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Heterocycles from Ylides. Reactivity of 2-Acetyl-5-bromothiophene and -5-Methylfuran with Stabilised and Non-stabilised Ylides

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Abstract—The title substrates **3** and **10** react with phosphonium salts **1a**,**b** under phase-transfer catalysis conditions to afford phosphoranes **9a**,**b** or pyrans **13**, respectively, along with the corresponding 2,3-fused products with *iso*-furan rings **7a**,**b** or **11a**,**b** instead of the expected Wittig products. The reaction of **3** with stabilised phosphorus ylides **15a**–**c** affords in the case of **15a**,**b**, the stereoisomers (*Z*) **17** and (*E*) **18** in addition to the corresponding phosphonium salts. Compounds **10** and **15a**,**b** yield, on the other hand, the *iso*-furans **23** and the dimeric products **22a**,**b** as well, according to a sequence involving an initial Wittig reaction between **10** and **15a**,**b**. © 2000 Elsevier Science Ltd. All rights reserved.

Introduction

In recent years, the focus of our research has been on the development of new synthetic methodology centred around exploiting phosphorus ylide synthons and Wittig reactions.[1–3a,b] We reported[2] that reaction of 2-acetyl-(3H)-naphtho[2,1-*b*]pyran-3-one with an appropriate phosphorus ylide provides access to the corresponding-[2,1-*b*]-fused substituted-benzenes, -cyclopentadienes and furocoumarins. In continuation of our earlier work[1a,3] exploring the behaviour of furanyl- and thienyl- derivatives toward various phosphorus reagents, the present investigation deals with synthesis of new furo- and thieno[2,3-*c*]-fused heterocycles by reacting some non-stabilised **2a**,**b** and stabilised phosphorus ylides **15a**–**c** with 2-acetyl-5-bromothiophene (**3**) and 2-acetyl-5-methylfuran (**10**), as depicted in Schemes 1–4. The incentive for this application was based on recorded biological potencies of numerous substituted furans.[4,5] In addition, furan derivatives are added to tobacco to improve the flavour and aroma of the tobacco,[6] used in the crosslinking of polyesters with styrene,[7] and in photographic developing by diffusion transfer process.[8] The attention paid to thiophene substrates was attributed to similar reasons.[9,10]

Results and Discussion

Treatment of 2-acetyl-5-bromothiophene (**3**) with excess (up to 2.2 mol/equiv.) of methylidenetriphenylphosphorane (**2a**), prepared in situ from its bromide salt **1a** in the presence of sodium hydride in THF, afforded 4-methylthieno[3,2-*c*]5-methylfuran (**7a**) and 2-(5-methylidenetriphenylphosphorane-2-thienyl)-propanol (**9a**) in 46 and 22% yield, respectively (Scheme 1). The chemical structures of **7a** and **9a** were substantiated by elemental analyses and spectral data. The IR spectrum of the diheteropentalene product **7a** showed the characteristic band due to the furan nucleus at 1610 cm^{-1} and the disappearance of the band at 1673 cm^{-1} due to the acetyl group. An integrated ^{1}H NMR spectrum of this compound revealed the absence of the signal at δ 2.55 for the acetyl methyl protons and the appearance of new signals at δ 2.02 (O–C–CH_3) and at δ 2.21 (S–C–CH_3). These two methyl groups were also attested to by signals at δ_C 14.2 (O–C–CH$_3$) and δ_C 15.6 (S–C–CH$_3$) in the ^{13}C NMR spectrum.[11] The ylide structure **9a** is assigned from its molecular weight determination and its IR and NMR spectra. Its infrared spectrum exhibited an absorption band at 3425 cm^{-1} due to the hydroxyl group. It also revealed the presence of strong bands around 1680, 1510 cm^{-1} due to C$=$P stretching, and around 1430, 985 cm^{-1} for the P–C (phenyl) absorption. The ^{1}H NMR spectrum of **9a** showed two doublets (J_{HH}=7.2 Hz) at δ 1.22 and 3.66 due to the methyl and the methylene protons, respectively, and a singlet at δ 4.35 assigned to the hydroxyl proton. The two exocyclic methine protons appear as a multiplet at δ 4.03 (Me–CH–CH$_2$OH) and as a doublet (J_{HP}=18.3 Hz) at δ 7.08. In its ^{13}C NMR spectrum, signals were observed at δ_C 18.6 (CH$_3$), 36.2 (Me–CH–CH$_2$OH)), 63.6 (CH$_2$OH) and 131.5 (d, J_{CP}=98.2 Hz, $C$$=$P). The

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Keywords: Wittig reaction; Diels–Alder reaction; thiophenes; furans; isofurans.

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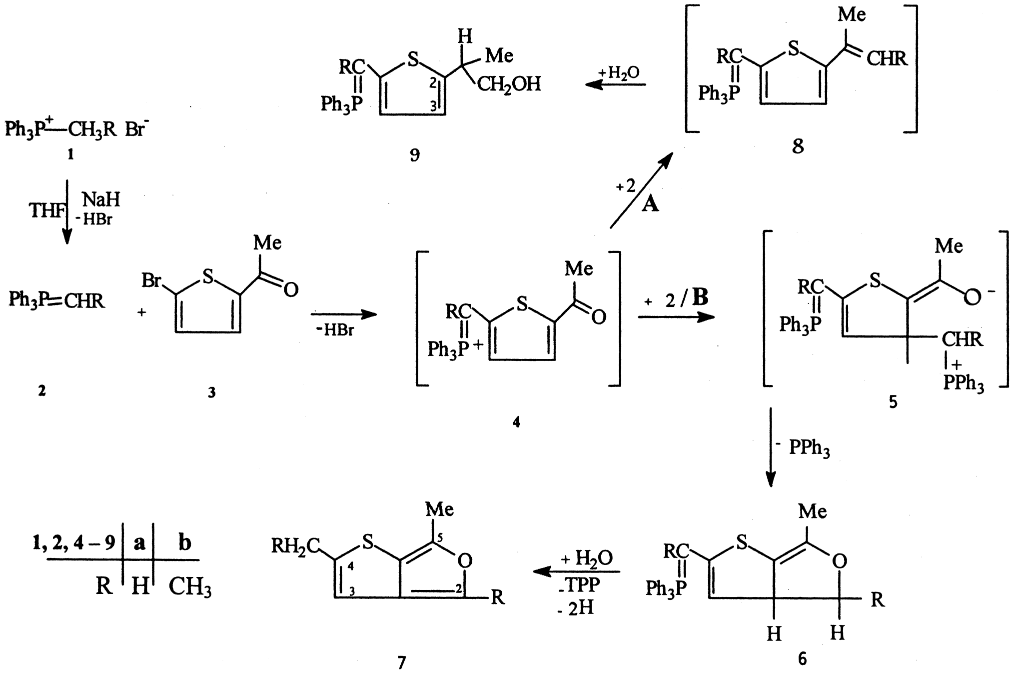
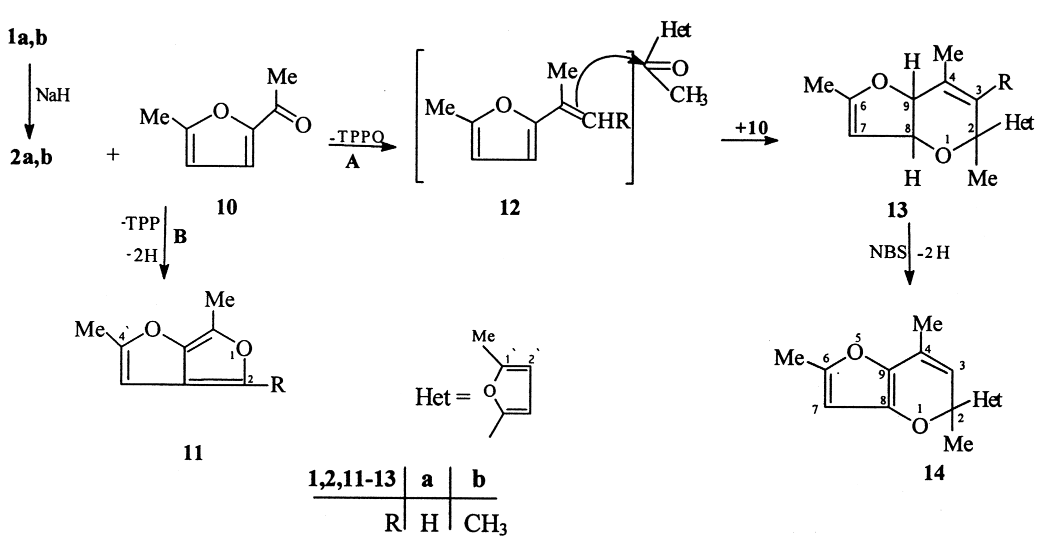


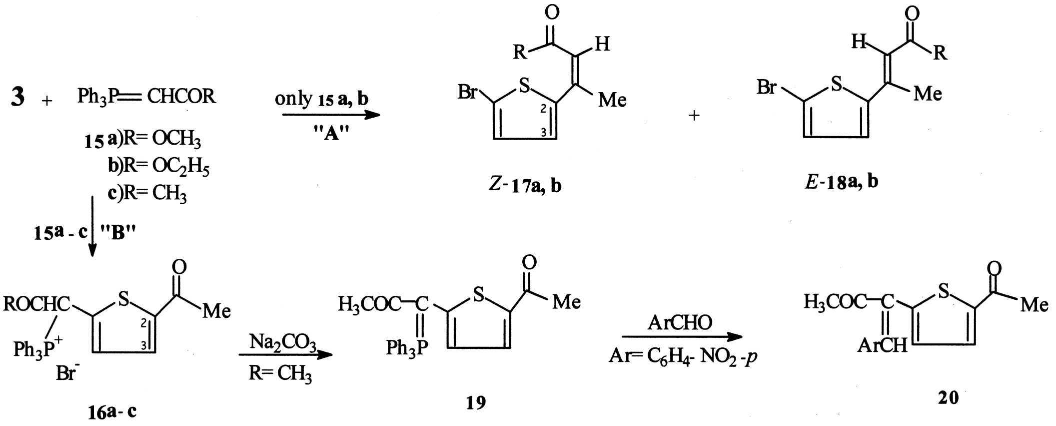
Scheme 1.

chemical shift of the ^{31}P NMR signal of **9a** is δ_P 19.7 ppm in agreement with an ylide structure. The reaction products of **3** with ethyltriphenylphosphonium bromide (**1b**) under phase-transfer catalysis conditions, as described for salt **1a**, were assigned analogous structures **7b** (47%) and **9b** (22%) on the basis of comparable spectroscopic arguments.

A mechanism that accounts for formation of the adducts **7** and **9** from the reaction of 2-acetyl-5-bromothiophene (**3**) with non-stabilised ylides **2a**,**b** can be assumed to follow the series of reactions outlined in Scheme 1 which implies that three positions in **3** are susceptible to nucleophilic attack: the ring-site halogen, the 3-position of the thiophene and the acetyl carbonyl group. Direct nucleophilic replacement of the bromine atom of **3** by the carbanion centre of **2** and abstraction of hydrogen bromide, enhanced by the presence of the alkaline medium, yields the phosphorane intermediate **4**, which reacts further with a second ylide species **2** in two different ways affording finally compounds **7** and **9**. Michael addition of the phosphonium ylide carbon of **2** at the **3**-position of the thiophene, followed by cycloelimination of the formed betaine intermediates **5** gives the ylides **6**. Further dehydrogenation of **6** gives the final products **7** through the action of a molecule of water on the ylide system in **6** accompanied by elimination of triphenylphosphine oxide. Conversely, Wittig reaction of the acetyl carbonyl of **4** with **2** yields the intermediates **8**, which are stabilised by the addition of the elements of water (adventitious H_2O) to give the products **9**. The dehydrogenation step can, however, be attributed to the long time of heating. Analogous dehydrogenation processes were also observed during some Wittig reactions[11] and Diels–Alder



Scheme 2.



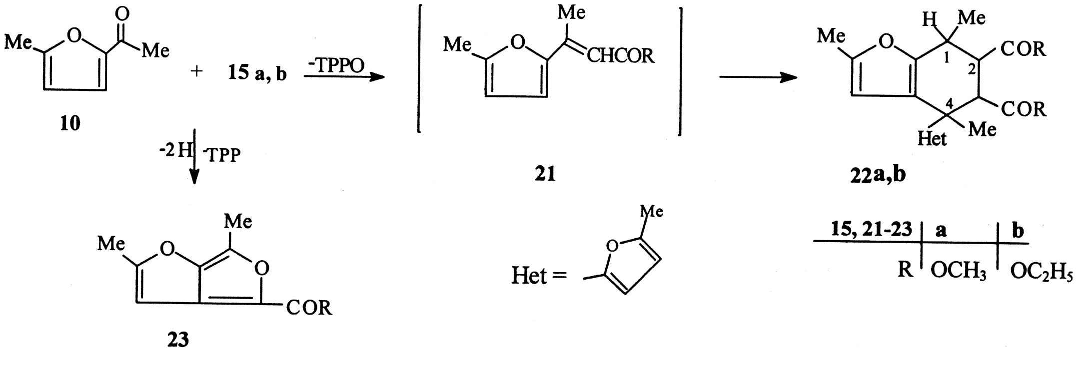
Scheme 3.

additions.[11,12] Similarly, fused furans have also been synthesised by us,[2] on treatment of 3-acetyl-5,6-benzocoumarin with alkylidene phosphoranes. Furthermore, this result is along the lines previously reported[2,13–15] for the tendency of this type of Wittig reagent to undergo an addition-elimination process rather than an olefination reaction.

Next, the behaviour of 2-acetyl-5-methylfuran (**10**) towards the same non-stabilised ylides **2a**,**b** was investigated (Scheme 2). When **10** was caused to react with **2a** (or **2b**) (1 mol/equiv.), prepared in situ from its bromide salt in the presence of a base, in THF, the reaction afforded the unexpected furopyrans **13** (~28%) along with furo-*iso*-furans **11** (~39%). Both MS and NMR spectra of the latter products favour structure **11** instead of the expected 2,3-dihydro-derivatives. The structure of 2,4-dimethyl-2-(5-methyl-2-furanyl) 8,9-dihydro-6-methylfuro[3,2-*b*]pyran **13a** is assigned from its molecular weight, and its ^{1}H NMR spectrum which showed two types of methyl groups: a doublet (J_{HH}=3 Hz) at δ 1.95 (3H, C-4–CH_3) and three singlets in the range δ 2.18–2.26 (9H, 3×CH_3). The C-8- and C-9 *endo*-protons are given as a doublet (J_{HH}=5.5 Hz) at δ 4.23 and as a multiplet at δ 4.48, respectively. The ^{13}C NMR data are also in accord with the suggested structure. When **13a** was treated with *N*-bromosuccinimide, derivative **14** (78%) was isolated.

As with the reaction between **2** and **3** (Scheme 1, 'B'), Michael addition of **2** at the 3-position of the furan and cycloelimination sequence followed by dehydrogenation afforded the product **11**. On the other hand, the formation of pyran derivatives **13** can be envisaged as a hetero-Diels–Alder addition of the substrate species **10** to the Wittig products **12** initially formed to give the final adducts **13** via a prototropic rearrangement. It should be mentioned that compounds **7**, **11** and **23** (vide infra, Scheme 4) were found to be stable under normal conditions. From the chemical point of view, diheteropentalene systems (iso-electronic with the pentalenedione), are usually quite unstable. According to calculations there is—if at all—only a low degree of aromatic stabilisation. Dioxaheteropentalenes of type **11** and **23** are especially rare and very few compounds have been synthesised so far.[16]

Furthermore, we have studied the reactions of **3** and **10** with some stabilised phosphorus ylides **15a**–**c**. A solution of equimolar amounts of **3** and [(methoxycarbonyl)methylene]triphenylphosphorane (**15a**) in toluene was refluxed for ~2 days to give the corresponding phosphonium salt **16a** (32%) and a mixture (25%) of stereoisomers of the Wittig products which could be further resolved by column chromatography to give **17a** (*Z*) (13%) and **18a** (*E*) (8%). The reaction is very slow and has been accelerated by using a catalytic amount of benzoic acid as a protonating catalyst in the reaction medium. The success of this procedure is attributable to the protonation of the carbonyl group, making it more electrophilic and therefore susceptible to nucleophilic attack by the ylides **15**. Structures of the



Scheme 4.

isolated products **16**–**18** were established on the basis of elemental analysis, molecular weight determination (MS) and the spectroscopic data.

The identity of *cis*- and *trans*-configuration for the isolated compounds **17a**,**b** (*Z*) and **18a**,**b** (*E*) was suggested according to ^1H NMR chemical shifts and melting point measurements. The determined chemical shifts of methyl groups and olefinic protons in the recorded ^1H NMR spectra are: δ 2.12 and 5.46 for **17a**, mp 84–85°C; δ 2.18 and 5.73 for **18**, mp 60–62°C. In all cases the higher melting point observed for the isomer suggested as *cis*- is greater than that those of the corresponding *trans* isomer, in agreement with the literature.[17] Compounds **16b**–**18b** were similarly obtained by reacting **3** with [(ethoxycarbonyl)-methylene]-triphenyl-phosphorane (**15b**) in boiling toluene containing benzoic acid. Conversely, only the phosphonium salt **16c** was isolated in 70% yield when **3** was caused to react with (acetylmethylene)triphenylphosphorane (**15c**) under the same experimental conditions. Obviously, the β-ketoalkylidenetriphenylphosphorane **15c** which is less nucleophilic comparatively to **15a**,**b** failed to undergo either a conjugate addition or an olefination process. It should be noted that the Wittig reaction of some ketones with β-keto ylides (**15**, $R{=}CH_3$, $R{=}C_6H_5$) has already been tried by Ramirez and Dershowitz,[18] however, without success. The phosphonium salt **16c**, which is taken as a representative example, was converted readily into the corresponding ylide **19** by the action of a base in the usual manner. On treating **19** with an aldehyde (e.g. *p*-NO_2–C_6H_4–CHO), the normal Wittig reaction took place to give the olefin **20** (Scheme 3).

In view of the above observations (**3**+**15a**–**c**), it is evident that in contrast with **2a**,**b**, the reaction went through two different pathways: a direct nucleophilic replacement of the bromine atom by the carbanion centre of **15a**–**c** to give the phosphonium salt **16a**–**c** or a Wittig olefination (only with **15a**,**b**) at the acetyl group to produce the stereoisomers **17** and **18**. Furthermore, the foregoing results showed that ring-site attack has predominated.

Finally, the reaction of 2-acetyl-5-methylfuran (**10**) with stabilised ylides **15a**,**b** represents another, even more interesting variation of the Wittig reaction (Scheme 4). Treatment of **10** with equimolar phosphorus ylide **15a** (or **15b**) in boiling toluene containing benzoic acid gave the substituted furofuran **23a** (18%) (or **23b**, 20%) and the dimer **22a** (28%) (or **22b**, 31%). In contrast to the reaction between **15** and **3** (Scheme 3, 'A'), the primary condensation products **21** seem to be unstable and highly reactive. However, stabilization, as expected by trapping in a Michael type addition of a second ylide species does not occur, instead the intermediates **21** undergo [4+2] intermolecular cycloaddition to give the cycloadduct dimers **22**.

An analogous dimerization reaction was also observed for the reaction of 9,10-phenanthrenequinone[19] and 10-(methoxyimino)phenanthrene-9-one[20] with phosphorus ylides. The structure **22** although not established with certainty, is supported by the recorded elemental analysis and spectral data. No reaction was observed, however, in a comparable experiment, using the ylide **15c**.

In conclusion, the title reactions provide an easy synthetic route to fused heterocycle derivatives in moderate yields. The results also showed that the behaviour of **10** with either the reactive ylides **2** or the stabilised ones **15** are in great disparity with that of the thiophene species **3**, which undergoes an addition–elimination reaction or a simple Wittig reaction toward the same synthons, respectively. This result, however, is attributable to the lower aromaticity of the furan ring, making its derivatives more reactive.[16,21]

Experimental

All melting points are uncorrected. IR spectra were recorded on a Perkin–Elmer spectrophotometer model 197 (Grating) using KBr disc. The ^1H and ^{13}C NMR spectra were run on a Varian Gemini 200 (200 MHz) instrument, using TMS as an internal reference. The ^{31}P NMR spectra were recorded relative to external H_3PO_4 (85%) with a Varian CFT-80 instrument. The mass spectra were performed at 70 eV on MS-50 Kratos (A.E.I.) spectrometer provided with data system. The appropriate precautions in handling moisture-sensitive compounds were observed. Materials and reagents were purchased from Aldrich Company. Light petroleum refers to the fraction 40–60°C.

I—Reaction of 2-acetyl-5-bromothiophene (3) with non-stabilised ylides 2a,b

General procedure: A solution of the appropriate salt **1a**,**b** (4.2 mmol) and the ketone **3** (0.4 g, 2 mmol) in dry THF (40 ml) was stirred by means of an efficient magnetic stirrer. A solution of a slurry of 240 mg of NaH dispersion (57% dispersion in oil) in 10 ml of dry THF was added in one portion to the mixture and the system was stirred at room temperature for 2 h and further was refluxed for 10–12 h (TLC). The product mixture was poured into 300 mL of distilled water, and extracted with 2×100 mL portion of chloroform. The combined organic extracts were back-washed with distd. water (50 mL), dried with Na_2SO_4 and the solvent was removed under reduced pressure. The residue was chromatographed on silica gel by using light petroleum/ethyl acetate as the eluent.

(a) The reaction of **3** (0.4 g, 2 mmol) with methyltriphenylphosphonium bromide (**1a**) (1.5 g, 4.2 mmol) gave compounds **7a** and **9a**, respectively.

4-Methylthieno[3,2-*c*]5-methylfuran (7a). This compound was obtained by (30% light petroleum/AcOEt)) as colourless crystals (137 mg, 46%), mp 68–70°C (*n*-pentane); [Found: C, 63.24; H, 5.23; S, 21.18. C_8H_8OS requires C, 63.12; H, 5.3; S, 21.06%]; ν_{max} (KBr) 1600–1610 cm^{-1} (–C=C–, furanyl); δ_H ($CDCl_3$) 2.02, 2.21 (2s, 2×3H, 2×CH_3), 7.25, 7.38 (2d, J_{HH}=1.5 Hz, 2×1H, Het-*H*); δ_C ($CDCl_3$) 14.2 (O–C–*C*H_3), 15.6 (S–C–*C*H_3), 124.7 (*C*-3), 127.6 (*C*-7), 141.2 (*C*-2), 139.5 (S–*C*–CH_3), 152.2 (O–*C*–CH_3), 155.7 (*C*-6); MS (EI), *m*/*z*(%): M^+, found 152 (43). C_8H_8OS requires 152.23.

2(5-Methylidenetriphenylphosphorane-2-thienyl)propanol (9a) This compound was obtained by (10% light petroleum/AcOEt) as colourless crystals (178 mg, 22%), mp

170–172°C (acetone/diethyl ether); [Found: C, 74.86; H, 5.96; P, 7.52; S, 7.64. $C_{26}H_{25}OPS$ requires C, 74.97; H, 6.05; P, 7.43; S, 7.7%]; ν_{max} (KBr) 3425 (OH), 1680, 1510 (C═P), 1430, 985 cm^{-1} (P–C); δ_H (d_6-DMSO) 1.22 (d, J_{HH}=7.2 Hz, 3H, C*H*$_3$), 3.66 (d, J_{HH}=7.2 Hz, 2H, C*H*$_2$), 4.03 (m, 1H, C*H*–CH_3), 4.35 (s, 1H, –CH_2O*H*), 7.08 (d, J_{HP}=18.3 Hz, 1H, P═C*H*), 7.7–7.87 (m, 17H, Ar-*H* & Het-*H*); δ_C (d_6-DMSO) 18.6 (–C–*C*H_3), 36.2 (Me–CH–*C*H_2OH), 63.6 (Me–*C*H–CH_2OH), 124.7, 126.4 (*C*-3, *C*-4), 121.3, 124.5, 127.9, 129.6 (C═C, Ph), 131.5 (d, J_{CP}=98.8 Hz, H*C*═P), 142.4 (d, $^2J_{CP}$=8.8 Hz, *C*–C═P); δ_P (d_6-DMSO) 19.7 ppm; MS (EI), *m/z* (%): M^+, found 416 (30). $C_{26}H_{25}OPS$ requires 416.53.

(b) The reaction of **3** (0.4 g, 2 mmol) with ethyltriphenylphosphonium bromide (**2b**) (1.6 g, 4.2 mmol) yielded compounds **7b** and **9b**.

4-Ethylthieno[3,2-*c*]2,5-dimethylfuran (7b). the compound was obtained by (30% light petroleum/AcOEt) as colourless crystals (164 mg, 47%), mp 68–70°C (*n*-pentane); [Found: C, 66.71; H, 6.63; S, 17.69. $C_{10}H_{12}OS$ requires C, 66.63; H, 6.71; S, 17.78%]; ν_{max} (KBr) 1600–1610 cm^{-1} (–C═C–, furanyl); δ_H ($CDCl_3$) 1.05 (t, J_{HH}= 6.5 Hz, 3H, –CH_2C*H*$_3$), 2.08, 2.21 (2s, 2×3H, 2×C*H*$_3$), 2.25 (q, J_{HH}=6.5 Hz, 2H, C–C*H*$_2$), 7.28, 7.37 (2d, J_{HH}=1.5 Hz, 2×1H, Het-*H*); MS (EI), *m/z*(%): M^+, found 180 (65). $C_{10}H_{12}OS$ requires 180.27.

2(5-Ethylidenetriphenylphosphorane-2-thienyl)propanol (9b). The compound was produced by (10% light petroleum/AcOEt) as colourless crystals (187 mg, 22%), mp 180–182°C (ethyl alcohol); [Found: C, 75.75; H, 6.44; P, 7.06; S, 7.3. $C_{28}H_{29}OPS$ requires C, 75.64; H, 6.57; P 6.97; S 7.21%]; ν_{max} (KBr) 3430 (OH), 1675, 1515 (C═P), 1440, 985 cm^{-1} (P–C); δ_H (d_6-DMSO) 1.08–1.22 (m, 9H, 3× –C*H*$_3$), 4.05–4.12 (m, 2H, –C*H* & C*H*OH), 4.46 (br. 1H, –O*H*), 7.23–7.78 (m, 17H, Ar-*H* & Het-*H*); δ_C (d_6-DMSO) 13.8, 14.5, 17.7 (3×C–*C*H_3), 62.6 (*C*HOH), 121.3, 124.5, 127.9, 129.6 (C═C, Ph), 124.7, 126.4 (*C*-3, *C*-4), 136.8 (*C*-2), 142.4 (d, $^2J_{CP}$=8.8 Hz, *C*–C═P), 143.3 (d, $^1J_{CP}$= 104 Hz, P═*C*); δ_P (d_6-DMSO) 19.3 ppm; MS (EI), *m/z*(%): M^+, found 444 (22). $C_{28}H_{29}OPS$ requires 444.58.

II—Reaction of 2-acetyl-5-methylfuran (10) with non-stabilised ylides (2a,b)

A THF solution of the appropriate salt **1a** or **1b** (8.5 mmol) and the furan derivative **10** (1 g, 8 mmol) was treated with sodium hydride (NaH) under the experimental conditions described above for the general procedure. The product residue was then separated by column chromatography using *n*-hexane/chloroform as the eluent.

(a) The reaction of **10** (1 g, 8 mmol) with **1a** (3.2 g, 8.5 mmol) afforded compounds **11a** and **13a**.

4-Methylfuro[3,2-*c*]5-methylfuran (11a). The compound was obtained by (80% *n*-hexane/$CHCl_3$) as brown crystals (300 mg, 28%), mp 76–77°C (light petroleum); [Found: C, 70.44; H, 5.81. $C_8H_8O_2$ requires C, 70.57; H, 5.92 %]; ν_{max} (KBr) 1600–1610 cm^{-1} (–C═C–, furanyl); δ_H ($CDCl_3$) 1.93, 2.05 (2s, 6H, 2×C*H*$_3$), 7.35, 7.65 (2d, J_{HH}=1.5 Hz, 2×1H, Het-*H*); MS (EI), *m/z* (%): M^+, found 136 (65). $C_8H_8O_2$ requires 136.15.

2,4-Dimethyl-2(5-methyl-2-furanyl) 8,9-dihydro-6-methylfuro[3,2-*b*]pyran (13a). The compound was obtained by (20% *n*-hexane/$CHCl_3$) as brown material (310 mg, 39%), mp 112–113°C (diethyl ether); [Found: C, 73.22; H, 7.29. $C_{15}H_{18}O_3$ requires C, 73.14; H, 7.36%]; ν_{max} (KBr) 1150–1125 (–C–O–C–), 1065 cm^{-1} (–C═C–O); δ_H ($CDCl_3$) 1.95 (d, J_{HH}=3 Hz, 3H, C-4–C*H*$_3$), 2.18, 2.23, 2.26 (3s, 3×3H, 3×O–C–CH_3), 4.23, 4.48 (q & d, diffused, 2×1H, C-8–*H* & C-9–*H*), 6.88–7.56 (4d, diffused, 4×1H, Het-*H*); δ_C ($CDCl_3$) 13.4, 13.7, 14.2 (3×O–C–*C*H_3), 15.8 (C-4–*C*H_3), 47.36, 49.82 (*C*-8–H& *C*-9–H), 106.2, 107.6, 108.6 (*C*-2′, *C*–3′, *C*-7), 133.1 (*C*-4), 136.4 (*C*-3), 149.7, 151.4, 155.5 (*C*-1′, *C*-4′,*C*-6); MS (EI), *m/z* (%): M^+, found 246 (13). $C_8H_8O_2$ requires 246.31.

(b) The reaction of **10** (1 g, 8 mmol) with ethyltriphenylphosphonium bromide (**1b**) (3.2 g, 8.5 mmol) afforded compounds **11b** and **13b**.

4-Methylfuro[3,2-*c*]2,5-dimethylfuran (11b). This compound was obtained by (90% *n*-hexane/$CHCl_3$) as brown crystals (300 mg, 25%), mp 100–102°C (light petroleum); [Found: C, 71.84; H, 6.66. $C_9H_{10}O_2$ requires C, 71.98; H, 6.71%]; ν_{max} (KBr) 1590–1610 cm^{-1} (–C═C–, furanyl); δ_H($CDCl_3$) 1.08, 1.22, 2.31 (3s, 3×3H, O–C–C*H*$_3$), 7.15 (q, diffused, 1H, Het-*H*); MS (EI), *m/z* (%): M^+, found 150 (100). $C_9H_{10}O_2$ requires 150.18.

2,3,4-Trimethyl-2-(5-methyl-2-furanyl)8,9-dihydro-6-methylfuro[3,2-*b*]pyran (13b). This compound was obtained by (20% *n*-hexane/$CHCl_3$) as brown material (344 mg, 33%), mp 120–122°C (acetonitrile); [Found C, 73.93; H, 7.66. $C_{16}H_{20}O_3$ requires C, 73.82; H, 7.74%]; ν_{max} (KBr) 1145–1125 (–C–O–C–), 1042 cm^{-1} (–C═C–O); δ_H ($CDCl_3$) 1.96 (d, J_{HH}=2.5 Hz, 3H, C-4–C*H*$_3$), 2.04 (s, 3H, C-6–C*H*$_3$), 2.16, 2.32, 2.35 (3s, 3×3H, 3×O–C–C*H*$_3$), 4.17 (d of q, diffused, C-8–*H*); 4.25 (d, J_{HH}=5.5 Hz, C-9–*H*), 7.25–7.54 (3d, diffused, 3×1H, Het-*H*); MS (EI), *m/z*(%): M^+, found: 260 (17). $C_{16}H_{20}O_3$ requires 260.33.

Reaction of 13a with NBS

N-Bromosuccinimide (NBS) (54 mg, 0.3 mmol) and benzoyl peroxide (7.2 mg, 0.04 mmol) were added to a solution of **13a** (74 mg, 0.3 mmol) in 20 mL of dry CCl_4. The mixture was refluxed for 2 h and filtered while hot. Evaporation of the solvent left a residue, which chromatographed (silica gel, 1:1 $CHCl_3$/ethyl acetate) to give the dehydro-derivative **14** (57 mg, 78%), mp 87–88°C (cyclohexane); [Found: C, 73.67; H, 6.73. $C_{15}H_{16}O_3$ requires C, 73.75; H, 6.6%]; ν_{max} (KBr) 1590–1610 (–C═C–, furanyl), 1055 cm^{-1} (–C═C–O); δ_H($CDCl_3$) 2.11–2.43 (m, 4×3H, 4×–C*H*$_3$), 7.33–7.58 (4d, diffused, 4×1H, Het-*H*); MS (EI): *m/z* (%): M^+, found 244 (16). $C_{15}H_{16}O_3$ requires 244.29.

III—Reaction of 2-acetyl-5-bromothiophene (3) with stabilised phosphorus ylides 15a–c

General procedure: A solution of compound **3** (1 g, 4.8 mmol) and the appropriate ylide **15a–c** (5 mmol) in dry toluene (30 mL) containing benzoic acid (0.2 g) was refluxed for ~2 days (TLC). After evaporation of the solvent, the remainder was subjected to a column previously charged with silica gel suspended in *n*-hexane. The column was then developed with *n*-hexane containing increasing amounts of ethyl acetate.

(a) The reaction of **3** (1 g, 4.8 mmol) with [(methoxycarbonyl)methylene]triphenylphosphorane (**15a**) (1.7 g, 5 mmol) gave two fractions:

The fractions that were collected by (60% *n*-hexane/AcOEt) afforded, after evaporation, a mixture (343 mg, 25%) of the two constituents *Z*-**17a** and *E*-**18a**; δ_H ($CDCl_3$) 2.13, 2.17 (2d, 2×3H, 2-CH_3, **17a**, **18a**); 3.35, 3.36 (2s, 2×3H, 2×OCH_3, **17a** & **18a**), 5.44, 5.73 (2q, 2×1H, 2×1H, **17a**, **18a**). The latter mixture was then injected to a silica gel column had packed in light petroleum and eluted with light petroleum–chloroform.

(*Z*)-Methyl 2(5-bromo-2-thienyl)prop-2-ene carboxylate (17a). This compound was obtained by (80% light petroleum/$CHCl_3$) as colourless crystals (178 mg, 13%, based on **3**), mp 84–85°C (cyclohexane); [Found: C, 41.45; H, 3.33; Br, 30.67; S, 12.31. $C_9H_9BrO_2S$ requires C, 41.39; H, 3.47; Br, 30.6; S, 12.28%]; ν_{max} (KBr) 1715 (C=O, ester), 1640 cm^{-1} (C=CH); δ_H ($CDCl_3$) 2.12 (d, J_{HH}=1.5 Hz, 3H, CH_3), 3.37 (s, 3H, OCH_3), 5.46 (q, J_{HH}=1.5 Hz, 1H,=C*H*), 6.62, 6.88 (2d, J_{HH}=2.5 Hz, Het-*H*), 3.37 (s, 3H, OCH_3), 5.46 (s, 1H,=C*H*), 6.6. 6.88 (2d, J_{HH}= 2.5 Hz, 2H, Het-*H*); δ_C ($CDCl_3$) 25.2 (=C–CH_3), 51.8 (OCH_3), 121.6, 124.1 (*C*-3, *C*-4), 126.0 (C=*C*H), 148.9, 151.4 (*C*-5, *C*-2), 171.6 (*C*=O, ester); MS (EI), *m*/*z*(%): M^+, found: 261 (100), M^++2, 263 (33). $C_9H_9BrO_2S$ requires 261.15.

(*E*)-Methyl 2(5-bromo-2-thienyl)prop-2-ene carboxylate (18a). This compound was obtained by (70% light petroleum/$CHCl_3$) as colourless crystals (93 mg, 8%, based on **3**), mp 62–64°C (pentane); [Found: C, 41.52; H, 3.38; Br, 30.54; S, 12.37. $C_6H_9BrO_2S$ requires C, 41.39; H, 3.47; Br, 30.6; S, 12.28%]; ν_{max} (KBr) 1720 (C=O, ester), 1635 cm^{-1} (C=CH); δ_H ($CDCl_3$) 2.18 (d, J_{HH}=2 Hz, 3H, CH_3), 3.32 (s, 3H, OCH_3), 5.73 (q, J_{HH}=2 Hz, 1H,=C*H*), 6.62, 6.86 (2d, J_{HH}=2.5 Hz, 2×1H, Het-*H*); δ_C ($CDCl_3$) 22.7 (=C–CH_3), 53.4 (OCH_3), 121.4, 123.5 (*C*-3, *C*-4), 128.4 (C=*C*H), 133.6 (*C*=CH), 148.2, 151.7 (*C*-5, *C*-2), 173.2 (C=O, ester); MS (EI), *m*/*z* (%): M^+, found 261(100), [M^++2], 263 (33). $C_6H_9BrO_2S$ requires 261.15.

2-Acetylthienyl-5-[(methoxycarbonyl)methyl]triphenylphosphonium bromide (16a). The compound was obtained (10% light petroleum/$CHCl_3$) as colourless crystals (0.84 g, 32%), mp 285–287°C (dil. ethanol); [Found: C, 60.08; H, 4.42; Br, 14.68; P, 6.04; S, 5.83. $C_{27}H_{24}BrO_3PS$ requires C, 60.11; H, 4.48; Br, 14.81; P, 5.74; S, 5.94%]; ν_{max} (KBr) 1722 (C=O, ester), 1675 (C=O, acetyl), 1455, 980 cm^{-1} (C–P, phenyl); δ_H (d_6-DMSO) 2.52 (s, 3H, C(O)CH_3), 3.35 (s, 3H, OCH_3), 3.88 (d, J_{HP}=18.5 Hz, 1H, P–C*H*), 7.25–7.78 (m, 17H, Ar-*H* & Het-*H*); δ_P 14.83 ppm; MS (EI), *m*/*z*(%): M^+, found 539 (18), M^++2, 541(6) $C_{27}H_{24}BrO_3PS$ requires 539.45.

(b) The reaction of **3** with [(ethoxycarbonyl)methylene]triphenylphosphorane (**15b**) (1.7 g, 5 mmol) afforded two fractions: The fractions that were collected up to 60% light petroleum/$CHCl_3$ indicated the presence of two products (*Z*) **17b** and (*E*)-**18b**. This eluent was re-evaporated to dryness and the residue was chromatographed on silica gel and eluted with light petroleum containing increasing amounts of chloroform.

***Z*-Ethyl 2(5-bromo-2-thienyl)prop-2-ene carboxylate (17b).** This compound was obtained by (80% light petroleum/$CHCl_3$) as colourless crystals (214 mg, 16%, based on **3**), mp 86°C (light petroleum); [Found: C, 44.53; H, 4.11; Br, 28.96; S, 11.59. $C_{10}H_{11}BrO_2S$ requires C, 43.64; H, 4.03; Br, 29.04; S, 11.65%]; ν_{max} (KBr) 1725 (C=O, ester), 1613 cm^{-1} (C=CH); δ_H ($CDCl_3$) 0.82 (t, J_{HH}=5.5 Hz, 3H, O–C–CH_3), 2.1 (d, J_{HH}=1.5 Hz, 3H,=C–CH_3), 3.85 (q, J_{HH}=5.5 Hz, 2H, O–CH_2), 5.48 (q, J_{HH}=1.5 Hz, 1H,=C*H*), 6.58, 6.82 (2d, J_{HH}=2.5 Hz, 2×1H, Het-*H*); δ_C($CDCl_3$) 14.8 (O–C–CH_3), 25.2 (=C–CH_3), 62.3 (OCH_2), 119.7, 122.8 (*C*-3, *C*-4), 128.8 (C=*C*H), 133.4 (*C*=CH), 147.8, 151.9 (*C*-5, *C*-2), 169.8 (*C*=O); MS (EI), *m*/*z*(%): M^+, found 275 (100), M^++2, 277 (33). $C_{10}H_{11}BrO_2S$ requires 275.18.

(*E*)-Ethyl 2(5-bromo-2-thienyl)prop-2-ene carboxylate (18b). This compound was obtained by (70% light petroleum/$CHCl_3$) as colourless crystals (94 mg, 7%), mp 58–60°C (pentane); [Found: C, 43.59; H, 3.88; Br, 28.93; S, 11.57. $C_{10}H_{11}BrO_2S$ requires C, 43.63; H, 4.03; Br, 29.04; S, 11.65%]; ν_{max} (KBr) 1715 (C=O, ester), 1622 cm^{-1} (C=CH); δ_H ($CDCl_3$) 0.85 (t, J_{HH}=5.5 Hz, 3H, OC–CH_3), 2.14 (d, J_{HH}=2 Hz, 3H, =C–CH_3), 3.82 (q, J_{HH}= 5.5 Hz, 2H, OC–CH_2), 5.73 (q, J_{HH}=2 Hz, 1H,=C*H*), 6.58, 6.81(2d, J_{HH}=2.5 Hz, 2×1H, Het-*H*); δ_C ($CDCl_3$) 15.3(O-C–CH_3), 23.6 (=C–CH_3), 63.4 (OCH_2), 121.1, 123.3 (*C*-3, *C*-4), 128.2 (C=*C*H), 135.4 (*C*=CH), 147.3, 154.6 (*C*-5, *C*-2), 171.5 (*C*=O); MS (EI), *m*/*z*(%): M^+, found 275 (100), M^++2, 277 (33). $C_{10}H_{11}BrO_2S$ requires 275.18.

2-Acetylthienyl-5-[(ethoxycarbonyl)methylene]triphenylphosphonium bromide (16b). This compound was obtained by (10% light petroleum/$CHCl_3$) as colourless crystals (0.89 g, 33%), mp 265–266°C (dil. ethanol); [Found: C, 61.63; H, 4.88; Br, 14.55; P 5.52; S, 5.86. $C_{28}H_{26}BrO_3PS$ requires C, 60.76; H, 4.75; Br, 14.44; P, 5.6; S, 5.79%]; ν_{max} (KBr) 1715 (C=O, ester), 1677 (C=O, acetyl), 1455, 980 cm^{-1} (P–C, phenyl); δ_H (d_6-DMSO) 1.07 (t, J_{HH}=6.2 Hz, 3H, O–C–CH_3), 2.26 (s, 3H, C(O)CH_3), 3.88 (q, J_{HH}=6.2 Hz, 2H, OCH_2), 4.24 (d, J_{HP}=20.5 Hz, 1H, P–C*H*), 6.82–7.83 (m, 17H, Ar-*H* & Het-*H*); δ_P (d_6-DMSO) 15.5 ppm; MS (EI), *m*/*z*(%): M^+, found 553 (6). $C_{28}H_{26}BrO_3PS$ requires 553.48.

(c) The reaction of **3** with (acetylmethylene)triphenylphosphorane (**15c**) (1.6 g, 5 mmol) gave only *2-acetylthienyl-5(acetylmethylene)triphenylphosphonium bromide* (**16c**) which obtained by (10% light petroleum/$CHCl_3$) as colourless crystals (1.78 g, 70%), mp>300°C (AcOEt/MeCN); [Found: C, 62.68; H, 4.13; Br, 15.01; P, 6.55; S, 5.38. $C_{27}H_{24}BrO_2P$ requires C, 62.75; H, 4.02; Br, 15.17; P, 5.62; S, 6.24%]; ν_{max} (KBr) 1674, 1658 (2×C(O), acetyl), 1450, 988 cm^{-1} (P–C, phenyl); δ_H (d_6-DMSO) 2.48, 2.51(2s, 2×3H, 2×C (O)C*H*$_3$), 4.52 (d, J_{HP}=20.2 Hz, 1H, P–C*H*), 6.76–7.64 (m, 17H, Ar-*H* & Het-*H*); δ_C (d_6-DMSO) 24.5, 25.2 (2×C(O)CH$_3$), 68.5 (d, J_{CP}=104 Hz, H*C*–P), 120.7, 124.5, 128.4, 129.1 (C=C, Ph), 121.6, 124.1 (*C*-3, *C*-4), 144.8, 155.2 (*C*-5, *C*-2), 192.7, 194.3 [2×*C*(O)]; δ_P (d_6-DMSO) 14.6 ppm; MS (EI), *m*/*z*(%): M$^+$, found 523 (13), M$^+$+2, 525 (5). $C_{27}H_{24}BrO_2P$ requires 523.45.

Alkaline treatment of the phosphonium salt 16c

A mixture of **16c** (1.5 g) and 20 mL of Na_2CO_3 (10%, aq.) was heated to reflux for one hour. The mixture was cooled, diluted with dist. H_2O (8 mL) and extracted with chloroform. The residue obtained on removal of $CHCl_3$ was boiled with light petroleum and then recrystallized from ethyl alcohol to give the corresponding ylide **19** as colourless crystals, mp 163°C (benzene); [Found: C, 73.37; H, 5.11; P, 6.86; S, 7.34. $C_{27}H_{23}O_2PS$ requires C, 73.28; H, 5.24; P, 7.0; S, 7.24%]; ν_{max} (KBr) 1670, 1656 cm^{-1} (2×C=O, acetyl); δ_H (d_6-DMSO) 2.35, 2.52 (2s, 2×3H, 2×C(O)C*H*$_3$), 6.78–7.65 (m, 17H, Ar-*H* & Het-*H*); δ_P (d_6-DMSO) 21.3 ppm; MS (EI), *m*/*z* (%): M$^+$, found 442 (25). $C_{27}H_{23}O_2PS$ requires 442.53.

Wittig reaction of the produced ylide 19

To a solution of **19** (0.5 g, 1.3 mmol) in ethyl methyl ketone (20 mL) containing triethylamine (0.2 mL), *p*-nitrobenzaldehyde (0.3 g, 2 mmol) was added. The reaction mixture was refluxed for 8 h. and the solvent was evaporated. Extraction of the residue with hot light petroleum gave on cooling triphenylphosphine oxide, mp 155°C. Crystallization of the residual substance from acetone yielded the exocyclic olefin **20** (230 mg, 66%), mp 117°C; [Found: C, 61.81; H, 4.03; N, 4.31; S, 10.05. $C_{16}H_{13}NO_4S$ requires C, 60.94; H, 4.15; N, 4.44; S, 10.17%]; ν_{max} (KBr) 1680, 1658 (2×C (O), acetyl), 616 cm^{-1} (C=CH, exocyclic); δ_H ($CDCl_3$) 2.34, 2.51(2s, 2×3H, 2× C(O)C*H*$_3$), 6.89–7.56 (m, 7H, Ar-*H*, Het-*H* &=C*H*); MS (EI), *m*/*z*(%): M$^+$, found 315 (42). $C_{16}H_{13}NO_4S$ requires 315.35.

IV—Reaction of 2-acetyl-5-methylfuran (10) with stabilised phosphorus ylides 15a–c

Treatment of compound **9** (1 g, **8** mmol) with the appropriate ylide **15a–c** (8.2 mmol) in toluene containing benzoic acid (0.2 g) was refluxed for ~2 days (TLC). The product mixture was worked up as above whereupon triphenylphosphine oxide along with **23a**,**b** which eluted by (60% light petroleum/$CHCl_3$) and **22a**,**b** which eluted by (10% light petroleum/$CHCl_3$), respectively, could be isolated.

The fused furan **23a** was obtained as yellow crystals (280 mg, 18%), mp 77–79°C (cyclohexane); [Found: C, 61.69; H, 5.26. $C_{10}H_{10}O_4$ requires C, 61.85; H, 5.19%]; ν_{max} (KBr) 1725 cm^{-1} (C=O, ester); δ_H ($CDCl_3$) 1.95, 2.04 (2s, 2× 3H, 2× C–C*H*$_3$), 3.48 (s, 3H, OC*H*$_3$), 7.43 (q, diffused, 1H, Het-*H*); MS (EI), *m*/*z* (%): M$^+$, found 194 (38). $C_{10}H_{10}O_4$ requires 194.19.

23b. It was obtained as yellow crystals (318 mg, 20%) mp 58–60°C (pentane); [Found: C, 64.31; H, 5.37. $C_{11}H_{12}O_4$ requires C, 63.45; H, 5.8%]; ν_{max} (KBr) 1720 cm^{-1} (C=O, ester); δ_H ($CDCl_3$) 1.06 (t, J_{HH}=6.5 Hz, 3H, C*H*$_3$, ester), 1.91, 2.13 (2s, 2×3H, 2×C*H*$_3$, furanyls), 3.92 (q, J_{HH}=6.5 Hz, 2H, OC*H*$_2$), 7.41(q, diffused, 1H, Het-*H*); MS (EI), *m*/*z* (%): M$^+$, found 208 (26). $C_{11}H_{12}O_4$ requires 208.22.

The dimeric product **22a** was obtained as yellow crystals (400 mg, 28%), mp 203–205°C (dichloromethane); [Found: C, 66.55; H, 6.65. $C_{20}H_{24}O_6$ requires C, 66.65; H, 6.71%]; ν_{max} (KBr) 1728, 1720 cm^{-1} (C=O, ester); δ_H (d_6-DMSO) 0.55 (d, J_{HH}=5.5 Hz, 3H, C-1–C*H*$_3$), 0.66 (d, J_{HH}=Hz, 3H, C-4–C*H*$_3$), 2.07, 2.15 (s, 2×3H, –C*H*$_3$, furanyls), 3.56–3.86 (m, 9H, C-1–, C-2–, C-3–*H* & 2×OC*H*$_3$), 6.55, 6.94 (2d, J_{HH}=2.5 Hz, 2H, Het-*H*), 7.38 (q, difused, 1H, Het-*H*); MS (EI), *m*/*z*(%): M$^+$, found 360 (20). $C_{20}H_{24}O_6$ requires 360.4.

22b. It was obtained as yellow crystals (468 mg, 31%), mp 182–184°C (dichloromethane); [Found: C, 68.12; H, 7.34. $C_{22}H_{28}O_6$ requires C, 68.02; H, 7.26%]; ν_{max} (KBr) 1735, 1730 cm^{-1}(C=O, ester); δ_H (d_6-DMSO) 0.52–1.23 (m, 12H, C-1–, C-4–C*H*$_3$ & 2×C*H*$_3$, ester); 2.05, 2.18 (2s, 2×3H, 2C*H*$_3$, furanyl), 3.55–3.95 (m, 7H, C-1, C-2–, C-3*H* & OC*H*$_3$, ester), 6.57, 6.99 (2d, J_{HH}=2.5 Hz, 2H, Het-*H*), 7.31 (q, diffused, 1H, Het-*H*); MS (EI), *m*/*z* (%): M$^+$, found 388 (20). $C_{22}H_{28}O_6$ requires 388.46.

Triphenylphosphine and its oxide were also isolated and identified from this reaction.

When **10** (1 g, 8 mmol) was allowed to react with **15c** (2.5 g, 8 mmol) under above same conditions and working up, the edducts (**10** and **15c**) were recovered practically unchanged (>80%).

References

1. For a recent accounts see references a–k: (a) Abdou, W. M.; Elkhoshnieh, Y. O.; Kamel, A. A. *Heteroatom Chem.* **1999**, *10*, 481–496. (b) Abdou, W. M.; Ganoub, N. A.; Shaddy, A. M. *Tetrahedron* **1998**, *54*, 9079–9088. (c) Abdou, W. M.; Ganoub, N. A. *Synth. Commun.* **1998**, *28*, 3579–3589. (d) Abdou, W. M.; Salem, M. A. I.; Sediek, A. A. *J. Chem. Res., Synop.* **1998**, 28–29; (*Miniprint*) **1998**, 327–339. (e) Abdou, W. M.; Salem, M. A. I.; Sediek, A. A. *Tetrahedron* **1997**, *53*, 13945–13958. (f) Abdou, W. M. *Synth. Commun.* **1997**, *27*, 3599–3604. (g) Abdou, W. M.; Yakout, E. S. M.; Ganoub, N. A. *Tetrahedron* **1995**, *51*, 11411–11420. (h) Abdou, W. M.; Ganoub, N. A.; Shaddy, A. M. *Heterocycl. Commun.* **1997**, *3*, 57–64. (i) Abdou, W. M.; Ganoub, N. A. *Phosphorus, Sulfur Silicon* **1995**, *105*, 63–67. (j) Elkhoshnieh, Y. O.; Hennawy, I. T.; Abdou, W. M. *Heterocycl. Commun.* **1995**, *1*, 167–175. (k) Abdou, W. M.; Ganoub, N. A. *Heterocycl. Commun.* **1995**, *1*, 383–387.

2. Abdou, W. M.; Salem, M. A. I.; Sediek, A. A. *J. Heterocycl. Commun.* **1998**, *4*, 145–150.

3. (a) Mahran, M. R.; Abdou, W. M.; Abd-Elrahman, N. A.; Khidre, M. D. *J. Heteroatom Chem.* **1992**, *3*, 93–99. (b) Abdou, W. M.; Khidre, M. D.; Mahran, M. R. *J. Prakt. Chem.* **1990**, *332*, 1029–1034. (c) Mahran, M. R.; Abdou, W. M.; Khidre, M. D.

Monatsh. Chem. **1990**, *121*, 51–58. (d) Mahran, M. R.; Abdou, W. M.; Khidre, M. D. *J. Chem. Indust. (Lond.)* **1989**, 726–727.

4. Hopff, H.; Kleiner, E.; El-Din, S. H. *Advan. Chem. Ser.* **1969**, *46* (91); *Chem. Abstr.* **1970**, *72*, 22018; Shrage, K. Fr. Demand 2,000,081(Cl-C8F), **1969**; *Chem. Abstr.* **1970**, *72*, 44322.

5. Isaacs, S. T.; Shen, C. J.; Hearst, C. J.; Rapoport, E. *Biochemistry* **1977**, *16*, 1058–1064.

6. Schumacher, J. N.; Joseph, N. (R. J. Reynolds Tobacco Co.), US 3,381,690, 1968; *Chem. Abstr.* **1968**, *69*, 41821.

7. Vereinigte Glazstoff-Fabriken A.G. Brit. 933,966, 1963; *Chem. Abstr.* **1963**, *59*, 15399.

8. Okubo, K.; Masuda, T.; Noguchi, J. (Fuji Photo Film Co. Ltd.) Fr. 1,542,505 (C1. GO3C), **1968**, *Chem. Abstr.* **1969**, *71*, 66055.

9. Chakrabart, J. K.; Horsman, L.; Hotten, T. M.; Pullar, I. A.; Tupper, D. E.; Wright, F. C. *J. Med. Chem.* **1980**, *23*, 878–884.

10. Abied, M. Y.; Elansary, A.; Kamel, M. M.; Kassem, E. M. M.; Abdou, W. M.; Zayed, N. *Bull. Fac. Pharm. Cairo Univ.* **1992**, *30*, 293–296.

11. Nicolaides, D. N.; Lefkaditis, D. A.; Lianis, P. S.; Litinas, K. E. *J. Chem. Soc., Perkin Trans. 1* **1989**, 2329–2333.

12. Nicolaides, D. N.; Papageorgiou, G. K.; Stephanatou, J. S. *Tetrahedron* **1989**, *45*, 4585–4592.

13. Sidky, M. M.; Boulos, L. S. *Phosphorus Sulfur* **1984**, *19*, 27–30.

14. Nicolaides, D. N.; Balouctsi, C. B.; Litinas, K. E.; Xenikaki, E. M.; Mentzafos, D.; Terzis, A. *J. Chem. Res., Sunop.* **1993**, 108–109; (*Miniprint*) **1993**, 826–851.

15. Abdou, W. M. *Phosphorus Sulfur Silicon* **1992**, *66*, 285–287.

16. Gutman, I.; Milun, M.; Trinajstic, N. *J. Am. Chem. Soc.* **1977**, *99*, 1692.

17. Aruduini, A.; Bosi, A.; Pochini, A.; Ungaro, R. *Tetrahedron* **1985**, *41*, 3095–3103.

18. Ramirez, F.; Dershowitz, S. *J. Org. Chem.* **1957**, *22*, 41–45.

19. Nicolaides, D. N.; Awad, R. W.; Papageorgiou, G. K.; Stephanidou- Stephanatou, J. *J. Org. Chem.* **1994**, *59*, 1083–1086.

20. Sullivan, W. W.; Ullman, D.; Shechter, H. *Tetrahedron Lett.* **1969**, 457–461.

21. Friguelli, F.; Marino, G.; Taticchi, A.; Grandolin, G. *J. Chem. Soc., Perkin Trans. 2* **1974**, 332–337.