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PALLADIUM-CATALYZED SYNTHESES OF NATURALLY-OCCURRING ACETYLENIC THIOPHENS AND RELATED COMPOUNDS†

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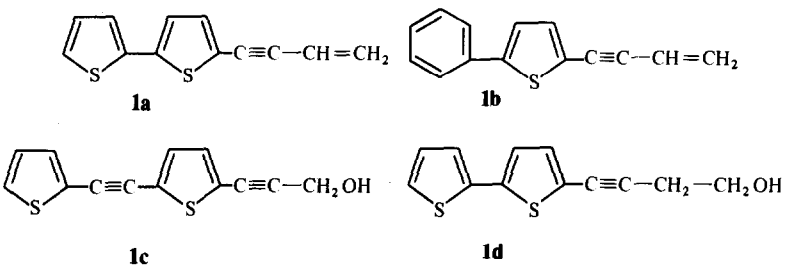
Abstract—5-(3-Buten-1-ynyl)-2,2′-bithienyl (**1a**), a natural product first isolated from *Tagetes* roots which shows nematicidal and photo-induced fungicidal activity, and 2-phenyl-5-(3-buten-1-ynyl) thiophen (**1b**) have been synthesized using two different methods. The first one (Method A) involves the palladium-catalyzed cross-coupling of vinyl bromide with the Grignard reagents derived from 5-ethynyl-2,2′-bithienyl (**6a**) and 2-ethynyl-5-phenylthiophen (**6b**). The second method (Method B) utilizes the coupling reaction of vinyl bromide with **6a** and **6b**, respectively, in the presence of a catalytic amount of $(PPh_3)_4Pd$ and CuI. Such reaction, which was carried out under phase-transfer conditions employing $BnEt_3N^+Cl^-$ as phase transfer agent and 2.5N aq NaOH as base, has been also employed to prepare a large number of heterocyclic acetylene derivatives including some naturally-occurring compounds. The experimetal conditions of Method B allow also the direct production of heterocyclic acetylene derivatives (**1**) starting from 1-alkynyltrimethylsilanes (**5**) and organic halides (**2**).

Natural plant products are receiving much attention as possible antifungal and nematicidal agents.[1–4] One of such compounds is 5-(3-buten-1-ynyl)-2,2′-bithienyl (**1a**), first isolated from *Tagetes* roots.[5,6] It shows nematicidal activity to *Ditylenchus dipsaci*, *Anguina tritici*, *Heterodera rosochiensis*, *Pratylenchus penetrans*,[7] and *Meloidogyne javanica*,[8] which is enhanced by near ultraviolet radiation.[9] Moreover, it elicits photo-induced fungicidal activity on ascomycetes and oomycetes.[10]

In order to verify if this type of biological activity involves the singlet oxygenation of the enyne system of **1a**[11,12] an economical synthesis of **1a** and related compounds was required, even though **1a** has been previously synthesized.[13–16] In fact, three of the previous routes produced low yields of **1a**,[14–16] and the fourth required the use of an explosive cuprous acetylide.[13]



We now report two new syntheses of **1a** and of 2-phenyl-5-(3-buten-1-ynyl)thiophen (**1b**). The first on (Method A) involves the palladium-catalyzed cross-coupling of vinyl bromide with the Grignard reagents derived from 5-ethynyl-2,2′-bithienyl (**6a**) and 2-ethynyl-5-phenylthiophene (**6b**). The second synthesis (Method B) is based on the palladium-catalyzed reaction of vinyl bromide with **6a** and **6b**, respectively, under phase transfer conditions. This type of reaction has been also employed to prepare a large number of heterocyclic acetylene derivatives which we needed for physiological testing, among which naturally-occurring 5-(4-hydroxybut-1-ynyl)-2,2′-bithienyl (**1d**)[17] 2-(3-hydroxyprop-1)ynyl)-5-(2-thienylethynyl)-thiophen (**1c**).[14,18]

In the first synthesis (Scheme 1) 2-iodothiophene (**2a**) was coupled with 2-thienylmagnesium iodide, in the presence of a catalytic quantity of $NiCl_2$ (dppe), (dppe = Ph_2P–CH_2–CH_2–PPh_2) to give 2,2′-bithienyl (**4a**) in 90% yield. Treatment of **4a** with mercuric chloride in the presence of sodium acetate, followed by reaction with iodine in chloroform[15] gave 5-iodo-2,2′-bithienyl (**2b**) in 85% yield. Reaction of a benzene solution of **2b** and $(PPh_3)_4Pd$ with a tetrahydrofuran solution of trimethylsilylethynyl-magnesium bromide afforded the trimethylsilyl protected 1-alkyne **5a**. Removal of the silyl group by treatment with dilute aqueous potassium hydroxide in methanol gave **6a** in 65% yield based on **2b**. Compound **6a** was then transformed into the corresponding Grignard reagent, which was coupled with vinyl bromide (**2d**) in the presence of $(PPh_3)_4Pd$ to afford pure **1a** in 93% yield. An analogous route was followed to prepare **1b** in 61% overall yield starting

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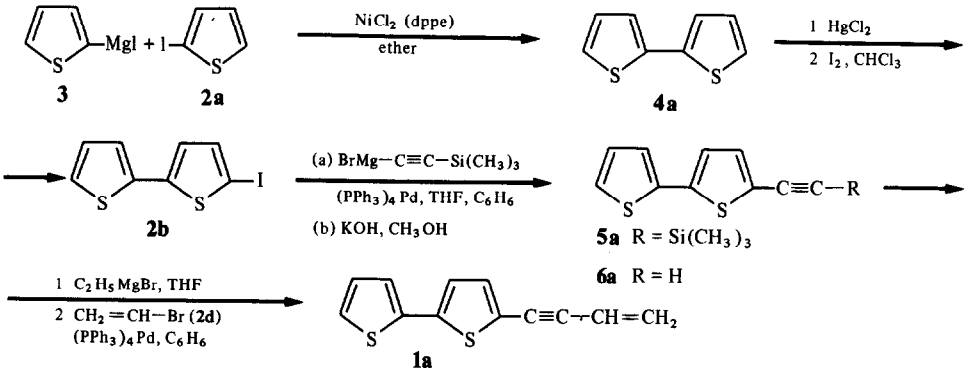


3 2a 4a 2b 5a R = Si(CH3)3 6a R = H 1a

Scheme 1.

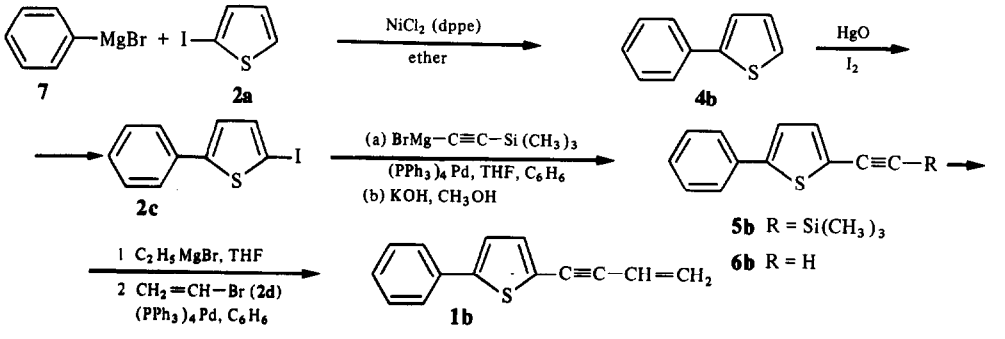
from **2a** and phenylmagnesium bromide (Scheme 2).

The other more direct synthesis devised to prepare **1a** and **1b** (Scheme 3) utilized a palladium-catalyzed reaction similar to that previously employed for the stereospecific or steroeselective synthesis of conjugated enynes starting from 1-alkynes and 1-halo-1-alkenes.[19-21]

Thus, the ethynylthiophenes **6a,b** were reacted with a benzene solution of a molar excess of **2d**, using a mixture of $(PPh_3)_4Pd$ (2 mol%) and CuI (4 mol%) as catalyst. The reactions were carried out at room temperature for 4–6 h under phase-transfer conditions, employing benzyltriethylammonium chloride (3 mol%) as phase-transfer agent and a large excess of 2.5N aq sodium hydroxide as base

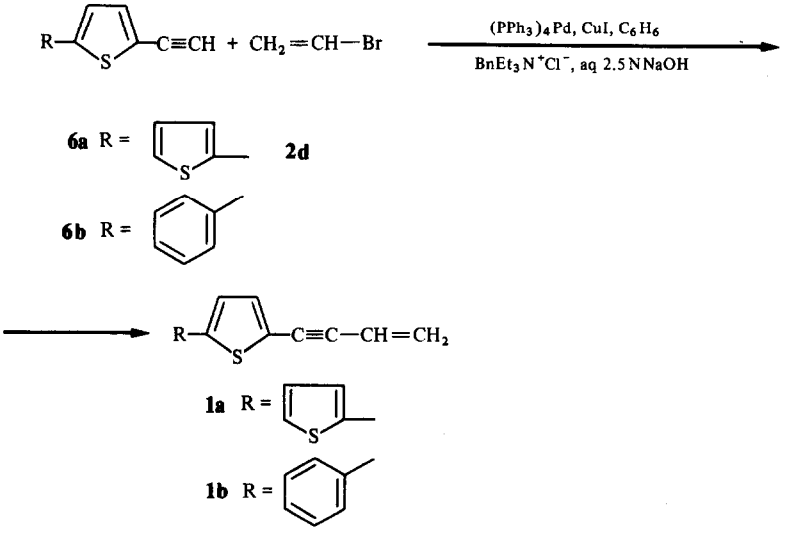
Compounds **1a** and **1b** were isolated in 93 and 89% yield, respectively, by chromatography of hexane solutions of the crude reaction products.

Similar palladium-catalyzed alkynylation reactions have been proved useful to prepare in rather good yields other heterocyclic acetylene derivatives, among which naturally-occuring **1a** and **1d** (Table 1).



7 2a 4b 2c 5b R = Si(CH3)3 6b R = H 1b

Scheme 2.

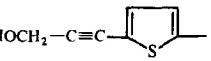
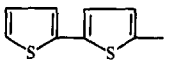
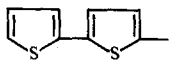
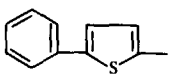
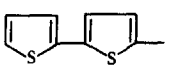
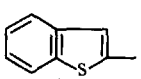


1a R = 1b R =

Scheme 3.

Table 1. Palladium-catalyzed synthesis of heterocyclic acetylene derivatives (1)

$$\underset{\mathbf{2}}{R_1-X} + \underset{\mathbf{6}}{H-C\equiv C-R_2} \xrightarrow[\text{BnEt}_3\text{N}^+\text{Cl}^-,\ \text{aq 2.5 N NaOH}]{(PPh_3)_4Pd,\ CuI,\ C_6H_6} \underset{\mathbf{1}}{R_1-C\equiv C-R_2}$$

Organic halide (2)	R_1	X	1-Alkyne (6)	R_2	(6)/(2) molar ratio	Reaction time (h)	Product (1)	Chromatographic yield (%)	Isolated yield (%)a,b
2e	$HOCH_2-C\equiv C-$ 	J	**6c**		2.0	12	**1c**	100	87(29.5)[23]
2b		J	**6e**	$HO-(CH_2)_2-$	2.5	10	**1d**	100	87(26)[14]
2d	$CH_2=CH-$	Br	**6a**		0.5	6	**1a**	100	93(35)[15]
2d	$CH_2=CH-$	Br	**6b**		0.5	5	**1b**	100	(19)[16] 89
2a		J	**6f**		2.0	6	**1e**	100	85(44)[15]
2b		J	**6f**		1.5	10	**1f**	—	77
2a		J	**6g**	$(C_2H_5O)_2CH-$	1.3	6	**1g**	100	100(47)[23]
2f		J	**6e**	$HO-(CH_2)_2-$	2.5	7	**1h**	100	80
2g		Br	**6d**	$HO-CH_2-$	2.0	12	**1i**	80	25
2a		J	**6d**	$HO-CH_2-$	2.0	12	**1l**	100	90(67)[13]
2h		Br	**6d**	$HO-CH_2-$	2.0	12	**1m**	—	(80)[23] 54(27)[24]

(a) The values in parentheses are referred to literature data.
(b) Calculated on the basis of the reagent in molar defect.

These reactions have the following advantages: they do not require the preparation and manipulation of organometallic reagents; they afford satisfactory yields and may be performed with a wide range of functional 1-alkynes.

Finally, it must be mentioned that minor modifications of the very mild typical reaction conditions, namely longer reaction times (*ca* 36 h) and higher reaction temperatures (*ca* 40°) allow the direct production of heterocyclic acetylene derivatives of general formula **1** (Table 2) starting from organic halides and 1-alkynyltrimethylsilanes (**5**), easily available according to the procedure employed to prepare **5a** and **5b**. In fact, the basic aqueous medium in which the reactions are carried out causes the removal of the silyl protecting group from **5** and produces *in situ* 1-alkynes (**6**), which react with the organic halides **2** to afford the acetylenic derivatives **1**.

Bioassays of the compounds obtained in this report are now under way.

EXPERIMENTAL

All b.ps and m.ps are uncorrected. IR spectra were determined on a Perkin–Elmer 283 B spectrometer. ^{1}H NMR spectra were recorded at 60 MHz on a Varian T60 spectrometer using TMS as internal standard. Mass spectra were recorded on a Hewlett–Packard 5995 A gas-chromatograph/mass spectrometer. UV spectra were recorded on a Jasco Uvidec 710 spectrometer. GLC analyses were performed on a Dani 3900 glass-capillary column dedicated gas-chromatograph using a FFAP glass capillary column (25 m × 0.25 mm i.d.) and a FID detector (carrier gas N_2, 0.3 kg cm^{-2}, split 40 ml/min; temp of detector 260°). Liquid chromatographic purifications were carried out on a Jobin–Yvon "Chromatospac Prep" liquid chromatograph using a Knauer differential refractometer as detector. TLC analyses were performed using Merck plastic sheets silica gel 60 F_{254}

All reactions of air and water-sensitive materials were performed in flame-dried glassware under nitrogen. Air-sensitive solutions or liquids were transferred with hypodermic syringes or double-ended needles. All solvents were freshly distilled, anhydrous, and degassed.

Tetrakis(triphenylphosphine)palladium was prepared according to the literature.[25]

2,2′-Bithienyl (**4a**)

A soln of 2-thienylmagnesium iodide (**3**) (0.22 mol) in ether (250 ml) was dropwise added to a mixture of 2-iodothiophen (**2a**) (42.0 g, 0.20 mol) and $NiCl_2$(dppe) (0.60 g, 1.14 mmol) in dry ether (150 ml). The mixture was refluxed for 3 h, hydrolyzed with sat NH_4Cl aq, and then extracted with ether. The organic layer was dried, concentrated, and fractionally distilled to give **4a** in 90% yield: b.p. 125°/12 torr; m.p. 33° (lit[26] m.p. 33°). GLC analysis showed that **4a** was chemically pure.

2-Phenylthiophen (**4b**)

It was prepared[27] in 80% yield starting from **2a** and phenylmagnesium bromide (**7**): b.p. 88°/0.2 torr; m.p. 36°.

5-Iodo-2,2′-bithienyl (**2b**)

A sat $HgCl_2$ aq soln (371 ml, 0.093 mol) was slowly added to a soln of **4a** (15.4 g, 0.093 mol) in ethanol (186 ml) and 20% aq sodium acetate (75 ml, 0.184 mol) which was heated at 40°. The resulting mixture was stirred at this temp for 20 h. The air-dried precipitate was washed with cold hesane (50 ml) and continuosly extracted in a Soxhlet with acetone for 48 h. Concentration of the extracts gave a white solid (18.6 g): m.p. 235°. This compound was added during 10 min to a stirred soln of iodine (11.8 g, 0.0465 mol) in dry $CHCl_3$ (250 ml). After 2 h at room temp the mixture was filtered and the filtrate was washed with 50% KJaq and water, dried and concentrated. Distillation of the residue gave **2b** in 85% yield: b.p. 108–109°/0.03 torr; m.p. 32° (lit[15] m.p. 32°).

2-Iodo-5-phenylthiophen (**2c**)

A stirred soln of **4b** (17.78 g, 0.111 mol) in benzene (20 ml) was treated at room temp with alternate portions of iodine (29 g, 0.114 mol) and yellow mercuric oxide (20 g, 0.0927 mol) during 1 h. The mixture was filtered and the filtrate was washed with sat $NaHSO_3$ aq and water, filtered, dried and concentrated *in vacuo*. The residue was crystallyzed from ethanol to give **2c** in 85% yield: m.p. 79–81° (lit.[28] m.p. 76–77°) GLC analysis showed that **2c** had 97% chemical purity.

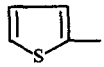
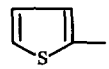
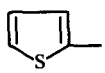
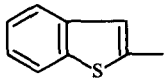
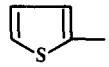
5-Ethynyl-2,2′-bithienyl (**6a**). *Typical procedure*

Trimethylsilylacetylene (10.79 g, 0.110 mol) was added to a soln of ethylmagnesium bromide(0.130 mol) in THF (180 ml). After the addition was complete, heating was continued for 1 h. The THF soln of so obtained trimethylsilylethynylmagnesium bromide was then slowly added to a mixture of **2b** (31.54 g, 0.108 mol) and $(PPh_3)_4Pd$

Table 2. Palladium-catalyzed synthesis of thiophene acetylenic derivatives (**1**) by coupling of 1-alkynyltrimethylsilanes (**5**) with organic halides (**2**)

$$(CH_3)_3Si{-}C{\equiv}C{-}R_2 + R_1{-}J \xrightarrow[BnEt_3N^+Cl^-,\ aq\ 2.5\ N\ NaOH]{(PPh_3)_4Pd,\ CuI,\ C_6H_6,\ 40^\circ} R_1{-}C{\equiv}C{-}R_2$$

5 **2** **1**

Organic halide (2)	R_1	1-Alkynyltrimethylsilane (5)	R_2	Reaction time (h)	(5)/(2) molar ratio	Product (1)	Isolated yield %
2a		**5c**		40	1	**1n**	68
2a		**5d**	$CH_2{=}C(CH_3){-}CH_2{-}$	36	1.1	**1o**	60
2f		**5c**		40	1.2	**1p**	65

(2.5 g, 2.16 mmol) in benzene (150 ml). After the addition was complete, the mixture was stirred for 1 h at room temp and for 5 h and 60°. It was then cooled to room temp and hydrolyzed with sat NH_4Cl aq. The organic layer was separated and the aq layer was extracted with hexane. The combined extracts were washed with sat NaCl aq, filtered, dried and concentrated. The residue (29.3 g) which was constituted of crude 5-trimethylsilylethynyl-2,2'-bithienyl (**5a**) was then suspended into methanol (110 ml) and treated at 0 under N_2 atmosphere with 1N KOH aq (120 ml, 0.12 mol) The mixture was stirred for 2 h at room temp and extracted with hexane. The organic layer was washed with sat NaCl aq, filtered, dried and concentrated. The residue (20.05 g) was purified by chromatography on a Merck H-60 silica gel column, using hexane as solvent (20 ml min^{-1}), to give pure **6a** as an oil, in 65% yield based on **2b**: ^{1}H–NMR (CCl_4): σ 3.40 (s, 1H), 6.67–7.17 ppm (m, 5H). υ_{max} (film) 3295, 3100, 3085, 2095, 1500, 1450, 1420, 1350, 1330, 1300, 1225, 1200, 1140, 1075, 1045, 880, 835, 820, 735, 690 and 660 cm^{-1}. These spectral properties were very similar to those reported in the literature.[14,16]

2-Ethynyl-5-phenylthiophen (**6b**)

Prepared in 60% yield starting from **5b** by the same procedure employed to synthesize **6a**: m.p. 67–68° (lit[29] m.p. 65–67°). ^{1}H NMR (CCl_4): σ 3.23 (1H, s), 6-97-7.7 ppm (7H, m).

5-(3-Buten-1-ynyl)-2,2'-bithienyl (**1a**) (*Method A*)

A soln of **6a** (11.88 g, 62.5 mmol) in THF (50 mol) was slowly added to a soln of ethylmagnesium bromide (65.6 mmol) in THF (70 ml). After the addition was complete the mixture was refluxed for 1 h, cooled at room temp, and slowly added to a soln of vinylbromide (**2d**) (8.36 g, 78.2 mmol) and $(PPh_3)_4Pd$ (1.80 g, 1.56 mmol) in benzene (110 ml). The resulting mixture was stirred for 1 h at room temp and for 2 h at 40°. It was then quenched with sat NH_4Cl aq and partitioned between hexane and water. The organic layer was washed with sat aq NaCl, filtered, dried and concentrated. The residue (14.74 g) was purified by chromatography on a Merck H-60 silica gel column using hexane as eluent (25 ml min^{-1}) to give **1a** in 93% yield based on **6a**: υ_{max} (film): 3100, 3085, 3000, 2195, 1600, 1505, 1455, 1425, 1410, 1290, 1240, 1225, 1190, 1070, 1050, 1035, 965, 915, 835, 790 and 690 cm^{-1}. ^{1}H NMR (CCl_4): δ 5.23–6.30 (3H, m), 6.67–7.28 ppm (5H, m). UV (hexane): λ_{max} 252 (log ϵ 3.93), 345.5 nm (log ϵ 4.42). These spectral properties were very similar to those reported for the natural product.[6,14] Mass spectrum: *m/e* 218 (M + 2, 19.4%), 217 (M + 1, 15.7%), 216 (M, 100%), 171 (32%), 139 (9.2%), 127 (11.1%), 121 (6.3%), 108 (9%), 95 (17.9%), 93 (10.7%) 87 (6.7%). (Found: C, 66.52; H, 3.74. Calc for $C_{12}H_8S_2$: C, 66.63; H, 3.73%.)

2-Phenyl-5-(3-buten-1-ynyl)-thiophene (**1b**)

Prepared in 90% yield starting from **2c**, using the above described procedure: m.p. 51–52.5°. υ_{max} (KBr): 3100, 3050, 3000, 2195, 1600, 1495, 1450, 1440, 1405, 1195, 1160, 1100, 1075, 1050, 1025, 1000, 970, 915, 885, 800, 755 and 690 cm^{-1}. ^{1}H NMR (CCl_4): δ 5.30–6.34 (3H, m), 6.96–7.66 ppm (7H, m). (Found: C, 80.21; H, 4.68. Calc for $C_{14}H_{10}S$: C, 79.96; H, 4.79%.)

General procedure for the preparation of the heterocyclic acetylene derivatives (**1**) *by palladium-catalyzed synthesis under phase-transfer conditions* (*Method B*)

In a typical experiment a de-aerated mixture of 1-alkyne (**6**) (0.2 mol) and organic halide (**2**) (0.1 mol) in benzene (35 ml) was rapidly added to a mixture of benzyltriethylammonium chloride (3 mmol), cuprous iodide (4 mmol) and $(PPh_3)_4Pd$ (2 mmol). De-aerated 2.5 M aq NaOH (150 ml) was then added and the reaction monitored TLC or GLC analysis. Sat NH_4Cl was then added and the resulting mixture, after stirring for 1 h, was extracted with hexane (or ether, in the case of highly polar compounds), filtered, and concentrated. The residue was purified by chromatography on a Merck H-60 silica gel column. Table 1 summarizes the detailed experimental conditions employed to prepare **1a–1p**. The synthesis of the heterocyclic acetulene derivatives **1n–1p** starting from 1-alkynyltrimethylsilanes (**5**) and organic halides (**2**) (Table 2) was performed using 6 mol% of phase-transfe catalyst, 4 mol% of $(PPh_3)_4Pd$ and 6 mol% of CuI. The reactions were carried out for 36–40 h and 40°.

5-(3-Buten-1-ynyl)-2, 2'-bithienyl (**1a**)

The spectral properties of this compound, which was prepared starting from **2d** and **6a**, were identical to those of **1a** propared according to Method A.

2-Phenyl-5-(3-buten-1-ynyl)thiophen (**1b**)

Prepared starting from **2d** and **6b**. Its spectral properties were identical to those of **1b** prepared according to Method A.

2-(3-Hydroxyprop-1-ynyl)-5-(2-thienylethynyl)thiophen (**1c**)

Prepared starting from 2-ethynylthiophene (**6c**) and 2-(-3-hydroxyprop-1-ynyl)-5-iodothiophen (**2e**). Compound (**6c**) [b.p. 53–54/25 torr; ^{1}H NMR (CCl_4): δ 3.25 (1H, s), 6.83–7.35 ppm (1H, m), 7.3 ppm (2H, m) (lit[30] b.p. 46°/15 torr)] was obtained in 78% yield starting from **2a**, according to the procedure followed to synthesize **6a** and **6b**. Compound **2e** m.p. 63–65° (lit[31] m.p. 58°); ^{1}H NMR (CS_2): δ 2.47 (1H, br S), 4.37 (2H, br S), 6.76–7.22 ppm (2H, m). υ_{max} (KBr): 3250, 3080, 2900, 2210, 1465, 1410, 1355, 1300, 1185, 1055, 1020, 1010, 970, 945, 905, 790 and 665 cm^{-1} was prepared in 37% yield using Method B, starting from equimolar amounts of 2,5-diiodothiophene and propargyl alcohol (**6d**). Attempts to prepare **2e** by reaction of 2-(3-hydroxyprop-1-ynyl)-thiophen (**1l**) with I_2 and HgO were unsuccessful. The reaction product consisted of a 1 : 1 complex of **1l** with iodine m.p. 99–101° (benzene–pentane). υ_{max} (KBr): 3200, 2905, 1600, 1400, 1415, 1390, 1220, 1145, 1060, 1020, 955, 850, 760 and 700 cm^{-1}. ^{1}H NMR (CS_2): δ 2.40 (1H, br s), 4.30 (2H, br m), 6.83–7.50 ppm (3H, m). (Found: S, 8.19. Calc for $C_7H_6I_2OS$: S, 8.18%.)

Compound **1c** had m.p. 93.5–95° (from hexane–ether). υ_{max} (KBr): 3350, 3250, 3100, 2900, 2850, 2220, 2190, 1535, 1500, 1460, 1440, 1410, 1355, 1195, 1185, 1050, 1020, 1010, 910, 850, 830, 805, 710, 690 and 620 cm^{-1}. ^{1}H NMR (CCl_4): δ 1.66 (1H, br s), 4.50 (2H, br s), 6.87–7.50 (4H, m). Mass spectrum: *m/e* 246 (M + 2, 10.1%), 245 (M + 1, 17% 244 (M, 100%), 227 (15.6%), 216 (14%), 215 (23.1%), 214 (17.2%), 190 (41.1%), 171 (68.3%), 139 (32.4%), 127 (16%). Found: C, 63.61; H, 3.16. Calcc. for $C_{13}H_8OS_2$: C, 63.91; H, 3.30, lit[22] m.p. 90.5°.

5-(4-Hydroxybut-1-ynyl)-2,2'-bithienyl (**1d**)

It was prepared starting from **2b** and and 3-butyn-1-ol (**6e**); m.p. 71–72°. υ_{max} (KBr): 3320, 3100, 3080, 3060, 2940, 2900, 1750, 1600, 1500, 1450, 1420, 1190, 1040, 875, 840, 825, 800, 710 and 700 cm^{-1}. ^{1}H NMR (CS_2): δ 2.60 (2H, t), 3.19 (1H, s), 3.68 (2H, t), 6.55–7.05 ppm (5H, m). UV (ethanol): λ_{max} 241 (log ϵ 3.79), 327 (log ϵ 4.33), 335.5 nm (log ϵ 4.33). Mass spectrum: *m/e* 236 (M + 2, 5.9%), 235 (M + 1, 8.7%), 234 (M, 57%), 205 (10.2%), 204 (15.5%), 203 (100%), 171 (17%), 158 (9.0%), 127 (12.9%), 115 (16.6%), 69 (17.2%). (Found: C, 61.68; H, 4.39. Calc for $C_{12}H_{10}OS_2$: 61.51; H, 4.30%), lit[14] m.p. 66–67°.

2-Thienylethynyl benzene (**1e**)

Prepared starting from **2a** and phenylacetylene (**6f**): m.p. 51–52°. ^{1}H NMR (CCl_4): δ 6.83–7.10 (1H, m), 7.13–7.63 ppm (7H, m), lit[32] m.p. 50–50.5°.

5-Phenylethynyl-2,2'-bithienyl (**1f**)

Prepared starting from **2b** and **6f**; m.p. 90–91°. υ_{max} (KBr): 2200, 1500, 1480, 1440, 1200, 840, 805, 755, 700 and 690 cm^{-1}, lit[15] m.p. 89–90°.

2-(3,3-*Diethoxyprop*-1-*ynyl*)*thiophen* (**1g**)

Prepared starting from **2a** and 3,3-diethoxyprop-1-yne (**6g**): b.p. 85°/0.05 torr. υ_{max} (film): 3110, 2980, 2930, 2880, 2230, 1520, 1480, 1445, 1435, 1390, 1360, 1350, 1325, 1190, 1155, 1110, 1090, 1050, 1005, 955, 895, 845, 825 and 695 cm^{-1}. ^1H NMR (CS_2): δ 1.17 (6H, t), 3.57 (4H, m), 5.32 (1H, s) and 6.7–7.3 ppm (3H, m), lit[23] b.p. 103–105°/0.6 torr.

2-(4-*Hydroxybut*-1-*ynyl*)*thianaphthen* (**1h**)

Prepared starting from 2-iodothianaphthen (**2f**) and **6e**. Compound **2f**, m.p. 66–68° (lit[33] m.p. 63.4–65°) was obtained in 83% yield by addition of a 1.6 M hexane soln of butyllithium to a soln of a equimolar of thiahaphthen in THF–HMPA cooled to −70°, followed by addition of a THF soln of iodine. Compound **1h** had m.p. 97–98°. υ_{max} (KBr): 3340, 3240, 3080, 3050, 3020, 2960, 2950, 2915, 2890, 2840, 2230, 1475, 1455, 1430, 1330, 1200, 1155, 1035, 1015, 945, 925, 870, 840, 755, 745, 725 and 675 cm^{-1}. ^1H NMR (CS_2): δ2.60 (2H, t), 3.33 (1H, s), 3.70 (2H, t), 7.0–7.6 ppm ç5H, m). (Found: C, 71.48; H, 4.97. Calc for $C_{12}H_{10}OS$: C, 71.26; H, 4.98%.)

3-(3-*Hydroxyprop*-1-*ynyl*)*furan* (**1i**)

Prepared starting from 3-bromofuran (**2g**) and **6d**: b.p. 63°/0.08 torr. υ_{max} (film): 3340, 3150, 2910, 2860, 2225, 1505, 1350, 1285, 1230, 1160, 1080, 1040, 1015, 990, 900, 870, 785 and 730 cm^{-1}. ^1H NMR (CCl_4): δ 3.63 (1H, br s), 4.40 (2H, s), 6.40 (1H, d), 7.33 (1H, t) and 7.57 ppm (1H, d), lit[34] b.p. 55–56°/0.05 torr.

2(3-*Hydroxyprop*-1-*ynyl*)*thiophen* (**1l**)

Prepared starting from **2a** and **6d** b.p. 82°/0.03 torr: υ_{max} (film): 3320, 3100, 2905, 2850, 2210, 1510, 1420, 1355, 1340, 1235, 1215, 1185, 1075, 1040, 1010, 965, 905, 840, 695 and 655 cm^{-1}. ^1H NMR (CCl_4): 3.50 (1H, s), 4.43 (2H, s), 6.76–7.33 ppm (3H, m). Mass spectrum: *m/e* 138 (M, 100%), 121 (25%), 110 (48%), lit[23] b.p. 88–89°/4.5 torr.

2-(3-*Hydroxyprop*-1-*ynyl*)*pyridine* (**1m**)

It was prepared starting from 2-bromopyridine (**2h**) and **6d** b.p. 116–118°/0.5 torr. υ_{max} (film): 3200, 3050, 1585, 1560, 1465, 1430, 1360, 1270, 1240, 1150, 1090, 1030, 995, 955, 885, 770 and 730 cm^{-1}. ^1H NMR ($CDCl_3$): δ 4.54 (2H, s), 5.12 (1H, br s), 7.1–7.7 (3H, m), 8.53 ppm (1H, m), lit[24] b.p. 125°/3 torr.

2-(2-*Thienylethynyl*)*thiophen* (**1n**)

Prepared starting from **2a** and 2-trimethylsilylethynylthiophen (**5c**). Compound **5c** [b.p. 104–105/15 torr. υ_{max} (film) 3110, 3090, 2960, 2880, 2140, 1515, 1420, 1245, 1160, 1140, 1075, 1040, 850, 840, 760, 730 and 695 cm^{-1}. ^1H NMR (CCl_4): δ 0.2 (9H, s), 6.83 (1H, m), 7.13 ppm (2H, m)] was obtained in 91% yield by reaction of **2a** with trimethylsilylethynylmagnesium bromide, in the presence of $(PPh_3)_4Pd$, according to the procedure employed to prepare 5a and **5b**. Compound **1n** had m.p. 99.5–101°. ^1H NMR (CCl_4): δ 6.86 (2H, m), 7.14 ppm (4H, m). IR (KBr): υ_{max} 3100, 3080, 1430, 1405, 1360, 1200, 1195, 1100, 1040, 1030, 850, 825, 745, 720 and 695 cm^{-1}, lit[35] m.p. 95–97°.

2-(4-*Methylpent*-4-*en*-1-*ynyl*)*thiophen* (**1o**)

Prepared starting from 1-trimethylsilyl-4-methylpent-4-en-1(yne (**5d**) [b.p. 98–103°/140 torr. ^1H NMR (CCl_4): δ 0.2 (9H, s), 1.73 (3H, br s), 2.80 (2H, br s), 4.73 (1H, br s), 4.90 ppm (1H, br s)] and **2a**. Compound **5d** was prepared by reaction of 2-methylallyl chloride with trimethylsilylethynylmagnesium bromide, in the presence of $(PPh_3)_4Pd$. Compound **1o** had b.p. 62°/0.2 torr; υ_{max} (film): 3100, 3070, 2965, 2930, 2910, 2870, 2800, 2225, 1790, 1655, 1515, 1440, 1425, 1425, 1410, 1375, 1270, 1240, 1220, 1190, 1080, 1040, 1020, 890, 845, 825 and 690 cm^{-1}. ^1H NMR (CCl_4): δ 1.83 (3H, br s), 3.08 (2H, br s), 4.83 (1H, m), 5.00 (1H, m), 6.73–7.26 ppm (3H, m). GLC analysis showed that **10** had 95% chemical purity. (Found: C, 73–81; H, 6.45. Calc for $C_{10}H_{10}S$: C, 74–0.3; H, 6.21%.

2-(2-*Thienylethynyl*)*thianaphthene* (**1p**)

Prepared starting from **2f** and **5c**: m.p. 119–121°. ^1H NMR (CCl_4): δ 6.91 (1H, m), 7.30–7.50 (5H, m), 7.50–7.87 ppm (2H, m) IR (KBr): υ_{max} 3100, 3080, 3055, 2200, 1455, 1435, 1415, 1350, 850, 840, 835, 745, 725, 720, 705, 680 and 760 cm^{-1}. (Found : C, 70.26 H, 3.26. Calc for C_{14} H_8S_2: C, 69.96; H, 3.35%.)

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