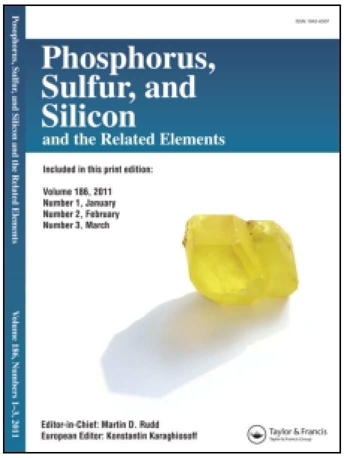

Phosphorus, Sulfur, and Silicon and the Related Elements
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713618290

Triphenylphosphine-Catalyzed Simple Synthesis of Vinyl-Substituted Saccharins

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Online publication date: 27 October 2010

To cite this Article Yavari, Issa and Bayat, Mohammad(2002) 'Triphenylphosphine-Catalyzed Simple Synthesis of Vinyl-Substituted Saccharins', Phosphorus, Sulfur, and Silicon and the Related Elements, 177: 11, 2537 — 2545
To link to this Article: DOI: 10.1080/10426500214574
URL: http://dx.doi.org/10.1080/10426500214574

Phosphorus, Sulfur and Silicon, 2002, Vol. 177:2537–2545

1042-6507/02 $12.00 + .00
DOI: 10.1080/10426500290110739

TRIPHENYLPHOSPHINE-CATALYZED SIMPLE SYNTHESIS OF VINYL-SUBSTITUTED SACCHARINS

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(Received January 15, 2002; accepted February 20, 2002)

*Saccharin (1,1-dioxo-1,2-dihydro-1λ^6-benzo[*d*]-isothiazol-3-one) undergoes a smooth reaction with dialkyl acetylenedicarboxylates in the presence of triphenylphosphine to produce highly-functionalized salt-free sulfur-containing ylides in nearly quantitative yields. These stabilized phosphorus ylides exist as a mixture of two geometrical isomers as a result of restricted rotation around the carbon-carbon partial double bond resulting from conjugation of the ylide moiety with the adjacent carbonyl group. These ylides are converted to dialkyl 2-(1,1-dioxo-1*H*-1λ^6-benzo[*d*]-isothiazol-3-yl)-but-2-enedioates in boiling toluene.*

Keywords: Acetylenic ester; intramolecular Wittig reaction; NH-acid; saccharin; triphenylphosphine

INTRODUCTION

For more than a 100 years, *o*-sulfobenzimide or saccharin (Scheme 1) in the form of its water-soluble salts has been commonly used as a noncaloric artificial sweetener, being the principal sweetening component of diabetic diets. For about three decades, the debate on its toxicity to humans has not reached a consensus, since reports on the carcinogenicity in laboratory animals were published.[1,2] Numerous *N*-substituted derivatives of saccharin have recently been assessed for in vitro biological activity[3,4] and several metal (II) saccharinates exhibit superoxide dismutase-like activity.[5] Aside from its relevance to the biological systems, saccharin has been readily exploited as an excellent model system for investigation of the structural pereferences of small heterocycles containing conjugated CO/NH or NH/SO_2 groups.[6] We report on the reaction between saccharin and dialkyl

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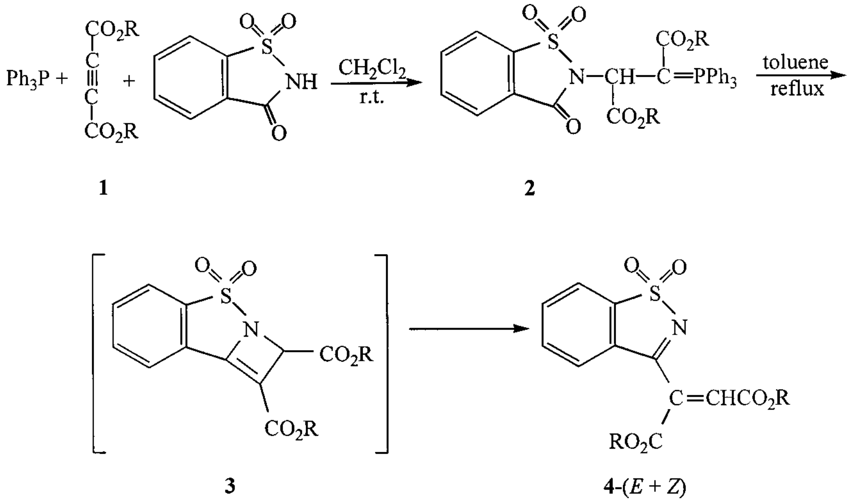


1-4	R	%Yield of **2**	%Yield of **4**	**4**-(*E*) : **4**-(*Z*)
a	Me	95	98	86 : 14
b	Et	86	94	88 : 12
c	^{t}Bu	98	95	85 : 15

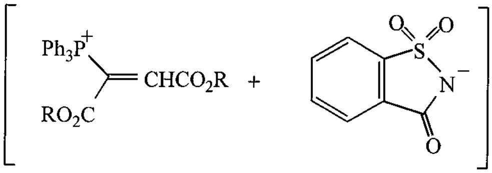
SCHEME 1

acetylenedicarboxylates **1** in the presence of triphenylphosphine. Thus, reaction of saccharin with the electron defficient acetylenic esters **1** leads to stable phosphorus ylides **2**, in good yields. These stable sulfur-containing phosphoranes undergo intramolecular Wittig reaction[7,8] followed by ring opening, in boiling toluene to produce dialkyl 2-(1,1-dioxo-1*H*-1λ^6-benzo[*d*]-isothiazol-3-yl)-but-2-enedioates **4** in good yields (see Scheme 1).

RESULTS AND DISCUSSION

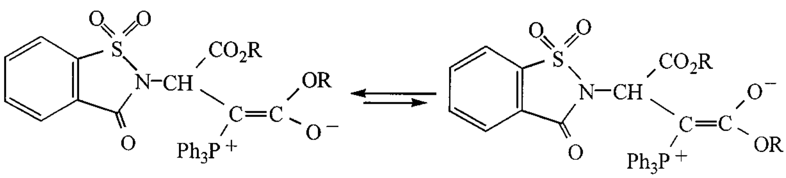
The reaction of saccharin with dialkyl acetylenedicarboxylates **1a–c** in the presence of triphenylphosphine proceeded spontaneously at room temperature in dicholoromethane and was finished within a few hours. ^{1}H and ^{13}C NMR spectra of the crude product clearly indicated the formation of phosphorane **2**. Any product other than **2** could not be detected by NMR spectroscopy.

On the basis of the chemistry of trivalent phosphorus nucleophiles,[9] it is reasonable to assume that compound **2** results from initial addition of triphenylphosphine to the acetylenic ester and subsequent protonation of the 1:1 adduct by saccharin. Then, the positively charged ion is attacked by the anion of saccharin to form ylide **2** (see Scheme 2).



SCHEME 2

The [1]H, [13]C, and [31]P NMR spectra of phosphoranes **2a** and **2b** are consistent with the presence of two isomers. The ylide moiety of these compounds is strongly conjugated with the adjacent carbonyl group and rotation about the partial double bond in (*E*)-**2** and (*Z*)-**2** geometrical isomers (Scheme 3) is slow on the NMR timescale at ambient temparature. Selected [1]H, [13]C, and [31]P NMR chemical shifts and coupling constants in the major (M) and minor (m) geometrical isomers of compounds **2a** and **2b** are shown in Table I. Only one stereoisomer was observed for di-*tert*-butyl derivative **2c** presumably, because of the unfavored steric interaction between the bulky *tert*-butyl and Ph_3P groups in **2**-(*Z*) isomer.



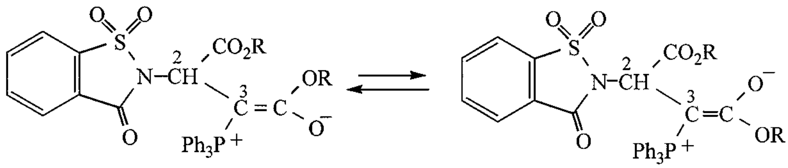
2-(*E*); Major **2**-(*Z*); Minor

SCHEME 3

The methoxy region of the [1]H NMR spectrum of **2a** in $CDCl_3$ at ambient temperature (25°C) exhibits two fairly broad singlets for the CO_2CH_3 groups of (*E*) and (*Z*) isomers and two broad singlets for the OCH_3 groups. Near 10°C the broad lines become sharper. Increasing the temperature results in coalescence of the CO_2CH_3 resonances at 45°C. At 58°C, a relatively broad singlet was observed for the CO_2CH_3 groups, while the OCH_3 protons appear as two broad resonance.

Although, an extensive line–shape analysis in relation to the dynamic [1]H NMR effect observed for **2a** was not undertaken, the variable temperature spectra allowed to calculate[10] the free energy barrier

TABLE I Selected ^{1}H, ^{13}C, and ^{31}P NMR Chemical Shifts (δ in ppm) and Coupling Constants (J in Hz) for H-2, OR, CO_2R, C-2, and C-3 in the Major (M) and Minor (m) Diastereoisomers of Compounds **2a–c**



2-(*E*); Major **2**-(*Z*); Minor

Compound	Isomer (%)	^{1}H NMR data: H-2 ($^{3}J_{PH}$)	OR	CO_2R	^{13}C NMR data: C-2 ($^{2}J_{PC}$)	C-3 ($^{1}J_{PC}$)	^{31}P NMR
2a	M (55)	4.85 (16)	3.22	3.80	54.9 (16)	37.2 (130)	23.48
	m (45)	4.88 (17)	3.69	3.77	54.3 (15)	38.9 (138)	23.81
2b	M (56)	4.98 (19)	3.59[a]	4.12[a]	54.9 (17)	39.9 (131)	22.86
	m (44)	5.02 (17)	4.01[a]	4.22[a]	55.4 (17)	38.6 (140)	23.14
2c	M (98)	4.42 (17)	0.96	1.52	56.2 (17)	36.4 (131)	22.45

[a]The methylen group of the OR moiety.

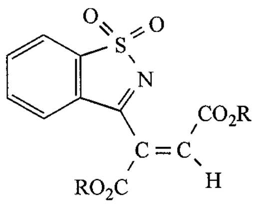
(if not the enthalpy and entropy of activation) for the dynamic NMR process in this ylide (see Table II). The experimental data available are not suitable for obtaining meaningful values of $\Delta H^{\neq}$ and $\Delta S^{\neq}$, even though the errors in $\Delta G^{\neq}$ are not large.[11] From coalescence of the methoxy proton resonances, the first-order rate constant for dynamic NMR in **2a** is 33 s^{-1} at 318 K. The calculated free-energy of activation for the dynamic process in **2a** is 68.7 ± 2 kJ mol^{-1} (see Table II).

Compound **2** undergoes intramolecular Wittig reaction in boiling toluene to produce the 2-azetine derivative **3**, which undergoes electrocyclic ring opening to produce **4**. The ^{1}H and ^{13}C NMR spectra of the crude product **4a–c** clearly indicated the formation of (*E*) and (*Z*) isomers. The ^{1}H NMR spectra of **4a–c** exhibited two signals at about δ 6.7 and δ 7.4 for the two olefinic protons in (*Z*) and (*E*) geometrical isomers, respectively. The structures of compounds **4a–c** were deduced from their elemental analyses and IR, ^{1}H, and ^{13}C NMR spectra. The

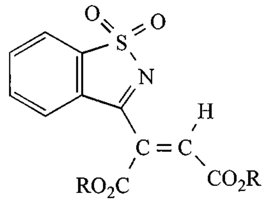
TABLE II Selected Proton Chemical Shifts (at 500.1 MHz, in ppm, Me_4Si) and Activation Parameters (kJmol^{-1}) for Compound **2a** in Chloroform

	Temp (°C)	δ (P–C–CO_2CH_3)		$\Delta\nu$ (Hz)	k (s^{-1})	T_c (K)	$\Delta G^{\neq}$
2a	25	3.77	3.80	15	33	318	68.7 ± 2
	58	3.78					

TABLE III Selected ^{1}H and ^{13}C Chemical Shifts (δ in ppm) for OR, CO_2R, C=CH, and Ester Moieties in the Major (*E*) and Minor (*Z*) Diastereoisomers of Compounds **4a–c**



4-(*E*); Major



4-(*Z*); Minor

Compound	Isomer (%)	^{1}H NMR data		^{13}C NMR data			
		C=CH	OR	*C*=CH	C=*C*H	CO_2R	CO_2R
4a	*E* (86)	7.40	3.74 and 3.89	128.38	135.28	161.79	162.53
	Z (14)	6.74	3.84 and 3.88	126.17	135.96	161.50	163.90
4b	*E* (88)	7.46	4.17[a] and 4.34[a]	128.28	135.47	161.27	162.11
	Z (12)	6.74	4.29[a] and 4.36[a]	125.87	135.97	160.77	163.26
4c	*E* (85)	7.30	1.38 and 1.49	128.15	136.82	160.35	161.53
	Z (15)	6.63	1.52 and 1.54	126.13	135.74	159.74	162.36

[a]The methylen group of the OR moiety.

mass spectra of these compounds displayed molecular ion peaks at appropriate *m/z* values. Any initial fragmetation involve loss from or complete loss of the side chains and scission of the heterocyclic ring system. Selected ^{1}H and ^{13}C NMR chemical shifts for OR, CO_2R, C=CH, and carbonyl groups ester in the major (*E*) and minor (*Z*) diastereoisomers of compounds **4a–c** are shown in Table III.

In summary, the presented method carries the advantage of being performed under neutral conditions and requiring no activation or modification of the educts. We anticipate that the reactions described herein represent a simple entry into the synthesis of functionalized saccharin derivatives of potential interest.

EXPERIMENTAL

Melting points were measured on an Electrothermal 9100 apparatus. Elemental analyses were performed using a Heraeus CHN-O-Rapid analyzer. IR spectra were measured on a Shimadzu IR 460 spectrometer. ^{1}H, ^{13}C, and ^{31}P NMR spectra were measured on a BRUKER DRX-500 AVANCE instrument with $CDC1_3$ as solvent at 500.1, 125.8, and 202.4 MHz, respectively. The mass spectra were recorded on a Shimadzu QP-1100-EX GC-Mass spectrometer operating at an ionization potential of 70 eV. Dialkyl acetylenedicarboxylates **1a–c**, triphenylphosphine and saccharin were obtained from Fluka (Buchs, Switzerland) and used without further purification.

General Procedure for Preparation of Dimethyl 2-(1,1-Dioxo-1,2-dihydro-1λ^6-benzo[*d*]-isothiazol-3-one-2-yl)-3-(triphenylphosphanylidene)-succinate (2a)

To a magnetically stirred solution of 0.262 g of triphenylphosphine (1 mmol) and 0.183 g of saccharin (1 mmol) in 10 mL of ethyl acetate was added, dropwise, a mixture of 0.142 g of dimethyl acetylenedicarboxylate (1 mmol) in 1 mL of ethyl acetate at −5°C over 10 min. The reaction mixture was then allowed to warm to room temperature and stirred for 4 h. The product was filtered off, and washed with ethyl acetate. Colorless solid, 0.56 g, yield 95%, m.p. 190–192°C. IR (KBr) (ν_{max}, cm^{-1}): 1741 and 1707 (C=O), 1640 (C=C), 1360 (SO_2). Anal. Calcd for $C_{31}H_{26}O_7NSP$ (587.6): C, 63.34; H, 4.46; N, 2.38%; Found: C, 63.5; H, 4.5; N, 2.4% MS (*m/z*, %): 587 (M^+, 2); 277 (22), 262 (78), 183 (100), 147 (32), 108 (57), 76 (54), 50 (26).

Major isomer **2a**-(*E*) (55%), ^1H NMR (500.1 MHz, $CDCl_3$): δ 3.22 and 3.80 (6H, 2 s, 2 OCH_3), 4.85 (1H, d, $^3J_{PH}$ 16 Hz, CH), 7.5–7.8 (19H, m, 3 C_6H_5 and C_6H_4). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 37.19 (d, $^1J_{PC}$ 130 Hz, P—C), 48.99 and 52.69 (2 OCH_3), 54.93 (d, $^2J_{PC}$ 16 Hz, CH), 123–133 (3 C_6H_5 and C_6H_4), 167.48 (N—C=O), 169.12 (d, $^3J_{PC}$ 14 Hz, C=O), 171.30 (d, $^2J_{PC}$ 14 Hz, P—C=*C*). ^{31}P NMR (202.4 MHz, $CDCl_3$): δ 23.48 (Ph_3P^+—C).

Minor isomer **2a**-(*Z*) (45%), ^1H NMR (500.1 MHz, $CDCl_3$): 3.69 and 3.77 (6H, 2 s, 2 OCH_3), 4.88 (1H, d, $^3J_{PH}$ 17 Hz, CH), 7.5–7.8 (19H, m, 3 C_6H_5 and C_6H_4). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 38.88 (d, $^1J_{PC}$ 138.2 Hz, P—C), 50.37 and 52.49 (2 OCH_3), 54.32 (d, $^2J_{PC}$ 15 Hz, CH), 123–133 (3 C_6H_5 and C_6H_4), 167.48 (N—C=O), 171.04 (d, $^3J_{PC}$ 17 Hz, C=O), 171.30 (d, $^2J_{PC}$ 14 Hz, P—C=*C*). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 23.81 (Ph_3P^+—C).

Diethyl 2-(1,1-Dioxo-1,2-dihydro-1λ^6-benzo[*d*]-isothiazol-3-one-2-yl)-3-(triphenylphosphanylidene)-succinate (2b)

Colorless crystals, 0.53 g, yield 86%, m.p. 156–158°C. IR (KBr) (ν_{max}, cm^{-1}): 1748 and 1705 (C=O), 1642 (C=C), 1338 (SO_2). Anal. Calcd for $C_{33}H_{30}O_7NSP$ (615.6) C, 64.38; H, 4.91; N, 2.27%; Found: C, 64.4; H, 4.9; N, 2.2%. MS (*m/z*, %): 615 (M^+, 1), 542 (5), 292 (16), 262 (85), 183 (100), 108 (28).

Major isomer **2b**-(*E*) (56%), ^1H NMR (500.1 MHz, $CDCl_3$) δ 0.90 and 1.1 (6H, 2 t, $^3J_{HH}$ 7 Hz, 2 CH_3), 3.59 and 4.12 (4H, 2 ABX_3 system, 2 OCH_2CH_3), 4.98 (1H, d, $^3J_{PH}$ 18.8 Hz, CH), 7.4–7.7 (19H, m, 3 C_6H_5 and C_6H_4). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 13.9 and 14.1 (2 CH_3), 39.9 (d, $^1J_{PC}$ 131 Hz, P—C), 54.9 (d, $^2J_{PC}$ 17 Hz, CH), 58.6 and 65.4 (2 OCH_2), 126–134 (3 C_6H_5 and C_6H_4), 167.5 (N—C=O), 170.1 (d, $^3J_{PC}$ 14 Hz, C=O), 172.2 (d, $^2J_{PC}$ 15 Hz, P—C=*C*). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 22.86 (Ph_3P^+—C).

Minor isomer **2b**-(*Z*) (44%), ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 0.92 and 1.26 (6H, 2 t, $^3J_{HH}$ 7 Hz, 2 CH_3), 4.01 and 4.22 (4H, 2 ABX_3 system, 2 OCH_2CH_3), 5.02 (1H, d, $^3J_{PH}$ 17.1 Hz, CH), 7.4–7.7 (19H, m, 3 C_6H_5 and C_6H_4). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 14.1 and 14.7 (2 CH_3), 38.6 (d, $^1J_{PC}$ 140 Hz, P—C), 55.4 (d, $^2J_{PC}$ 17 Hz, CH), 57.5 and 61.3 (2 OCH_2), 126–134 (3 C_6H_5 and C_6H_4), 168.1 (N—C=O), 171.1 (d, $^3J_{PC}$ 14 Hz, C=O), 172.4 (d, $^2J_{PC}$ 14 Hz, P—C=*C*), ^{31}P NMR (202.4 MHz, $CDCl_3$): δ 23.14 (Ph_3P^+—C).

Di-*tert*-butyl 2-(1,1-Dioxo-1,2-dihydro-1λ^6-benzo[*d*]-isothiazol-3-one-2-yl)-3-(triphenylphosphanylidene)-succinate (2c)

Colorless crystals, 0.65 g, yield 98%. IR (KBr) (ν_{max}, cm^{-1}): 1747, 1710 (C=O), 1647 (C=C), 1347 (SO_2). Anal. Calcd for $C_{37}H_{38}O_7NPS$ (671.7): C, 66.15; H, 5.70; N, 2.08%; Found: C, 66.2; H, 5.8; N, 2.1%.

Major isomer **2c**-(*E*) (98%), ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 0.96 and 1.52 (18H, 2 s, 2 CMe_3), 4.42 (1H, d, $^3J_{PH}$ 17.2 Hz, CH), 7.5–7.8 (19H, m, 3 C_6H_5 and C_6H_4). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 28.5 and 28.7 (2 CMe_3), 36.4 (d, $^1J_{PC}$ 131 Hz, P—C), 56.2 (d, $^2J_{PC}$ 18 Hz, CH), 77.3 and 81.2 (2 *C*Me_3), 128–134 (3 C_6H_5 and C_6H_4), 167.2 (N—C=O), 168.9 (d, $^3J_{PC}$ 12 Hz, C=O), 170.8 (d, $^2J_{PC}$ 14 Hz, P—C=C). ^{31}P NMR (202.4 MHz, $CDCl_3$): δ 22.45 (Ph_3P^+—C).

General Procedure for Preparation of Dimethyl 2-(1,1-Dioxo-1*H*-1λ^6-benzo[*d*]-isothiazol-3-yl)-but-2-enedioate (4a)

Compound **2a** (0.58 g, 1 mmol) was refluxed in toluene (10 mL) for 24 h. The solvent was removed and the residue was purified by silica gel (Merck silica gel 60, 70–230 mesh) column chromatography using hexane-ethyl acetate (8:2) as eluent. The solvent was removed to afford the product **4a** as a white solid, 0.31 g, yield 98%, m.p. 137–139°C, IR (KBr) (ν_{max}, cm^{-1}): 1749 and 1718, (C=O), 1643 (C=C), 1343 and 1185 (SO_2). Anal. Calcd for $C_{13}H_{11}O_6NS$ (309.3): C, 50.48; H, 3.58; N, 4.53%; Found: C, 50.2; H, 3.6; N, 4.5%. MS (*m/z*, %): 309 (M^+, 4); 308 (16), 289 (61), 217 (22), 189 (45), 171 (30), 104 (77), 105 (100), 76 (75), 58 (30).

4a-(*E*) (86%): colorless crystals, m.p. 145–147°C, ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 3.74 and 3.89 (6H, 2 s, 2 OCH_3), 7.47 (1H, s, =CH), 7.85–8.03 (3H, m, CH_{arom}), 8.16 (1H, d, J_{ortho} 12 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 52.70 and 53.75 (2 OCH_3), 121.36 (C-6), 125.91 (C-4), 126.84 (C-3a), 128.38 (*C*=CH), 134.62 (C-5), 135.22 (C-7), 135.28 (C=*C*H), 138.42 (C-7a), 158.15 (C-3), 161.79 and 162.53 (2 C=O ester).

4a-(*Z*) (14%): ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 3.84 and 3.88 (6H, 2 s, 2 OCH_3), 6.74 (1H, s, =CH), 7.84–8.03 (3H, m, CH_{arom}), 8.11 (1H, d, J_{ortho} 12 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 52.70 and 53.59 (2 OCH_3), 121.24 (C-6), 125.60 (C-4), 126.00 (C-3a), 126.17 (*C*=CH), 131.29 (C-5), 135.08 (C-7), 135.96 (C=*C*H), 138.01 (C-7a), 157.35 (C-3), 161.50 and 163.90 (2 C=O ester).

Diethyl 2-(1,1-Dioxo-1*H*-1λ^6-benzo[*d*]-isothiazol-3-yl)-but-2-enedioate (4b)

Pale yellow solid, 0.32 g, yield 94%, m.p. 52–53°C. IR (KBr) (ν_{max}, cm^{-1}): 1724 (C=O), 1645 (C=C), 1338 and 1176 (SO_2).). Anal. Calcd for $C_{15}H_{15}O_6NS$ (337.3): C, 53.40; H, 4.50; N, 4.15%; Found: C, 53.3; H, 4.6; N, 4.1%. MS (*m/z*, %): 337 (M^+, 0.3); 336 (2), 280 (8), 245 (3), 189 (14), 104 (21), 57 (100), 41 (43).

4b-(*E*) (88%): ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 1.52 and 1.32 (6H, 2 t, $^3J_{HH}$ 7.2 Hz, 2 CH_3), 4.17 and 4.34 (4H, 2 q, $^3J_{HH}$ 7.2 Hz, 2 CH_2), 7.46 (1H, s, =CH), 7.86–7.97 (3H, m, CH_{arom}), 8.10 (1H, d, J_{ortho} 8 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 13.69 and 13.94 (2 CH_3), 61.84 and 63.09 (2 OCH_2), 121.28 (C-6), 125.72 (C-4), 126.69 (C-3a), 128.28 (*C*=CH), 134.70 (C-5), 135.43 (C-7), 135.47 (*C*=CH), 138.29 (*C*-7a), 158.12 (C-3), 161.27 and 162.11 (2 C=O ester).

4b-(*Z*) (12%): ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 1.27 and 1.39 (6H, 2 t, $^3J_{HH}$ 7.2 Hz, 2 CH_3), 4.29 and 4.36 (4H, 2 q, $^3J_{HH}$ 7.2 Hz, 2 CH_2), 6.74 (1H, s, =CH), 7.86–7.97 (3H, m, CH_{arom}), 8.08 (1H, d, J_{ortho} 8 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 13.69 and 13.98 (2 CH_3), 61.70 and 62.79 (2 OCH_2), 121.44 (C-6), 122.10 (C-4), 125.67 (C-3a), 125.87 (*C*=CH), 130.88 (C-5), 135.05 (C-7), 135.97 (C=*C*H), 137.72 (C-7a), 157.26 (C-3), 160.77 and 162.26 (2 C=O ester).

Di-*tert*-buthyl 2-(1,1-Dioxo-1*H*-1λ^6-benzo[*d*]-isothiazol-3-yl)-but-2-enedioate (4c)

White solid, 0.37 g, yield 95%, m.p. 131–133°C. IR (KBr) (ν_{max}, cm^{-1}): 1746 and 1721, (C=O), 1655 (C=C), 1340 and 1184 (SO_2). Anal. Calcd for $C_{19}H_{23}O_6NS$ (393.4): C, 57.99; H, 5.89; N, 3.56%; Found: C, 58.2; H, 5.9; N, 3.5%. MS (*m/z*, %): 393 (M^+, 2); 294 (45), 261 (79), 216 (28), 104 (82), 76 (100), 59 (45), 50 (51).

4c-(*E*) (85%): ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 1.38 and 1.49 (18H, 2 s, C*Me*$_3$), 7.30 (1H, s, =CH), 7.85–7.95 (3H, m, CH_{arom}), 8.11 (1H, d, $^3J_{ortho}$ 8 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 27.89 (2 C*Me*$_3$), 83.37 and 84.26 (2 OC*Me*$_3$), 121.33 (C-6), 125.77 (C-4), 127.09 (C-3a), 128.15 (*C*=CH), 134.61 (C-5), 135.28 (C-7), 135.82 (C=*C*H), 138.68 (C-7a), 158.23 (C-3), 160.35 and 161.53 (2 C=O ester).

4c-(*Z*) (15%): ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 1.52 and 1.54 (18H, 2 s, C*Me*$_3$), 6.63 (1H, s, =CH), 7.85–7.95 (3H, m, CH_{arom}), 8.09 (1H, d, $^3J_{ortho}$ 10 Hz, CH-7). ^{13}C NMR (125.8 MHz, $CDCl_3$): δ 27.76 (2 C*Me*$_3$), 82.74 and 84.20 (2 OC*Me*$_3$), 121.49 (C-6), 124.60 (C-4), 125.87 (C-3a), 126.13 (*C*=CH), 130.96 (C-5), 134.90 (C-7), 135.74 (C=*C*H), 138.22 (C-7a), 157.65 (C-3), 159.74 and 162.36 (2 C=O ester).

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