91 (C-2), 77.20 (C-2′), 54.75 (C-10′), 51.51 (C-1′), 48.30 (C-7′), 45.27 (C-4′), 42.65

(NMe_2), 38.60 (C-3′), 30.98 and 27.32 (C-5′,6′), 20.60 and 20.02 (C-8′,9′).

MS: *m/z* (%) = 375 (21) (M + 1), 95 (51), 81 (59), 69 (71), 55 (100), 43 (67).

Anal. Calcd for $C_{21}H_{30}N_2O_2S$: C, 67.34; H, 8.07; N, 7.48. Found: C, 67.52; H, 8.09; N, 7.50.

(R_S,1*Z*,2*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal Dimethylhydrazone (15)
Oil.

^{1}H NMR: δ = 7.6–7.4 (m, 5 H, Ph), 7.07 (s, 2 H, H-1,2),[16] 4.10 (m, 1 H, H-2′), 3.18 and 2.29 (AB system, 2 H, $J_{10'A,10'B}$ = 14.2 Hz, H_2-10′), 2.96 (s, 6 H, NMe_2), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.00 (s, 3 H, H_3-8′), 0.63 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 139.67 (C-3), 132.79 (C-1″), 130.08 (C-1), 129.18 (C-3″,5″), 129.05 (C-2″,6″), 128.86 (C-4″), 127.69 (C-2), 76.43 (C-2′), 52.38 (C-10′), 51.42 (C-1′), 48.83 (C-7′), 44.40 (C-4′), 42.37 (NMe_2), 39.45 (C-3′), 31.20 and 27.33 (C-5′,6′), 20.24 and 19.97 (C-8′,9′).

Anal. Calcd for $C_{21}H_{30}N_2O_2S$: C, 67.34; H, 8.07; N, 7.48. Found: C, 67.05; H, 8.03; N, 7.47.

(R_S,*E*,*E*)-2-[(1*S*)-isoborneol-10-sulfinyl]-3-phenyl-2-propenal Dimethylhydrazone (16)
Oil.

^{1}H NMR: δ = 7.6–7.4 (m, 5 H, Ph), 6.90 (s, 1 H, H-1), 6.87 (s, 1 H, H-3), 4.04 (dd, 1 H, $J_{2',3'}$ = 7.5, 3.7 Hz, H-2′), 3.21 and 2.74 (AB system, 2 H, $J_{10'A,10'B}$ = 13.9 Hz, H_2-10′), 3.06 (s, 6 H, NMe_2), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.04 (s, 3 H, H_3-8′), 0.73 (s, 3 H, H_3-9′).

Anal. Calcd for $C_{21}H_{30}N_2O_2S$: C, 67.34; H, 8.07; N, 7.48. Found: C, 67.59; H, 8.02; N, 7.47.

Thermolysis of (1*S*)-10-[(2-Cyanoethyl)sulfinyl]isoborneols 9 in the Presence of Phenylpropargyl Aldehyde (14); Typical Procedure
Sulfoxides **9** (mixture of sulfur epimers,[2] 0.98 g, 4.1 mmol) in toluene (10 mL) containing commercial aldehyde **14** (1.00 g, 7.7 mmol) were maintained at reflux temperature. When the reaction appeared complete by TLC (after ca 5 h) the solvent was removed under reduced pressure. The column chromatography of the crude product mixture, eluted with petroleum ether containing 30–60% EtOAc, afforded the isoborneol sulfoxides **17**–**20** (**17**/**18**/**19**/**20** in a 43:40:11:6 ratio, 73% total yield), which eluted in the order given.

(R_S,*E*)-2-[(1*S*)-isoborneol-10-sulfinyl]-3-phenyl-2-propenal (19)
^{1}H NMR: δ = 10.09 (s, 1 H, H-1), 8.18 (s, 1 H, H-3), 7.6–7.4 (m, 5 H, Ph), 4.12 (m, 1 H, H-2′), 1.07 (s, 3 H, H_3-8′), 0.85 (s, 3 H, H_3-9′).

(R_S,*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal (17)
Major isomer **17** was always obtained in a mixture with **19** and was isolated as an oil.

IR (neat oil): 3442 (OH), 2954, 1680 (CO), 1037 (SO), 756 cm^{-1}.

^{1}H NMR: δ = 9.72 (d, 1 H, $J_{1,2}$ = 7.6 Hz, H-1), 7.6–7.3 (m, 5 H, Ph), 6.82 (d, 1 H, H-2), 4.10 (m, 1 H, H-2′), 3.08 and 2.21 (AB system, 2 H, $J_{10'A,10'B}$ = 13.2 Hz, H_2-10′), 1.9–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 0.98 (s, 3 H, H_3-8′), 0.56 (s, 3 H, H_3-9′).

Anal. Calcd for $C_{19}H_{24}O_3S$: C, 68.64; H, 7.28. Found: C, 68.72; H, 7.30.

(S_S,*E*)-2-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal (20)
Oil; $[\alpha]_D^{23}$ –48.2 (*c* 4.5).

IR (neat oil): 3545 and 3448 (OH), 2958, 1739 (CO), 1047 (SO), 757 cm^{-1}.

^{1}H NMR: δ = 10.05 (s, 1 H, H-1), 8.19 (s, 1 H, H-3), 7.52 (s, 5 H, Ph), 4.12 (m, 1 H, H-2′), 3.58 and 2.72 (AB system, 2 H, $J_{10'A,10'B}$ = 13.9 Hz, H_2-10′), 2.0–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.10 (s, 3 H, H_3-8′), 0.82 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 188.82 (C-1), 149.10 (C-3), 142.66 (C-2), 132.22 (C-1″), 131.55 (C-4″), 130.56 (C-3″,5″), 129.30 (C-2″,6″), 76.66 (C-2′), 55.29 (C-10′), 52.51 (C-1′), 48.84 (C-7′), 44.60 (C-4′), 39.16 (C-3′), 30.77 and 27.42 (C-5′,6′), 20.40 and 19.89 (C-8′,9′).

Anal. Calcd for $C_{19}H_{24}O_3S$: C, 68.64; H, 7.28. Found: C, 68.63; H, 7.15.

(S_S,*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal (18)
Oil.

IR (neat oil): 3451 (OH), 2955, 1681 (CO), 1037 (SO), 758 cm^{-1}.

^{1}H NMR: δ = 9.74 (d, 1 H, $J_{1,2}$ = 7.7 Hz, H-1), 7.6–7.4 (m, 5 H, Ph), 6.86 (d, 1 H, H-2), 4.06 (m, 1 H, H-2′), 3.20 and 2.37 (AB system, 2 H, $J_{10'A,10'B}$ = 13.8 Hz, H_2-10′), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 0.93 (s, 3 H, H_3-8′), 0.66 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 189.94 (C-1), 167.88 (C-3), 131.33 (C-2), 129.73 (C-1″), 129.58 (C-3″,5″), 129.11 (C-2″,6″), 128.56 (C-4″), 76.42 (C-2′), 52.36 (C-10′), 52.33 (C-1′), 48.95 (C-7′), 44.42 (C-4′), 39.95 (C-3′), 31.03 and 27.19 (C-5′,6′), 20.15 and 19.88 (C-8′,9′).

Anal. Calcd for $C_{19}H_{24}O_3S$: C, 68.64; H, 7.28. Found: C, 68.70; H, 7.25.

(R_S,*E*,*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal Dimethylhydrazone (8)
Sulfoxide **8**, which is reported above as a product of the addition of sulfenic acid **10** to (*E*)-3-phenyl-2-propynal dimethylhydrazone (**12**), was prepared in very good yield by adding dropwise a solution of 1,1-dimethylhydrazine (0.15 g, 2.5 mmol) in Et_2O (2 mL) to a solution of (R_S,*E*)-3-[(1*S*)-isoborneol-10-sulfinyl]-3-phenyl-2-propenal (**17**) (0.70 g, 2.1 mmol) in Et_2O (10 mL) at 0 °C. After allowing the solution to warm to r.t., water (5 mL) was added, the crude mixture was extracted with Et_2O (3 × 10 mL), and the organic layers collected and dried over Na_2SO_4. After removing the solvent under reduced pressure, the column chromatography of the crude product, eluted with petroleum ether–EtOAc (70:30), afforded the pure sulfoxide **8** in 92% yield.

(S_S,*E*,*E*)-3-[(1*S*)-Isoborneol-10-sulfinyl]-3-phenyl-2-propenal Dimethylhydrazone (21)
To a solution of **18** (0.50 g, 1.5 mmol) in Et_2O (10 mL) kept at 0 °C under stirring, 1,1-dimethylhydrazine (0.11 g, 1.8 mmol) in Et_2O (2 mL) was added dropwise. After allowing the solution to warm to the r.t., water (5 mL) was added, the crude mixture was extracted with Et_2O (3 × 10 mL), and the organic layers collected and dried over Na_2SO_4. After removing the solvent under reduced pressure, the column chromatography of the crude product, eluted with petroleum ether–EtOAc (50:50), afforded the pure sulfoxide **21** in 86% total yield as a solid; mp 181–183 °C; $[\alpha]_D^{21}$ +138.8 (*c* 4.0).

IR (nujol): 3394 (OH), 1532, 1283, 1078, 1036 (SO), 766, 696 cm^{-1}.

^{1}H NMR: δ = 7.5–7.3 (m, 5 H, Ph), 7.06 (d, 1 H, $J_{1,2}$ = 9.6 Hz, H-1), 7.03 (d, 1 H, H-2), 4.08 (dd, 1 H, $J_{2',3'}$ = 7.8, 3.8 Hz, H-2′), 3.16 and 2.28 (AB system, 2 H, $J_{10'A,10'B}$ = 14.1 Hz, H_2-10′), 2.94 (s, 6 H, NMe_2), 1.8–1.2 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.00 (s, 3 H, H_3-8′), 0.62 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 139.52 (C-3), 132.76 (C-1″), 130.10 (C-1), 129.10 (C-3″,5″), 129.01 (C-2″,6″), 128.77 (C-4″), 127.02 (C-2), 76.47 (C-2′), 52.41 (C-10′), 51.61 (C-1′), 48.86 (C-7′), 44.49 (C-4′), 42.39 (NMe_2), 39.57 (C-3′), 31.31 and 27.42 (C-5′,6′), 20.34 and 20.09 (C-8′,9′).

MS: *m/z* (%) = 375 (25) (M + 1), 154 (48), 136 (60), 107 (45), 91 (71), 77 (79), 55 (100).

Anal. Calcd for $C_{21}H_{30}N_2O_2S$: C, 67.34; H, 8.07; N, 7.48. Found: C, 67.39; H, 8.04; N, 7.50.

Thermolysis of (1*S*)-10-[(2-Cyanoethyl)sulfinyl]isoborneols 9 in the Presence of Propiolaldehyde Diethyl Acetal (22); Typical Procedure

Sulfoxides **9** (mixture of sulfur epimers,[2] 0.66 g, 2.7 mmol) in toluene (5 mL) containing commercial acetal **22** (1.00 g, 7.8 mmol) were maintained at reflux temperature. When the reaction appeared complete by TLC (after ca 3 h) the solvent was removed under reduced pressure. The column chromatography of the crude product mixture, eluted with petrol containing 10–50% EtOAc, afforded the sulfoxides **23**–**25** (**23**/**24**/**25** in a 47:30:23 ratio, 65% total yield), which eluted in the order given.

(*R*$_S$)-3,3-diethoxy-2-[(1*S*)-isoborneol-10-sulfinyl]propene (23)

Oil; $[\alpha]_D^{22}$ +0.6 (*c* 6.2).

^{1}H NMR: δ = 6.18 (br s, 1 H, H-1 *cis* to SO), 6.01 (br s, 1 H, H-1 *trans* to SO), 5.24 (t, 1 H, $J_{1,3}$ = 0.9 Hz, H-3), 4.11 (dd, 1 H, $J_{2',3'}$ = 8.0, 4.2 Hz, H-2′), 3.7–3.5 (m, 4 H, OCH_2), 3.08 and 3.02 (AB system, 2 H, $J_{10'A,10'B}$ = 13.2 Hz, H_2-10′), 1.9–1.6 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.25 (m, 6 H, CH_2CH_3), 1.07 (s, 3 H, H_3-8′), 0.83 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 151.65 (C-2), 119.17 (C-1), 99.60 (C-3), 76.85 (C-2′), 62.41 and 62.19 (OCH_2), 56.39 (C-10′), 51.62 (C-1′), 48.05 (C-7′), 44.96 (C-4′), 38.28 (C-3′), 30.50 and 27.00 (C-5′,6′), 20.25 and 19.70 (C-8′,9′), 14.85 (CH_2CH_3).

MS: *m/z* (%) = 331 (16) (M + 1), 285 (57) (M + 1 – C_2H_6O), 239 (15), 135 (99), 69 (78), 55 (100), 43 (81).

Anal. Calcd for $C_{17}H_{30}O_4S$: C, 61.78; H, 9.15. Found: C, 61.96; H, 9.12.

(*S*$_S$)-3,3-Diethoxy-2-[(1*S*)-isoborneol-10-sulfinyl]propene (24)

Oil; $[\alpha]_D^{22}$ +23.3 (*c* 3.0).

IR (nujol): 3384 (OH), 1726, 1288, 1117, 1074, 1059 (SO), 940 cm^{-1}.

^{1}H NMR: δ = 6.18 (d, 1 H, $J_{1,3}$ = 0.9 Hz, H-1 *cis* to SO), 6.03 (d, 1 H, $J_{1,3}$ = 1.1 Hz, H-1 *trans* to SO), 5.27 (t, 1 H, H-3), 4.08 (dd, 1 H, $J_{2',3'}$ = 7.4 and 4.1 Hz, H-2′), 3.7–3.5 (m, 4 H, OCH_2), 3.73 and 2.48 (AB system, 2 H, $J_{10'A,10'B}$ = 14.2 Hz, H_2-10′), 1.8–1.4 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.26 (m, 6 H, CH_2CH_3), 1.09 (s, 3 H, H_3-8′), 0.84 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 151.26 (C-2), 120.27 (C-1), 99.99 (C-3), 76.90 (C-2′), 62.98 and 61.82 (OCH_2), 55.62 (C-10′), 51.87 (C-1′), 48.42 (C-7′), 44.68 (C-4′), 39.29 (C-3′), 30.55 and 27.35 (C-5′,6′), 20.40 and 19.88 (C-8′,9′), 14.72 (CH_2CH_3).

MS: *m/z* (%) = 285 (19) (M + 1 – C_2H_6O), 239 (36), 135 (100), 69 (78), 55 (96), 43 (69).

Anal. Calcd for $C_{17}H_{30}O_4S$: C, 61.78; H, 9.15. Found: C, 61.66; H, 9.14.

(1*R*,3*S*,7*S*,10*R*,*R*$_S$)-3-Ethoxy-4-methylene-2-oxa-5-thiatricyclo[5.4.0.1^{7,10}]dodecane 5-Oxide (25)

Oil.

IR (nujol): 1725, 1178, 1113, 1072, 1048 (SO), 943 cm^{-1}.

^{1}H NMR: δ = 6.03 and 5.89 (2 × br s, 2 H, 4=CH_2), 5.24 (t, 1 H, $J_{long\text{-}range}$ = 1.2 Hz, H-3), 3.85 and 3.56 (16 lines, 2 H, J_{gem} = 9.4, J_{vic} = 7.1 Hz, OCH_2), 3.71 (dd, 1 H, $J_{1,11}$ = 8.3, 3.7 Hz, H-1), 3.10 and 2.95 (AB system, 2 H, $J_{6A,6B}$ = 13.5 Hz, H_2-6), 2.0–1.4 (m, 7 H, H_2-8,9,11, H-10), 1.26 (t, 3 H, CH_2CH_3), 1.20 (s, 3 H, H_3-13), 0.96 (s, 3 H, H_3-14).

^{13}C NMR: δ = 155.93 (C-4), 118.63 (4 = CH_2), 102.06 (C-3), 85.09 (C-1), 63.46 (OCH_2), 57.90 (C-6), 52.99 (C-7), 47.85 (C-12), 44.65 (C-10), 38.80 (C-11), 32.99 and 26.94 (C-8,9), 20.68 and 20.16 (C-13,14), 14.84 (CH_2CH_3).

MS: *m/z* (%) = 285 (59) (M + 1), 135 (52), 95 (54), 81 (62), 69 (79), 55 (100).

Anal. Calcd for $C_{15}H_{24}O_3S$: C, 63.35; H, 8.51. Found: C, 63.39; H, 8.47.

Thermolysis of (1*S*)-10-[(2-Cyanoethyl)sulfinyl]isoborneols 9 in the Presence of 4-Phenyl-3-butyn-2-one (30); Typical Procedure

Sulfoxides **9** (mixture of sulfur epimers,[2] 0.37 g, 1.4 mmol) in toluene (4 mL) containing commercial butynone **30** (0.30 g, 2.1 mmol) were maintained at reflux temperature. When the reaction appeared complete by TLC (after ca 3.5 h) the solvent was removed under reduced pressure. The column chromatography of the crude product mixture, eluted with petrol containing 7–20% EtOAc, afforded the sulfur epimers **31** and **32** (**31**/**32** in a 61:39 ratio, 70% total yield), which eluted in the order given.

(*R*$_S$,*E*)-4-[(1*S*)-isoborneol-10-sulfinyl]-4-phenyl-3-buten-2-one (31)

Oil; $[\alpha]_D^{25}$ +51.5 (*c* 0.1).

^{1}H NMR: δ = 7.5–7.3 (m, 5 H, Ph), 6.87 (s, 1 H, H-3), 4.11 (dd, 1 H, $J_{2',3'}$ = 8.0, 4.3 Hz, H-2′), 3.00 and 2.23 (AB system, 2 H, $J_{10'A,10'B}$ = 13.2 Hz, H_2-10′), 2.15 (s, 3 H, H_3-1), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.00 (s, 3 H, H_3-8′), 0.56 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 197.69 (C-2), 157.33 (C-4), 130.89 (C-1″), 130.43 (C-3), 129.27 (C-3″,5″), 128.12 (C-2″,6″), 128.05 (C-4″), 76.89 (C-2′), 54.12 (C-10′), 51.36 (C-1′), 48.24 (C-7′), 44.96 (C-4′), 38.43 (C-3′), 31.00 (C-1), 30.63 and 26.97 (C-5′,6′), 20.21 and 19.69 (C-8′,9′).

Anal. Calcd for $C_{20}H_{26}O_3S$: C, 69.33; H, 7.56. Found: C, 69.45; H, 7.59.

(*S*$_S$,*E*)-4-[(1*S*)-Isoborneol-10-sulfinyl]-4-phenyl-3-buten-2-one (32)

Oil.

^{1}H NMR: δ = 7.5–7.3 (m, 5 H, Ph), 6.88 (s, 1 H, H-3), 4.02 (t, 1 H, $J_{2',3'}$ = 5.8 Hz, H-2′), 3.16 and 2.30 (AB system, 2 H, $J_{10'A,10'B}$ = 13.9 Hz, H_2-10′), 2.15 (s, 3 H, H_3-1), 1.8–1.0 (m, 7 H, H_2-3′,5′,6′, H-4′), 0.92 (s, 3 H, H_3-8′), 0.66 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 197.91 (C-2), 157.27 (C-4), 131.14 (C-1″), 130.43 (C-3), 129.19 (C-3″,5″), 128.45 (C-2″,6″), 128.41 (C-4″), 76.53 (C-2′), 52.42 and 52.11 (C-1′,10′), 48.80 (C-7′), 44.54 (C-4′), 39.96 (C-3′), 31.17 and 27.30 (C-5′,6′), 30.87 (C-1), 20.25 and 19.99 (C-8′,9′).

Anal. Calcd for $C_{20}H_{26}O_3S$: C, 69.33; H, 7.56. Found: C, 69.15; H, 7.54.

(4*R*,4a*R*,7a*S*,*R*$_S$)-4,6-Dimethyl-1-dimethylamino-3-[(1*S*)-isoborneol-10-sulfinyl]-4,4a,6,7a-tetrahydro-1*H*-pyrrolo[3,4-*b*]pyridine-5,7-dione (29)

A solution of azadiene **6** (0.03 g, 0.1 mmol) and *N*-methylmaleimide (0.02 g, 0.2 mmol) in 1,2-dichloroethane (3 mL) was refluxed under stirring. When the reaction appeared complete by TLC (after 4 days) the solvent was removed under reduced pressure. Purification by column chromatography eluting with petrol–EtOAc (60:40) afforded the adduct **29** as an oil (20% yield).

^{1}H NMR: δ = 6.94 (s, 1 H, H-2), 4.24 (d, 1 H, $J_{4a,7a}$ = 8.0 Hz, H-7a), 4.06 (dd, 1 H, $J_{2',3'}$ = 7.4, 3.4 Hz, H-2′), 3.76 and 2.08 (AB system, 2 H, $J_{10'A,10'B}$ = 13.2 Hz, H_2-10′), 3.41 (dq, 1 H, $J_{4,4a}$ = 3.4, $J_{4,Me}$ = 6.9 Hz, H-4), 2.61 (s, 6 H, NMe_2), 3.08 (dd, 1 H, H-4a), 3.00 (s, 3 H, 6-

Me), 1.9–1.1 (m, 7 H, H_2-3′,5′,6′, H-4′), 1.45 (d, 3 H, 4-Me), 1.18 (s, 3 H, H_3-8′), 0.84 (s, 3 H, H_3-9′).

^{13}C NMR: δ = 175.80 and 173.35 (C-5,7), 166.98 (C-3), 133.58 (C-2), 76.91 (C-2′), 56.29 (C-7a), 52.80 (C-10′), 51.10 (C-1′), 49.46 (C-4a), 48.20 (C-7′), 44.89 and 44.77 (C-4′, NMe_2), 38.35 (C-3′), 30.80 and 29.60 (C-5′,6′), 24.99 and 24.08 (4,6-Me), 21.72, 20.41, and 19.83 (C-4,8′,9′).

MS: *m/z* (%) = 424 (3) (M + 1), 270 (7), 109 (27), 95 (54), 81 (60), 69 (80), 55 (100), 43 (78).

Anal. Calcd for $C_{21}H_{33}N_3O_4S$: C, 59.55; H, 7.85; N, 9.92. Found: C, 59.58; H, 7.83; N, 9.94.

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References

(1) Aversa, M. C.; Bonaccorsi, P.; Giannetto, P.; Jafari, S. M. A.; Jones, D. N. *Tetrahedron: Asymmetry* **1992**, *3*, 701.
(2) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Jones, D. N. *J. Org. Chem.* **1997**, *62*, 4376.
(3) (a) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Panzalorto, M.; Rizzo, S. *Tetrahedron: Asymmetry* **1998**, *9*, 1577. (b) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Nicolò, F.; Rizzo, S. *Tetrahedron: Asymmetry* **1999**, *10*, 3907. (c) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Nicolò, F. *J. Org. Chem.* **1999**, *64*, 2114. (d) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Bruno, G.; Caruso, F.; Giannetto, P. *Tetrahedron: Asymmetry* **2001**, *12*, 2901.
(4) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Bruno, G.; Giannetto, P.; Panzalorto, M. *Tetrahedron: Asymmetry* **1997**, *8*, 2989.
(5) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Bonini, B. F.; Giannetto, P.; Nicolò, F. *Tetrahedron: Asymmetry* **1999**, *10*, 3919.
(6) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Policicchio, M. *J. Org. Chem.* **2001**, *66*, 4845.
(7) Serck-Poncin, B.; Hesbain-Frisque, A. M.; Ghosez, L. *Tetrahedron Lett.* **1982**, *23*, 3261.
(8) Tietze, L. F.; Kettschau, G. *Top. Curr. Chem.* **1997**, *189*, 1.
(9) (a) Beaudegnies, R.; Ghosez, L. *Tetrahedron: Asymmetry* **1994**, *5*, 557. (b) Knölker, H. J.; Baum, G.; Gonser, P. *Tetrahedron Lett.* **1995**, *36*, 8191. (c) Maywald, F.; Eilbracht, P. *Synlett* **1996**, 380. (d) Knölker, H. J.; Herzberg, D. *Tetrahedron Lett.* **1999**, *40*, 3547.
(10) Severin, T.; Wanninger, G.; Lerche, H. *Chem. Ber.* **1984**, *117*, 2875.
(11) (a) Eremeev, A. V.; Tikhomirov, D. A.; Tyusheva, V. A.; Liepins, E. *Khim. Get. Soedin.* **1978**, 753; *Chem. Abstr.* **1978**, *89*, 146873. (b) Usanova, E. A.; Khramchikhin, A. V.; Stadnichuk, M. D. *Russ. J. Gen. Chem. (Engl. Trans.)* **2000**, *70*, 1120; *Chem. Abstr.* **2001**, *134*, 295781.
(12) Bell, R.; Cottam, P. D.; Davies, J.; Jones, D. N. *J. Chem. Soc., Perkin Trans. 1* **1981**, 2106.
(13) (a) Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Bruno, G.; Giannetto, P.; Nicolò, F. *J. Chem. Soc., Perkin Trans. 2* **1997**, 273. (b) Aversa, M. C., unpublished results.
(14) Aucagne, V.; Aversa, M. C.; Barattucci, A.; Bonaccorsi, P.; Giannetto, P.; Rollin, P.; Tatibouët, A. *J. Org. Chem.* **2002**, *67*, 6925.
(15) (a) Adams, H.; Aversa, M. C.; Bonaccorsi, P.; Giannetto, P.; Jones, D. N. *Tetrahedron Lett.* **1993**, *34*, 6481. (b) Aversa, M. C.; Bonaccorsi, P.; Giannetto, P.; Jones, D. N. *Tetrahedron: Asymmetry* **1994**, *5*, 805.
(16) In CD_3CN solution, H-1 and H-2 resonate as two doublets at δ = 7.05 and 6.83 respectively with $J_{1,2}$ = 9.5 Hz.