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BIOLOGICALLY ACTIVE THIOSULPHINATES AND α-SULPHINYL-DISULPHIDES FROM *ALLIUM CEPA*

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Key Word Index—*Allium cepa*, Alliaceae; onion; antiasthmatic principle; α-sulphinyldisulphides; thiosulphinates; structure elucidation; ^{1}H and ^{13}C NMR.

Abstract—From the chloroform extract of onion juice five partially new thiosulphinates and six hitherto unknown α-sulphinyldisulphides ('cepaenes') were isolated and their structures elucidated as *trans*-and *cis*-methylsulphinothioic acid-*S*-1-propenyl ester, *cis*- and *trans*- *n*-propylsulphinothioic acid-*S*-1-propenyl ester, *n*-propylsulphinothioic acid-*S*-*n*-propyl ester and *trans*-5-ethyl-4,6,7-trithia-2-decene 4-*S*-oxide, *trans, trans* and *trans, cis* 5-ethyl-4,6,7-trithia-2,8-decadiene 4-*S*-oxide and the diastereoisomers of the latter three compounds. Structure elucidation was performed mainly by CI/EIMS and highfield NMR spectroscopy. The α-β-unsaturated thiosulphinates exert antiasthmatic activity *in vivo* and both thiosulphinates and α-sulphinyldisulphides were found to be dual inhibitors of cyclooxygenase and 5-lipoxygenase *in vitro*.

INTRODUCTION

The chemical constituents of *Allium cepa* L. as well as those of other *Allium* species (especially *Allium sativum* L.) have been investigated and reviewed in numerous publications [e.g. 1, 2]. Most of the sulphur-containing compounds isolated from *Allium* species are not genuine constituents. They are generated from highly reactive sulphenic acids which are released from the various naturally occurring *S*-alk(en)yl-L-cysteinsulphoxides by the action of the enzyme alliinase [3, 4] when the tissues are disintegrated. The known sulphur-containing compounds were stable enough and could be isolated and analysed by GC/GS-MS. Investigations dealing with unstable intermediates have been performed on diallylthiosulphinate (allicin), the major thiosulphinate of *Allium sativum* L. [5] and with thiopropanal-*S*-oxide, the lachrymatory factor of onions [6, 7]. Pharmacological studies with extracts and pure compounds from the genus *Allium* have shown that *Allium* constituents exhibit various activities such as enhancement of fibrinolysis [8] and inhibition of thrombocyte aggregation [9] as well as of fatty acid oxygenases [10].

In 1983 the first antiasthmatic effects of onion extracts were reported [11]. This paper describes the localisation, isolation and structure elucidation of novel sulphur-containing constituents of *Allium cepa* with antiasthmatic and antiallergic properties.

RESULTS AND DISCUSSION

Preliminary investigations using whole-body-plethysmography [12] as test assay had shown that freshly prepared onion juice as well as 'lipophilic' extracts thereof contain the antiasthmatic principle [13]. We succeeded in localizing the active compounds in the chloroform extract of onion juice by monitoring the antiasthmatic activity of various fractions, mainly obtained by medium pressure liquid chromatography (MPLC), with the whole-body-plethysmographic *in vivo* assay.

R_1–S(O)–S–R_2

1 R_1 = Me R_2 = CH=CH–Me (*trans*)
2 R_1 = Me R_2 = CH=CH–Me (*cis*)
5 R_1 = *n*Pr R_2 = CH=CH–Me (*cis*)
6 R_1 = *n*Pr R_2 = CH=CH–Me (*trans*)
7 R_1 = *n*Pr R_2 = CH_2–CH_2–Me

Seven compounds were isolated from the two active subfractions II/2 and II/3 using MPLC. The on-line recorded UV spectra revealed that **1**, **2**, **5**–**7** were closely related thiosulphinates. Elementary analysis showed that all compounds contained sulphur and oxygen. Strong IR absorption bands at 1088 cm^{-1} suggested the presence of a thiosulphinate (ts) or sulphoxide structure. The M_rs were determined by CIMS (NH_3) to be 136 for **1** and **2**, 164 for **5** and **6** and 166 for **7**. Isotope peaks due to ^{34}S with an intensity of 8% of the molecular ion peaks indicated the presence of two sulphur atoms in each compound. The mass spectral data were consistent with the molecular formulas of $C_4H_8OS_2$ for **1** and **2**, $C_6H_{12}OS_2$ for **5** and **6** and $C_6H_{14}OS_2$ for **7**.

As **1** and **2**, as well as **5** and **6**, were rapidly converted into each other at room temperature, as evidenced by HPLC-analysis, the presence of isomeric pairs was suggested. The measurement of samples containing different proportions led to the rationalisation and assignment of the NMR data of the pure compounds **1**, **2**, **5** and **6** (Tables 1–4).

The low-field chemical shift of the methyl-singlet of each compound is in agreement with the reported shift of a methyl-group adjacent to the sulphinyl-sulphur in dimethylthiosulphinate [14]. From these data **1** and **2** are

Table 1. ^{1}H NMR spectral data of **1** and **2** (360 MHz)

1	**2**
1.93 (3H, *d*, 5.5 Hz)	1.87 (3H, *dd*, 6.9/1.6 Hz)
2.97 (3H, *s*)	3.03 (3H, *s*)
6.38 (2H, *m**)	6.33 (1H, *qd* AB, 5.5/8.9 Hz)
	6.46 (1H, *qd* AB, 1.6/8.9 Hz)

*Second order system.

Table 2. ^{13}C NMR chemical shift data of compounds **1** and **2** (90 MHz)

Assignment	**1**	**2**
Me–CH=	15.2	19.0
Me–S(O)	42.2	42.7
–S–CH=	137.5	144.3
Me–CH=	116.9	115.7

Table 3. ^{1}H NMR spectral data of compounds **5** and **6** (360 MHz)

5	**6**	Assignment
1.11 (3H, *t*, 7.3 Hz)	1.09 (3H, *t*, 7.4 Hz)	H_γ
1.85 (2H, *m*)	1.85 (2H, *m*)	H_β
3.12 (2H, *m*)	3.12 (2H, *m*)	H_α
1.86 (2H, *qd*, 1.5/6.8 Hz)	1.92 (3H, *d*, 5 Hz)	H_γ
6.29 (1H, *qd*, 6.8/8.9 Hz)	6.36 (2H, *m**)	H_β/H_α
6.44 (1H, *qd*, 1.5/8.9 Hz)		H_α

*Second order system.

Table 4. ^{13}C NMR chemical shift data of compounds **5** and **6** (90 MHz)

Assignment	**5**	**6**
C_γ	13.2	13.2
C_β	17.2	17.2
$C_{\gamma'}$	19.0	15.7
C_α	57.5	58.0
$C_{\beta'}$	115.9	117.2
$C_{\alpha'}$	143.4	136.6

methyl 1-propenyl thiosulphinates. The two isomers could only differ in the configuration of the double bonds or in the position of the S=O group. The latter possibility could be excluded as positional isomerism would result in much larger chemical shift differences for the methyl singlets [15]. Furthermore no isomerisation of this type would occur at room temperature [16]. The configuration of the double bond in **2** is *cis* ($J = 8.9$ Hz), whereas the coupling constant of the olefinic protons in **1**, due to the second order system, could not be directly deduced.

As in the ^{13}C NMR spectra (Table 2) only a very small shift difference of 0.5 ppm between the methyl-carbons at the thiosulphinate (ts) moieties was observed, these methyl groups in **1** and **2** must be linked to the sulphinyl-sulphur. Thus the new compounds **1** and **2** are *trans* and *cis* methylsulphinothioic acid-*S*-1-propenyl ester.

The ^{1}H NMR spectrum of compound **5** (Table 3) again showed signals at δ1.86, 6.29 and 6.44 indicating the presence of a *cis* 1-propenyl group ($J = 8.9$ Hz) linked to the sulphenyl -sulphur of a ts moiety. The methyl singlet at δ3.03 for **2** was replaced in **5** by a three proton triplet at δ1.11 and two methylene multiplets at δ1.85 and 3.12.

These data are compatible with the presence of a *n*-propyl side-chain linked to the sulphinyl-sulphur in a thiosulphinate [15]. The ^{1}H NMR spectrum of **6** differs from that of **5** only in the olefinic region (Table 3). Instead of the two proton AB system of a *cis* double bond a two proton second order system centered at δ6.36 appears. This system is almost identical with the second order system of **1**.

The chemical shifts of the deshielded methylene carbons of δ57.5 and 58.0 in the ^{13}C NMR spectra for **5** and **6** (Table 4) indicated that in both compounds the *n*-propyl side-chain is linked to the sulphinyl-sulphur. The signals of the *n*-propyl side-chain (δ13.2, 17.2, 57.5 in **5** and δ13.2, 17.2, 58.0 in **6**) are in accordance with the literature [15] and our own measurements with synthetic authentic di-*n*-propyl ts. The signals at δ143.4, 115.9, 19.0 and at δ136.3, 117.2, 15.7, respectively, which exhibit only very small differences to the corresponding shifts observed for **1** and **2** again indicate the presence of *cis* and *trans* 1-propenyl residues attached to the sulphenyl-sulphur **5** and **6**. Thus we assign **5** and **6** as *cis* and *trans* *n*-propylsulphinothioic acid-*S*-1-propenyl ester.

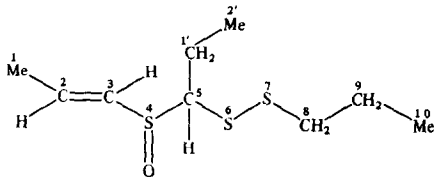
The ^{1}H and ^{13}C NMR spectra indicate that **7** lacks an unsaturated side-chain. All spectral data are in agreement with the structure of *n*-propylsulphinothioic acid-*S*-*n*-propyl-ester. Chromatographic comparison of **7** with a synthetic sample confirmed this assignment.

Thiosulphinates are known in *Allium* species as unstable intermediates in the enzymatically initiated degradation of *S*-alk(en)yl-L-cysteinsulphoxides. They are formed by a condensation reaction from sulphenic acids. The reported isolation of methyl and *n*-propyl 1-propenyl ts is in agreement with the presence of *S*-methyl-, *S*-*n*-propyl- and S-1-propenyl-L-cysteinsulphoxides in *Allium cepa* [17, 18]. While **7** is a known compound, the α,β-unsaturated ts **1**, **2**, **5** and **6** have so far not been isolated from plants nor synthesized.

Compounds **3** and **4** which have also been isolated from the antiasthmatic fractions of the extract are isomeric bicyclic molecules of formula $C_6H_{10}OS_2$. The structure elucidation and synthesis of these unusual compounds will be published elsewhere [19]. The following six novel α-sulphinyldisulphides (**8**–**13**) have been isolated from a more hydrophilic fraction of the chloroform extract of onion juice. While with RP-HPLC compounds **8** and **9**, as well as **10**–**13**, could not be separated, pure **8**, **9** and mixtures of the *trans*/*cis*-isomers **10**/**12** and **11**/**13** were obtained by MPLC with silica gel (solvent system: *n*-hexene–ethyl acetate, 10:3). The structures of **10**–**13** were deduced from the spectral data of both mixtures.

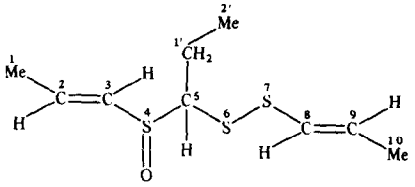
Strong IR absorption bands at 1050 cm^{-1} suggested the presence of a S=O group in each compound. The CI mass spectrum (NH_3) of **8** exhibited a molecular ion peak at m/z 239 $[M+H]^+$ (100%) and led together with the ^{34}S-isotope peak (13%), to the formula $C_9H_{18}OS_3$.

In the ^{1}H NMR spectrum of **8** signals at δ6.51 (*qd*), 6.33



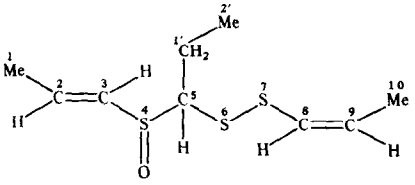
8

9 diastereoisomer **8**



10

11 diastereoisomer **10**



12

13 diastereoisomer **12**

(*qd*) and 1.95 (*dd*) indicated the presence of a *trans* 1-propenyl group ($J_{2,3}$ = 14.9 Hz) linked to a sulphur atom. The 2D ^{1}H COSY spectrum showed the coupling of the three signals and the coupling of the one proton double doublet at δ3.68 with the one proton multiplets at δ2.20 and 1.42 (which are also coupled to one another, and the coupling of both multiplets with the three proton triplet at δ1.17. Thus these signals represent a CH–CH_2–Me moiety which must be linked to two sulphur atoms. From the 2D ^{1}H COSY spectrum it was also evident that the signals at δ2.78, 1.73 and 1.01 derive from a *n*-propyl side-chain. Therefore the following structure for **8** can be deduced: Me–CH–CH–X_a–CH(CH_2–Me)– X_b–CH_2–CH_2–Me–

X_a and X_b consist of one oxygen and three sulphur atoms. The chemical shift of the methylene protons at C-8 (δ2.78) is in agreement with shifts of CH_2-protons adjacent to a disulphide moiety [20, 21], excluding a ts [17, 18] and a sulphide [18] structure for X_b, while a sulphoxide is unlikely [18, 22]. The assignment of X_b as disulphide and therefore of X_a as a sulphoxide (formula $C_9H_{18}OS_3$) was confirmed by the mass spectral fragmentation pattern of **8**. Prominent peaks appeared at *m/z* 149 (90%) for $[C_3H_6$–SS–$C_3H_7]^+$ and *m/z* 107 (25%) for $[SS$–$C_3H_7]^+$, whereas no prominent peaks have been observed at *m/z* 147 or 105 for $[C_3H_5$–SS–$C_3H_6]^+$ and for $[C_3H_5$–SS$]^+$, respectively. Thus we assign **8** as *trans* 5-ethyl-4,6,7-trithia-2-decene 4-*S*-oxide.

Compound **9** exhibited identical mass spectral fragmentation patterns (EI/CI) to those of **8**. In the ^{1}H NMR spectra a marked difference between **9** and **8** was observed only for the chemical shifts of protons at C-3, 5 and 1′ (Table 5). As the configuration of the double bond in **9** is also *trans* ($J_{2,3}$ = 15.1 Hz), **8** and **9** must be diastereoisomers. The stereochemistry at the asymmetric centres (C-5 and sulphoxide), however, could not be determined on the basis of the available spectral data.

Table 5. ^{1}H NMR chemical shift data for compounds **8**–**13** (300/360/400 MHz)

H	8	9	10	12	11	13
1	1.97	1.97	1.96	1.96	1.96	1.96
2	6.51	6.55	6.51	6.52	6.56	6.57
3	6.33	6.44	6.32	6.32	6.44	6.46
5	3.68	3.48	3.69	3.68	3.52	3.50
1′a	1.42	1.89	1.45	1.45	1.90	1.90
1′b	2.20	2.27	2.21	2.21	2.26	2.28
2′	1.17	1.14	1.15	1.16	1.13	1.14
8	2.78	2.73	6.12	6.16	6.1*	6.11
9	1.73	1.71	6.04	5.82	6.1*	5.79
10	1.01	1.00	1.81	1.79	1.79	1.79

The CIMS of a mixture of **10** and **12** indicated the same molecular ion peak at *m/z* 237 (95%) for both compounds in accord with the formula $C_9H_{16}OS_3$ (^{34}S-isotope peaks), suggesting the presence of two double bonds. In the ^{1}H NMR spectrum of **10** and **12** the signals of the *n*-propyl side-chain of **8** at δ2.78, 1.71 and 1.01 were replaced by an additional three proton double doublet at δ1.81 and further signals in the olefinic region between δ5.75 and 6.20, which together integrated for two protons. The presence of a mixture of two compounds in a ratio of *ca* 2:1 could be most clearly seen from the two double doublets for the protons at C-5. In the 2D ^{1}H COSY spectrum of **10** and **12** two Me–CH=CH– and one Me–CH_2–CH_2 systems were observed for each compound. The configuration of the double bonds are apparent from the magnitude of the coupling in the 1D spectra. The major component (**10**) is the *trans, trans* isomer ($J_{2,3}$ = 15.1 Hz; $J_{8,9}$ = 14.5 Hz), whereas the minor component (**12**) is the *trans, cis* isomer ($J_{2,3}$ = 15.1 Hz; $J_{8,9}$ = 9.2 Hz).

The assignment of the signals in the olefinic region has been performed by comparison of the corresponding signals of **8** and **10/12**. The mass spectra of **10** and **12** show prominent peaks at *m/z* 147 and 105 corresponding to $[C_3H_6$–SS–$C_3H_5]^+$ and $[SS$–$C_3H_5]^+$, respectively. Thus **10** and **12** are *trans, trans* and *trans, cis* 5-ethyl-4,6,7-trithia-2,8-decadiene 4-*S*-oxide.

The mass spectra of the mixture of **11** and **13** (ratio *ca* 2:1) exhibited no significant differences to those recorded for **10** and **12**. Comparison of the ^{1}H NMR spectrum of **11/13** with that observed for the **10/12** mixture revealed marked differences in the chemical shifts of the protons at C-3, 5 and 1′ as well as a second order system for the signals of the olefinic protons of the 1-propenyl group attached to the disulphide moiety of the major compound **11**. The configuration of the 1-propenyl double bond linked to the sulphoxide in **11** must be *trans* ($J_{2,3}$ = 15.1 Hz), while the geometry of the double bonds in **13** is *trans* ($J_{2,3}$ = 15.1 Hz), *cis* ($J_{8,9}$ = 9.2 Hz).

From the shift differences of the protons at C-3, 5 and 1′ between **10/12** and **11/13** which are almost the same as those between **8** and **9** it can be deduced that **10** and **11** as well as **12** and **13** are again diastereoisomers. Thus the second order system of the highfield Me–CH=CH–group in **11** must be due to protons of a *trans* double bond. The compounds **11** and **13** are therefore *trans, trans* and *trans, cis* 5-ethyl-4,6,7-trithia-2,8-decadiene 4-*S*-oxide, the diastereoisomers of **10** and **12**.

We named these novel unsaturated α-sulphinyldisulphides isolated from *Allium cepa* 'cepaenes'. They could be formed from the thiosulphinates of onions by a mechanism similar to that proposed by Block [23] for the formation of the ajones from allicin in garlic extracts.

The α,β-unsaturated thiosulphinates are the major antiasthmatic principle of freshly prepared onion extracts *in vivo* [24]. *In vitro* they are potent dual inhibitors of cyclooxygenase [25]. The cepaenes also inhibit very effectively cyclooxygenase and 5-lipoxygenase *in vitro* [26]. Whether the cepaenes also exert antiasthmatic activity *in vivo* could not be evaluated.

EXPERIMENTAL

Spectroscopic methods. ^{1}H NMR (300, 360 and 400 MHz) and ^{13}C NMR (90.56 MHz) were recorded in $CDCl_3$ soln with TMS (^{1}H) or solvent (^{13}C) as int. standard. MS were measured by direct inlet with 70 (EIMS) or 120 eV (CIMS) ionisation. CIMS were recorded using NH_3 as reagent gas. UV spectra were measured online during HPLC-separation using a diode array detector.

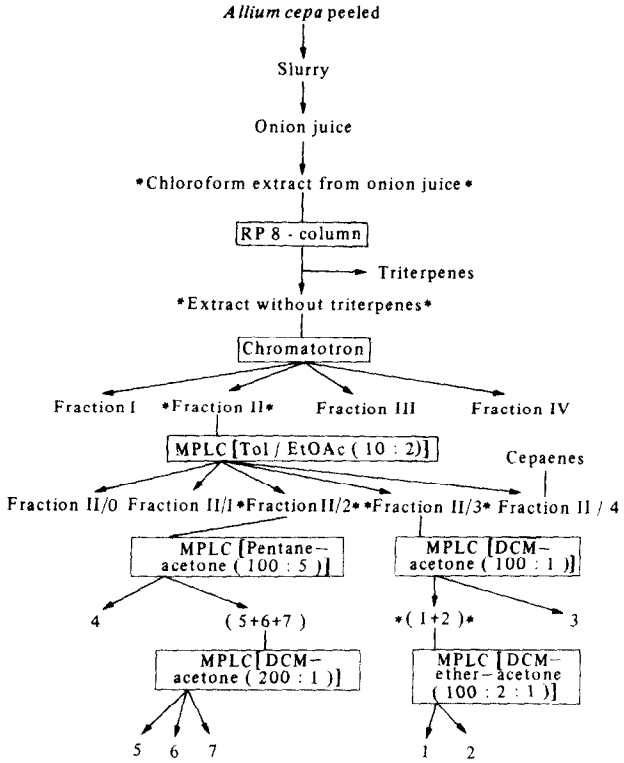
Extraction, fractionation and isolation. Peeled bulbs of *Allium cepa* (yellow variety) were chopped, homogenized and after 30 min (room temp) sqeezed to afford onion juice. The juice was extd twice with $CHCl_3$ to yield (after evapn of the $CHCl_3$ under vacuum) 0.026% (of bulbs) brown residue. Triterpenes (tt) were removed by flash-chromatography on RP 8 material (100 mm × 13 mm i.d.): Elution with MeOH gave tt (20%) in frs 11–16 and the other constituents in frs 6–10. The tt-free extract (0.5 g) was roughly separated by rotating disk chromatography on a silica gel (2 mm) coated disk. Elution with $CHCl_3$ afforded fr. I (13%) and fr. II (34%), with $CHCl_3$–MeOH (10/1) fr. III (36%) and with MeOH fr. IV (12%). For further separation of II, 2 g tt-free extract were submitted to MPLC (silica gel, column: 460 mm × 49 mm i.d., solvent system: toluene–EtOAc 10/2) to yield II/O (5.5%), II/1 (4.6%), II/2 (2.0%), II/3 (5.6%) and II/4 (4.3%). From II/2 and II/3 compounds **4**–**7** and **1**–**3**, respectively, were isolated by repeated MPLC on silica gel (column 460 × 26 mm i.d., solvent systems see Fig. 1). Compounds 8–13 were obtained by MPLC on silica gel from II/4 (solvent system: *n*-hexene–ethyl acetate 10:3). Prior to the spectroscopic investigations the isolates were finally purified by flash-chromatography (silica gel, 100 × 8 mm i.d.).

Characterization of compounds. The molecular formulae were deduced from low resolution MS and ^{34}S-isotope peaks together with the data from the NMR spectra.

trans-*Methylsulphinothioic acid*-S-1-*propenylester* (**1**). Colourless oil. UV λ_{max} nm: 215 (sh), 250. IR (film) ν_{max} cm^{-1}: 1088 (*s*, S=O). CIMS *m/z* (rel. int.): 290 (7) $[2M + NH_4]^+$, 273 (22) $[2M + H]^+$, 156 (5), 154 (65) $[M + NH_4]^+$, 139 (8), 137 (100) $[M + H]^+$, 120 (5), 90 (6), 73 (7). ^{1}H and ^{13}C NMR: see Tables 1 and 2.

cis-*Methylsulphinothioic acid*-S-1-*propenylester* (**2**). Colourless oil. UV λ_{max} nm: 215 (sh), 250. IR and CIMS: see **1**. ^{1}H and ^{13}C NMR: see Tables 1 and 2.

cis-*Propylsulphinothioic acid*-S-1-*propenylester* (**5**). Colourless oil. UV λ_{max} nm: 215 (sh), 250. IR (film) ν_{max} cm^{-1}: 1088 (s, S=O).



* *= fractions showing antiasthmatic activity in vivo;
MPLC = medium pressure liquid chromatography.

Fig. 1. Fractionation and isolation scheme.

EIMS *m/z* (rel. int.) = 166 (6), 164 (48) $[M]^+$, 148 (24), 122 (20), 106 (25), 92 (30), 73 (100.). CIMS *m/z* (rel. int.) = 184 (3), 182 (30) $[M+NH_4]^+$, 167 (7), 165 (82) $[M+H]^+$, 35 (100). ^1H and ^{13}C NMR: see Tables 3 and 4.

trans-*Propylsulphinothioic acid*-S-1-*propenylester* (**6**). Colourless oil. UV λ_{max} nm: 215 (sh), 250 nm. IR and EI-CIMS: see **5**. ^1H and ^{13}C NMR: see Tables 3 and 4.

n-*Propylsulphinothioic acid*-S-n-*propylester* (**7**). Colourless oil. UV λ_{max} nm: 240. IR (film) ν_{max} cm^{-1}: 1088 (s, S=O). EIMS *m/z* (rel. int.): 168 (7), 166 (66) $[M]^+$, 150 (25), 124 (60), 108 (30), 106 (40), 92 (40), 82 (50), 75 (65), 59 (85), 43 (100). CIMS *m/z* (rel. int.): 184 (25) $[M+NH_4]^+$, 169 (9), 167 (100) $[M+H]^+$, 35 (32). ^1H NMR (360 MHz): 1.045 (3H, *t*, *J* = 7.1 Hz), 1.095 (3H, *t*, *J* = 7.1 Hz), 1.83 (2H, *m*), 1.89 (2H, *m*), 3.08 (2H, *m*), 3.13 (2H, *m*). ^{13}C NMR (90.56 MHz): 13.16 (2C), 17.17, 24.25, 34.87, 57.98.

trans-5-*Ethyl*-4,6,7-*trithia*-2-*decene* 4-S-*oxide* (**8**). Colourless oil. UV λ_{max} nm: 240 (sh). IR (film) ν_{max} cm^{-1}: 1050 (*s*, S=O). EIMS *m/z* (rel. int.): 149 (90), 107 (25), 90 (20), 73 (100), 43 (70). CIMS *m/z* (rel. int.): 256 (7) $[M+NH_4]^+$, 241 (12), 239 (100) $[M+H]^+$, 182 (15), 165 (30), 151 (8), 149 (95), 131 (11), 73 (25), 58 (15), 35 (80). ^1H NMR (360 MHz): δ1.01 (3H, *t*, *J* = 7.2 Hz), 1.17 (3H, *t*, *J* = 7.2 Hz), 1.42 (1H, *ddq*, *J* = 14.4/10.8/7.2 Hz), 1.73 (2H, *sextet*, *J* = 7.2 Hz), 1.97 (3H, *dd*, *J* = 6.3/1.35 Hz), 2.20 (1H, *ddq*, *J* = 14.4/3.6/7.2 Hz), 2.78 (2H, t_g *J* = 7.0 Hz), 3.68 (1H, *dd*, *J* = 10.8/3.6 Hz), 6.33 (1H, *qd*, *J* = 1.35/14.9 Hz), 6.51 (1H, *qd*, *J* = 6.8/14.9 Hz). Assignment see Table 5.

trans-5-*Ethyl*-4,6,7-*trithia*-2-*decene* 4-S-*oxide* (**9**, *diastereoisomer of* **8**). Colourless oil. UV, IR, EI-CIMS see **8**. ^1H NMR (300 MHz): δ1.00 (3H, *t*, *J* = 7.3 Hz), 1.14 (3H, *t*, *J* = 7.3 Hz), 1.71 (2H, *sextet*, *J* = 7.3 Hz), 1.89 (1H, *ddq*, *J* = ?/10.5/7.3 Hz), 1.97 (3H, *dd*, *J* = 6.2/0.9 Hz), 2.27 (1H, *ddq*, *J* = 3.5/?/7.3 Hz), 2.73 (2H, *t*, *J* = 7.3 Hz), 3.48 (1H, *dd*, *J* = 10.5/3.5 Hz), 6.44 (1H, *qd*, *J* = 0.9/15.1 Hz), 6.55 (1H, *qd*, *J* = 6.3/15.1 Hz). Assignment see Table 5.

trans, trans-5-*Ethyl*-4,6,7-*trithia*-2,8-*decadiene* 4-S-*oxide* (**10**). Colourless oil. UV λ_{max} nm: 230 (sh). IR (film) ν_{max} cm^{-1}: 1050 (*s*, S=O). EIMS *m/z* (rel. int.): 147 (68), 105 (65), 83 (85), 43 (100). CIMS *m/z* (rel. int.): 473 (30) $[2M+H]^+$, 239 (12), 237 (95) $[M+H]^+$, 180 (65), 162 (80), 147 (100), 105 (35), 73 (30), 35 (25). ^1H NMR (400 MHz): δ1.149 (3H, *t*, *J* = 7.3 Hz), 1.45 (1H, *ddq*, *J* = 10.9/?/7.3 Hz), 1.81 (3H, *dd*, *J* = 6.3/1.1 Hz), 1.960 (3H, *dd*, *J* = 6.8/1.5 Hz), 2.21 (1H, *ddq*, *J* = 3.5/?/7.3 Hz), 3.686 (1H, *dd*, *J* = 10.9/3.5 Hz), 6.04 (1H, *dq*, *J* = 14.5/6.3 Hz), 6.122 (1H, *qd*, *J* = 1.1/14.5 Hz), 6.318 (1H, *qd*, *J* = 1.2/15.1 Hz), 6.509 (1H, *qd*, *J* = 6.8/15.1 Hz). Assignment see table 5.

trans, cis-5-*Ethyl*-4,6,7-*trithia*-2,8-*decadiene* 4-S-*oxide* (**12**). Colourless oil. UV, IR, EI-CIMS see 10. ^1H NMR (400 MHz): δ1.159 (3H, *t*, *J* = 7.3 Hz), 1.45 (1H, *ddq*, *J* = 10.9/?/7.3 Hz), 1.79 (3H, *dd*, *J* = 6.8/1.6 Hz), 1.963 (3H, *dd*, *J* = 6.8/1.1 Hz), 2.21 (1H, *ddq*, *J* = 3.4/?/7.3 Hz), 3.680 (1H, *dd*, *J* = 10.9/3.4 Hz), 5.82 (1H, *dq*, *J* = 9.2/6.9 Hz), 6.122 (1H, *qd*, *J* = 1.6/9.2 Hz), 6.318 (1H, *qd*, *J* = 1.2/15.1 Hz), 6.517 (1H, *qd*, *J* = 6.8/15.1 Hz). Assignment see Table 5.

trans, trans-5-*Ethyl*-4,6,7-*trithia*-2,8-*decadiene* 4-S-*oxide* (**11**) (*diastereoisomer of* **10**). Colourless oil. UV, IR, EI-CIMS see **10**. ^1H NMR (300 MHz): δ1.13 (3H, *t*, *J* = 7.3 Hz), 1.791 (3H, *dd*, *J* = 6.1/0.9 Hz), 1.90 (1H, *ddq*, *J* = 10.9/10.6/7.3 Hz), 1.96 (3H, *dd*, *J* = 6.2/1.0 Hz), 2.26 (1H, *ddq*, *J* = 10.9/3.5/7.3 Hz), 3.52 (1H, *dd*, *J* = 10.6/3.5 Hz), 6.02–6.07 (2H, sec. order system), 6.44 (1H, *qd*, *J* = 1.1/15.1 Hz), 6.56 (1H, *qd*, *J* = 6.3/15.1 Hz). Assignment see Table 5.

trans, cis-5-*Ethyl*-4,6,7-*trithia*-2,8-*decadiene* 4-S-*oxide* (**13**) (*diastereoisomer of* **12**). Colourless oil. UV, IR, EI-CIMS see **12**. ^1H NMR (300 MHz): δ1.14 (3H, *t*, *J* = 7.3 Hz), 1.794 (3H, *dd*, *J* = 6.90/1.6 Hz), 1.90 (1H, *ddq*, *J* = 10.9/10.6/7.3 Hz), 1.96 (3H, *dd*, *J* = 6.2/1.0 Hz), 2.28 (1H, *ddq*, *J* = 10.9/3.5/7.3 Hz), 3.50 (1H, *dd*, *J* = 10.7/3.5 Hz), 5.79 (1H, *qd*, *J* = 6.9/9.2 Hz), 6.11 (1H, *qd*, *J* = 1.5/9.2 Hz), 6.46 (1H, *qd*, *J* = 1.1/15.1 Hz), 6.57 (1H, *qd*, *J* = 6.2/15.1 Hz). Assignment see Table 5.

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