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A new catalytic method for the synthesis of selectively substituted biphenyls containing an oxoalkyl chain

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Dedicated to Professor J.P. Genêt in recognition of his significant contributions to the art of organic synthesis (on the occasion of his 60th birthday)

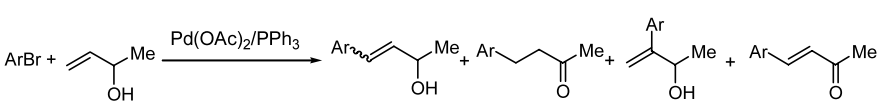
Abstract

A novel reaction sequence leading to the synthesis of substituted biphenyls containing a carbonyl group in an aliphatic chain has been achieved in one-pot reaction starting from iodoarenes and allylic alcohols under the catalytic action of palladium and norbornene. The latter is temporarily incorporated into a palladacycle, which directs the reaction towards the selective formation of an aryl–aryl bond. Norbornene spontaneously deinserts to allow the biphenylylpalladium bond thus formed to react in its turn with the allylic alcohol.

Keywords: Palladium; Palladacycles; Aromatic arylation; Allylic alcohols; Heck reaction; Catalysis

1. Introduction

The present work stems from the confluence of two research directions: the synthesis of aromatics containing an aldehydic or ketonic chain and the synthesis of biphenyls via palladacycles. The former has its origin in the palladium-catalysed arylation of C–C double bonds, now called the Heck reaction which was discovered by the groups of Mizoroki [1] and Heck [2] more than 30 years ago, and since then has been extensively used in organic synthesis [3]. A few years later, the teams of Heck [4] and Chalk [5] simultaneously and independently reported the first palladium-catalysed arylation of allylic alcohols, which afforded various products as shown in Eq. 1 [4]. The reaction was thoroughly studied under various experimental conditions and it was observed that α-arylated [6], di-β-arylated [7] or di-(β-arylated) α,β-unsaturated [6b,7b] carbonyl compounds



(1)

are additionally produced. The reaction can now be directed towards the selective formation of either the saturated carbonyl compound or the α,β-unsaturated alcohol by choosing proper experimental conditions [8].

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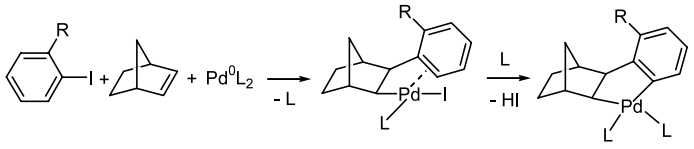
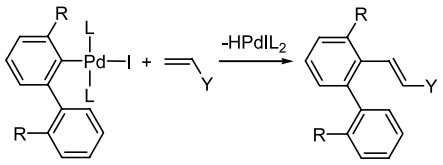


Scheme 1.

The biphenyl synthesis was worked out in the framework of research directed towards new synthetic methodologies based on aryl to aryl coupling via palladacycles [9], followed by sequential coupling of the palladium coordinated carbon thus formed with an aromatic or acetylenic carbon. In this way, selectively substituted phenanthrenes [9b] or terphenyls [9c] could be obtained in one-pot catalytic reactions. The key feature of these reactions is the temporary assembly of palladacycles [10] which direct formation of new bonds with complete regioselectivity [9,11]. These palladacycles are formed sequentially starting from ortho-susbtituted aryl iodides according to Scheme 1 (L = solvent or coordinating molecule).

They originate from an electrophilic palladation reaction [10d] which is favored by the pre-organised structure of its precursor [12], where η-type interaction has been revealed [12b,12d]. The same palladacycle is able to react with a second molecule of the aryl halide giving rise to a biphenylylnorbornylpalladium complex which spontaneously expels norbornene (Scheme 2) [11].

The biphenylylpalladium complex readily reacts with carbon compounds able to replace palladium with concomitant liberation of the latter in the zero oxidation state needed to start a new catalytic cycle. Olefins lend themselves to reaction according to Heck methodology [13] (Eq. 2).



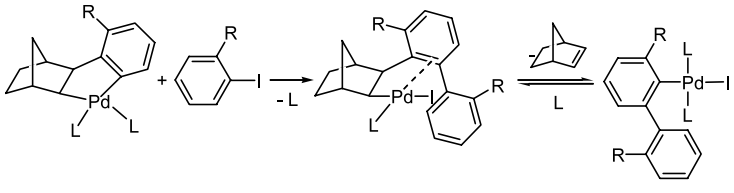
(2)

In this context our attention was drawn to the possibility to utilize allylic alcohols in the last stage of the reaction sequence.

2. Results and discussion

The combination of the methodology of sequential reactions via palladacycle with that of an allylic alcohol coupling with aryls raised several problems. First of all in a sequential process there are several steps in which a carbon–palladium bond, able to react with allylic alcohols, is present. Only if these reactions are much slower than the desired one, the process can proceed until the end of the sequence. Second, the conditions adopted for coupling with allylic alcohols must not affect the sequential process negatively and vice versa. For example, palladium must be set free from the last reductive elimination step at a sufficient rate to feed the initiation of new catalytic cycles.

Reagent concentration and ratio, medium basicity, solvent and temperature all proved to be determining factors. A 2:1 ratio between the aryl iodide and the allylic alcohol, corresponding to the stoichiometric one, was adopted. Norbornene formally acts as catalyst but to enable it to insert efficiently into the arylpalladium bond formed by oxidative addition of the aryl iodide to palladium(0) (Scheme 1) it must be used at a sufficient concentration. On the other side, if the concentration is too high its elimination according to Scheme 2 becomes more difficult and the entire process is hampered. A 4:1 ratio between aryl iodide and norbornene experimentally proved to be satisfactory. A 1:1 ratio between aryl iodide and K_2CO_3 as the base also turned out to be effective in promoting ring formation and final HI neutralization. The solvent of choice was dimethylformamide and the most convenient temperature was found to be 105 °C (Eq. 3). Attempts were made to use ionic liquids such as tetra-*n*-butylammonium bromide above its melting point. This medium, however, favoured the Heck-type reaction of the aryl iodide [6c], thus preventing the desired sequence initiated by norbornene insertion. Attempts to vary the reaction selectivity by using the additives adopted for the 'normal' Heck reaction with allylic alcohols also failed because the latter reaction was favoured. Thus, using silver carbonate [8] to shift the reaction towards **4** was unsuccessful owing to the preferential formation of products of the normal Heck reaction, 4-(2-methylphenyl)-3-buten-2-ol being obtained in 82% yield from **1**



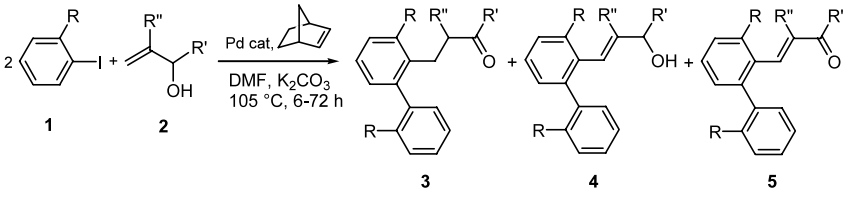
Scheme 2.

Table 1
Reaction of *o*-substituted aryl iodides with allylic alcohols in the presence of $Pd(OAc)_2$ and norbornene as catalysts and K_2CO_3 as a base [a]

Entry	R	R′	R″	Conversion (%)	Yield [b] (%)		
				1	**3**	**4**	**5**
a	Me [c]	H	H	75	56		
b	Me	Me	H	84	60	4	8
c	Et	Me	H	82	60	6	6
d	*i*-Pr	Me	H	81	61	2	7
e	$-(CH)_4-$	Me	H	100	75	5	
f	OMe	Me	H	93	62	3	8
g	CO_2Me [d]	Me	H	100	93		
h	Me	Ph	H	82	53	4	7
i	Et	Ph	H	71	51	4	5
j	*i*-Pr [e]	Ph	H	92	62	3	6
k	Me [f]	Me	Me	75	33	6 [g]	16 [h]
l	*i*-Pr [e]	Me	Me	89	36	3 [g]	20 [h]
m	CO_2Me	Me	Me	100	54		10 [h]

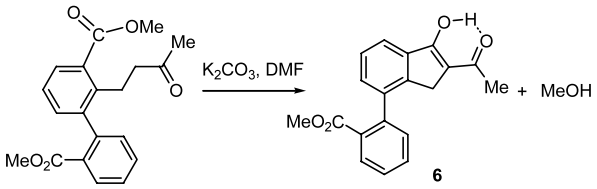
[a] Molar ratio of the reagents in the order reported in the title: 80:45:1:20:80; 105 °C, 24 h, DMF as solvent, under dinitrogen; 0.4×10^{-2} mmol $Pd(OAc)_2$/mL DMF.
[b] Compounds **3** and **4**: isolated yield on the charged amount of the aryl iodide; compound **5**: GC yield, characterized as **3** after hydrogenation.
[c] For 8 h.
[d] For 6 h.
[e] For 72 h.
[f] For 48 h.
[g] A mixture of isomers (ArCH=CMeCH(OH)Me and $ArCH_2C(=CH_2)CH(OH)Me$) was obtained.
[h] A mixture of isomers (ArCH=CMeCOMe and $ArCH_2C(=CH_2)COMe$ was obtained.

(R = Me) and **2** (R′ = Me, R″ = H). The correct combination of all the factors mentioned above eventually allowed us to work out a satisfactory process based on the following global equation 3 in which the saturated ketonic compound **3** predominates.



(3)

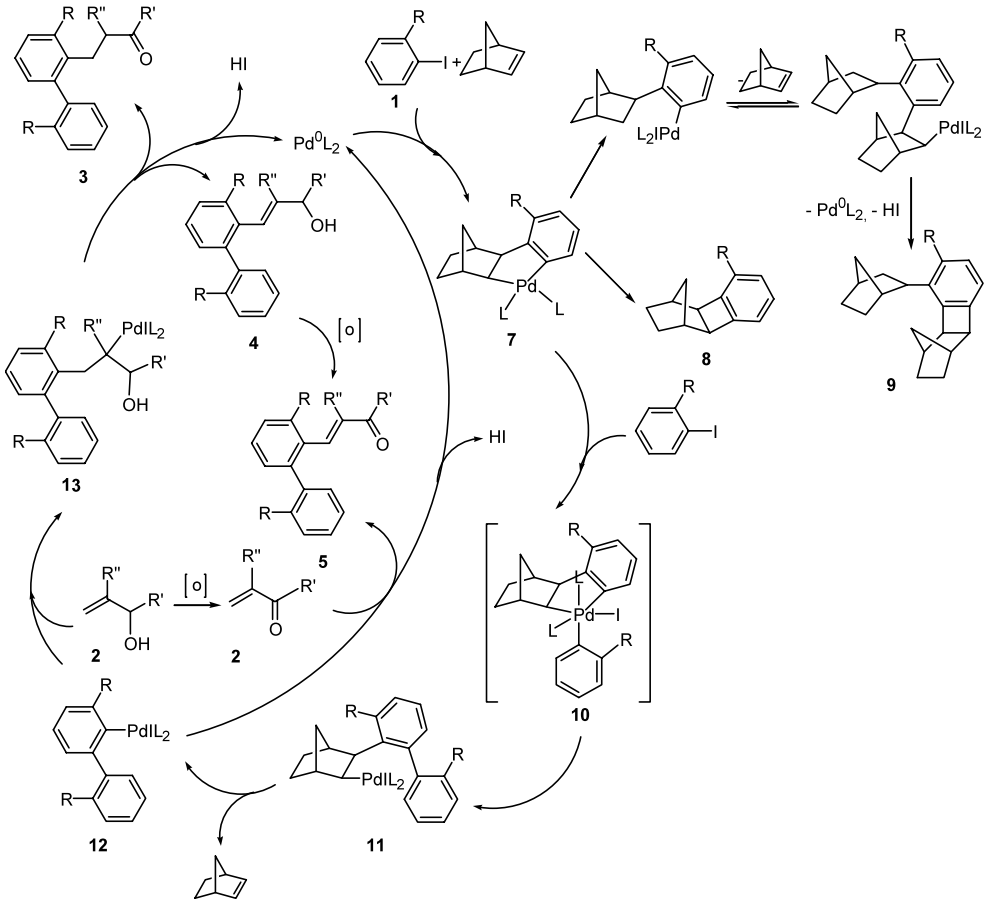
As shown in Table 1 satisfactory yields of **3** were obtained with **4** and **5** in a relatively low percentage except for entries k–m where the presence of a R″ = methyl group in **2** favours the formation of both the terminal and internal double bond conjugated with the phenyl ring. The best result was obtained using 3-buten-2-ol and the aryl iodide bearing the electron-withdrawing substituent CO_2Me (entry g). It should be pointed out, however, that the conditions adopted require to be adjusted for each case to obtain optimum yield values. For example the reaction of 2-propen-1-ol with *o*-iodotoluene nicely gives the aldehyde (entry a; **3a**: R = Me, R′, R″ = H) in 8 h. If the reaction is prolonged, other secondary reactions involving the aldehyde group occur, causing a decrease of yield. In another instance, when methyl *o*-iodobenzoate is reacted with 3-buten-2-ol for 24 h instead of 6 h (entry g), the corresponding biphenyl derivative (**3g**: R = CO_2Me, R′ = Me, R″ = H) is obtained in 67% yield together with 23% of product **6** (Eq. 4). As shown by a blank experiment, the latter derives from **3g** through the following transformation caused by the basic conditions (Eq. 4).



(4)

A general picture of the reaction course including isolated by-products is shown in Scheme 3 which also includes two additional by-products (**8** and **9**) formed to a low extent (1–9% yield) from a reaction not involving the allylic alcohol.

Descending, through **1** and **7**, the central sequence of Scheme 3 one finds a simplified picture of the previously mentioned (Schemes 1 and 2) reaction course. On the basis of the isolation of analogous alkylpalladium(IV) complex [14] a palladium(IV) species **10** is assumed to result from the oxidative addition of a second iodoarene molecule to the palladium(II) metallacycle. Reductive elimination from this intermediate leads to sp^2–sp^2 carbon–carbon coupling with formation of a palladium(II) complex **11** from which norbornene is expelled spontaneously owing to steric crowding [11]. The resulting biphenylylpalladium complex **12** now undergoes reaction with the allylic alcohol, leading to **13**. The latter species can eliminate H–Pd–I in two ways



Scheme 3.

depending on the chain site where C–H cleavage occurs [16]: compound **3** derives from hydrogen elimination from the carbon bearing the hydroxyl group with formation of the enolic form of a carbonyl group. Hydrogen elimination from the benzylic CH_2 leads to the unsaturated allylic alcohol **4**. Further oxidation of **4** would give **5** which, alternatively, could also be formed by reaction of the biphenylylpalladium complex **12** with compound **2′**, resulting in its turn by oxidation of the allylic alcohol **2** (Scheme 3) [17].

From the central sequence of Scheme 3 other secondary reactions depart, leading to compounds **8** and **9** according to well established pathways [14].

3. Conclusion

In conclusion we have worked out a complex one-pot reaction sequence which leads selectively to substituted biphenyl compounds containing a carbonyl chain. These are interesting materials from the pharmaceutical and specialty chemicals point of view.

4. Experimental

4.1. General

All reactions were carried out under an atmosphere of dinitrogen, using standard Schlenk techniques. Most chemicals were obtained commercially and used as received. 1-Phenyl-2-propen-1-ol [18] and 3-methyl-3-buten-2-ol [19] were prepared according to reported procedures. DMF was dried and stored over 4 Å molecular sieves under dinitrogen. Known compounds (**8** R = Me, OMe [15], Et, *i*-Pr [20], *n*-Pr [9c], naphthyl [21]; **9** R = Me, Et, *n*-Pr, *i*-Pr [9c]) were identified by comparison with the data reported in the literature. ^{1}H- and ^{13}C-NMR spectra were recorded in $CDCl_3$ at 20 °C using Bruker AC300 and AVANCE300 spectrometers at 300.1 and 75.4 MHz, respectively. All the chemical shifts values are given in ppm and are referenced with respect to residual protons in the solvent for ^{1}H spectra and to solvent signals for ^{13}C spectra. The assignment of NMR resonances is based on decoupling and 2D experiments; one or more asterisks (*) indicate interchangeable

assignments. EI and CI mass spectra were recorded using a Finnigan Mat SSQ 710 mass spectrometer. IR were recorded on a Perkin–Elmer 298 FT-IR spectrophotometer. Gas chromatography analyses were performed with a Carlo Erba HRGC 5300 instrument using a 30 m long SE-30 gas capillary column. Flash column chromatography was performed on Merck Kieselgel 60 and analytical TLC on Merck $60F_{254}$ plates.

4.2. General procedure

4.2.1. Reaction of o-substituted aryl iodides with allylic alcohols

A mixture of $Pd(OAc)_2$ (5 mg, 0.022 mmol), K_2CO_3 (250 mg, 1.80 mmol), the desired aryl iodide (1.80 mmol), 2-norbornene (43 mg, 0.45 mmol) and the allylic alcohol (1.00 mmol) in DMF (5 ml) under dinitrogen was heated at 105 °C with stirring for 6–72 h. The mixture was cooled to room temperature (r.t.), diluted with CH_2Cl_2 (20 ml) and extracted twice with a 5% solution of H_2SO_4 (2×15 ml). The organic layer was washed with water (20 ml) and dried over anhydrous Na_2SO_4. The crude was analysed by GC, GC–MS and TLC. Products were isolated by flash column chromatography using mixtures of hexane–EtOAc as the eluents. Unless when R = OMe, the unsaturated ketone **5** was eluted together with **3**. The mixture was hydrogenated and compound **5** was characterized as the corresponding saturated ketone **3**. The yield of **5** as well as those of by-products **8** and **9** were determined by GC analysis. Yield of **8** and **9** ranges from 1 to 9%. Hydrogenation was carried out in EtOAc under hydrogen at atmospheric pressure and at r.t. for 6–72 h in the presence of Pd/C.

4.2.2. 3,2′-Dimethyl-2-(3-oxopropyl)-1,1′-biphenyl (**3a**: *R = Me; R′, R″ = H*)

Yield 56%. M.p. (*n*-hexane) 42–43 °C; ^{1}H-NMR: δ 9.55 (1H, t, $J = 1.4$ Hz), 7.29–7.13 (5H, m), 7.13–7.08 (1H, m), 6.98–6.93 (1H, m), 2.93–2.80 (1H, m), 2.65–2.52 (1H, m), 2.46–2.35 (5H, m with a singlet at 2.38), 2.05 (3H, s); ^{13}C-NMR: δ 201.46, 141.69, 141.26, 136.38, 136.26, 135.65, 130.00, 129.61, 129.32, 127.65, 127.37, 126.06, 125.47, 43.51, 22.27, 20.07, 19.86; IR (KBr, cm^{-1}): *v* 1713; MS (EI, 70 eV): M^+ 238 (91), *m/z* 220 (100), 207 (42), 205 (57), 195 (42), 194 (32), 193 (33), 179 (94), 178 (67), 165 (70).

4.2.3. 3,2′-Dimethyl-2-(3-oxobutyl)-1,1′-biphenyl (**3b**: *R, R′ = Me; R″ = H*)

Yield 60%. M.p. (*n*-hexane) 53–54 °C; ^{1}H-NMR: δ 7.28–7.19 (3H, m, H3′, H4′, H5′), 7.19–7.13 (2H, m, H4, H5), 7.13–7.08 (1H, m, H6′), 6.97–6.91 (1H, m, H6), 2.86–2.74 (1H, m, CH(C2)), 2.55–2.41 (1H, m, CH(C2)), 2.40–2.32 (5H, m, CH_2CO, CH_3(C3) centred at 2.36), 2.04 (3H, s, CH_3(C2′)), 1.92 (3H, s, CH_3CO); ^{13}C-NMR: δ 208.06 (q), 141.66 (q), 141.37 (q), 136.89 (q), 136.28 (q), 135.71 (q), 129.96 (C3′), 129.53 (C4), 129.32 (C6′), 127.53 (C6), 127.31 (C4′), 125.89 (C5), 125.38 (C5′), 43.25 (CH_2CO), 29.38 (CH_3CO), 24.19 (CH_2(C2)), 20.10 (CH_3(C2′)), 19.81 (CH_3(C3)); IR (KBr, cm^{-1}): *v* 1716; MS (EI, 70 eV): M^+ 252 (7), *m/z* 234 (58), 219 (49), 195 (28), 194 (43), 193 (26), 180 (37), 179 (100), 178 (43), 165 (43).

4.2.4. 3,2′-Dimethyl-2-(3-hydroxybut-1-enyl)-1,1′-biphenyl (**4b**: *R, R′ = Me; R″ = H*)

Yield 4%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.23–7.14 (5H, m, H4′, H5, H3′, H4, H5′), 7.13–7.08 (1H, m, H6′), 7.06–7.00 (1H, m, H6), 6.33 (1H, d, $J = 16.1$ Hz, =CH(C2)), 5.33, 5.31 (1H, two overlapping dd, $J = 16.1$, 6.6, $J = 16.1$, 6.8 Hz, =C*H*CH(OH)), 4.15 (1H, br quint, $J = 6.4$ Hz, C*H*(OH)), 2.38 (3H, s, CH_3(C3)), 2.04, 2.03 (3H, two s, CH_3(C2′)), 1.13 (1H, br s, OH), 1.01, 1.00 (3H, two d, $J = 6.4$ Hz, CH_3CO); ^{13}C-NMR: δ 142.04, 142.02 (q), 140.95, 140.92 (q), 139.03, 138.98 (=*C*HCH(OH)), 136.05, 136.01 (q), 135.52, 135.41 (q), 135.26, 135.22 (q), 130.08, 129.99 (C6′), 129.68, 129.60 (C3′), 129.13 (C4), 127.64, 127.57 (C6), 126.98, 126.95 (C4′), 126.62, 126.60 (C5), 126.12, 125.97 (=CH(C2)), 125.35, 125.32 (C5′), 69.14, 68.95 (CH(OH)), 22.87, 22.81 (*C*H_3CH(OH)), 20.98 (CH_3(C3)), 20.08, 20.07 (CH_3(C2′)); MS (CI): M^+ 252.

4.2.5. 3,2′-Dimethyl-2-(3-oxobut-1-enyl)-1,1′-biphenyl (**5b**: *R, R′ = Me; R″ = H*)

Yield 8%. MS (EI, 70 eV): M^+ 250 (4), *m/z* 235 (13), 207 (100), 193 (23), 192 (68), 191 (28).

4.2.6. 3,2′-Diethyl-2-(3-oxobutyl)-1,1′-biphenyl (**3c**: *R = Et; R′ = Me; R″ = H*)

Yield 60%. ^{1}H-NMR: δ 7.34–7.27 (2H, m, H3′, H4′), 7.25–7.16 (3H, m, H5′, H5, H4), 7.14–7.07 (1H, m, H6′), 7.01–6.94 (1H, m, H6), 2.89–2.73 (1H, m, CH(C2)), 2.73–2.63 (2H, m, CH_2(C3)), 2.57–2.44 (1H, m, CH(C2)), 2.44–2.26 (4H, m, CH_2CO, CH_2(C2′)), 1.91 (3H, s, CH_3CO), 1.28 (3H, t, $J = 7.5$ Hz, CH_3CH_2(C3)), 1.07 (3H, t, $J = 7.5$ Hz, CH_3CH_2(C2′)); ^{13}C-NMR: δ 207.96 (q), 141.14 (q), 141.62 (q), 141.55 (q), 140.88 (q), 136.29 (q), 129.44 (C6′), 128.16 (C3′*), 127.66 (C6), 127.59 (C5), 127.50 (C4′*), 125.84 (C4), 125.22 (C5′), 44.13 (CH_2CO), 29.32 (CH_3CO), 26.15 (CH_2(C2′)), 25.76 (CH_2(C3)), 23.66 (CH_2(C2)), 15.53 (CH_3CH_2(C3)), 15.03 (CH_3CH_2(C2′)); IR (neat, cm^{-1}): *v* 1713; MS (EI, 70 eV): M^+ 280 (2), *m/z* 262 (44), 247 (25), 222 (23), 207 (37), 193 (100), 179 (47), 178 (48), 165 (38).

*4.2.7. 3,2′-Diethyl-2-(3-hydroxybut-1-enyl)-1,1′-biphenyl (**4c**: R = Et; R′ = Me; R″ = H)*

Yield 6%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.29–7.13 (5H, m), 7.11–7.03 (2H, m), 6.35 (1H, dd, $J = 16.1$, 1.0 Hz), 5.28, 5.27 (1H, two overlapping dd, $J = 16.1$, 6.6 Hz), 4.19–4.05 (1H, m), 2.72 (2H, q, $J = 7.5$ Hz), 2.46, 2.36 (2H, m), 1.57 (1H, br s, OH), 1.24 (3H, t, $J = 7.4$ Hz), 1.04 (3H, t, $J = 7.5$ Hz), 1.00, 0.99 (3H, 2d, $J = 6.4$ Hz); ^{13}C-NMR: δ 142.10, 142.05, 141.61, 141.60, 141.43, 141.36, 140.87, 140.85, 139.27, 139.21, 134.98, 134.93, 130.37, 130.33, 127.86, 127.78, 127.71, 127.24, 127.16, 127.13, 126.67, 126.00, 125.88, 125.19, 125.15, 69.11, 68.94, 26.82, 26.14, 26.12, 22.80, 22.77, 15.10, 14.81; MS (CI): M^+ 280.

*4.2.8. 3,2′-Diethyl-2-(3-oxobut-1-enyl)-1,1′-biphenyl (**5c**: R = Et; R′ = Me; R″ = H)*

Yield 6%. MS (EI, 70 eV): M^+ 278 (5), *m/z* 249 (54), 235 (100), 207 (43), 191 (57), 179 (80), 178 (44), 165 (28).

*4.2.9. 3,2′-Di-i-propyl-2-(3-oxobutyl-1,1′-biphenyl (**3d**: R = i-Pr; R′ = Me; R″ = H)*

Yield 61%. M.p. (*n*-hexane) 73–74 °C; ^{1}H-NMR: δ 7.39 (1H, dd, $J = 7.8$, 1.8 Hz, H3′), 7.34, 7.30 (2H, td, dd partly overlapping, H4′, H4), 7.22, 7.19 (2H, t, td partly overlapping, H5, H5′), 7.09 (1H, dd, $J = 7.5$, 1.4 Hz, H6′), 6.95 (1H, dd, $J = 7.3$, 1.5 Hz, H6), 3.12 (1H, hept, $J = 6.8$ Hz, CH(C3)), 2.92–2.80 (1H, m, CH(C2)), 2.65 (1H, hept, $J = 6.9$ Hz, CH(C2′)), 2.60–2.48 (1H, m, CH(C2)), 2.46–2.33 (2H, m, CH_2CO), 1.91 (3H, s, CH_3CO), 1.30, 1.28 (6H, 2d, $J = 6.8$ Hz, 2CH_3CH(C3)), 1.19 (3H, d, $J = 6.9$ Hz, CH_3CH(C2′)), 1.07 (3H, d, $J = 6.9$ Hz, CH_3CH(C2′)); ^{13}C-NMR: δ 207.92 (CO), 146.94 (C3*), 146.39 (C2′), 141.53 (C1*), 140.43 (C1′*), 135.53 (C2), 129.48 (C6′), 127.71 (C4′), 127.52 (C6), 125.86 (C5), 125.45 (C3′), 125.06 (C5′), 124.54 (C4), 44.72 (CH_2CO), 29.87 (CH(C2′)), 29.33 (CH_3CO), 28.95 (CH(C3)), 25.10 (CH_3CH(C2′)), 24.72 (CH_3CH(C3)), 24.03 (CH_3CH(C3)), 23.58 (CH_2(C2)), 22.89 (CH_3CH(C2′)); IR (KBr, cm^{-1}): *v* 1712; MS (EI, 70 eV): M^+ 308 (2), *m/z* 290 (18), 237 (33), 235 (30), 207 (100), 193 (29), 179 (33), 178 (27), 165 (25).

*4.2.10. 3,2′-Di-i-propyl-2-(3-hydroxybut-1-enyl)-1,1′-biphenyl (**4d**: R = i-Pr; R′ = Me; R″ = H)*

Yield 2%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.35–7.22 (4H, m, H3′, H4, H4′, H5), 7.18–7.10 (1H, m, H5′), 7.07–7.02 (2H, m, H6, H6′), 6.37 (1H, dd, $J = 16.1$, 0.8 Hz, =CH(C2)), 5.25 (1H, dd, $J = 16.1$, 6.7 Hz, =C*H*CH(OH)), 4.13 (1H, br quint, C*H*(OH)), 3.23, 3.22 (1H, two overlapping hept, $J = 6.8$ Hz, CH(C3)), 2.70 (1H, hept, $J = 6.9$ Hz, CH(C2′)), 1.55 (1H, brs, OH), 1.26, 1.23 (6H, two overlapping d, $J = 6.9$ Hz, (CH_3)$_2$CH(C3)), 1.16, 1.14 (3H, two overlapping d, $J = 6.9$ Hz, CH_3CH(C2′)), 1.05, 1.04 (3H, two overlapping d, $J = 6.8$ Hz, CH_3CH(C2′)), 0.98, 0.96 (3H, two overlapping d, $J = 6.3$ Hz, CH_3CH(OH)); ^{13}C-NMR: δ 146.66, 146.59 (q), 146.20, 146.18 (q), 141.11, 141.09 (q), 140.93, 140.90 (q), 139.71, 139.65 (=*C*HCH(OH)), 134.94, 134.89 (q), 130.43, 130.41 (C6′), 127.52, 127.46 (C6), 127.29, 127.26 (C4′), 126.66, 126.63 (C5), 126.52, 126.39 (=CH(C2)), 125.09, 124.99 (C3′*), 124.91, 124.84 (C5′), 123.81 (C4*), 68.98, 68.91 (CH(OH)), 29.80 (2*C*H(CH$_3$)$_2$), 25.08 (*C*H$_3$CH(C2′)), 23.76, 23.71, 23.64, 23.59 ((*C*H$_3$)$_2$CH(C3)), 22.79 (*C*H$_3$CH(C2′)), 22.69, 22.68 (*C*H$_3$CH(OH)); MS (CI): M^+ 308.

*4.2.11. 3,2′-Di-i-propyl-2-(3-oxobut-1-enyl)-1,1′-biphenyl (**5d**: R = i-Pr; R′ = Me; R″ = H)*

Yield 7%. MS (EI, 70 eV): M^+ 306 (4), *m/z* 263 (49), 221 (21), 179 (100).

*4.2.12. 1′-(3-Oxobutyl)-1,2′-binaphthyl (**3e**: R = –(–CH–)$_4$–; R′ = Me; R″ = H)*

Yield 75%. ^{1}H-NMR: δ 8.09–8.04 (1H, m, H8′), 7.99–7.90 (3H, m, H5′, H5, H4), 7.82 (1H, d, $J = 8.3$ Hz, H4′), 7.64–7.46 (4H, m, H7′, H6′, H3, H6), 7.45–7.31 (4H, m, H8, H2, H3′, H7), 3.30–3.19 (1H, m, CH(C1′)), 3.00–2.88 (1H, m, CH(C1′)), 2.70–2.49 (2H, m, CH_2CO), 1.88 (3H, s, CH_3CO); ^{13}C-NMR: δ 207.84 (CO), 139.62 (C1), 137.44 (C2′), 135.29 (C1′), 133.63 (C4a), 133.44 (C4′a), 132.25 (C8a), 131.60 (C8′a), 128.95 (C5′), 128.77 (C3′), 128.27 (C5), 127.78 (C4), 126.72 (C2), 126.61 (C7′), 126.35 (C4′), 126.10 (C8), 126.07 (C7), 125.91 (C6), 125.68 (C6′), 125.24 (C3), 123.95 (C8′), 44.71 (CH_2CO), 29.50 (CH_3CO), 23.65 (CH_2(C1′); IR (neat, cm^{-1}): *v* 1715; MS (EI, 70 eV): M^+ 324 (33), *m/z* 279 (20), 267 (57), 266 (62), 265 (100), 252 (45), 132 (28), 131 (21).

*4.2.13. 1′-(3-Hydroxybut-1-enyl)-1,2′-binaphthyl (**4e**: R = –(–CH–)$_4$–; R′ = Me; R″ = H)*

Yield 5%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 8.24–8.16 (1H, m), 7.98–7.84 (4H, m), 7.69–7.53 (3H, m), 7.52–7.31 (5H, m), 6.63–6.60 (2H, two partly overlapping dd, $J = 16.2$, 1.0 Hz), 5.55, 5.52 (2H, two partly overlapping dd, $J = 16.2$, 6.7 Hz), 4.14–3.98 (2H, m), 1.60 (1H, br s), 0.78, 0.76 (6H, two d, $J = 6.8$ Hz); ^{13}C-NMR: δ 140.24, 140.14, 140.03, 140.00, 136.63, 136.60, 133.99, 133.47, 133.44, 133.08, 133.05, 131.91, 131.85, 131.65, 131.60, 128.82, 128.34, 128.20, 128.14, 127.79, 127.73, 127.42, 127.05, 126.45, 126.36, 125.88, 125.83, 125.68, 125.65, 125.49, 125.47, 125.38, 125.22, 125.19, 68.97, 68.81, 22.54, 22.47; MS (CI): M^+ 324.

*4.2.14. 3,2′-Dimethoxy-2-(3-oxobutyl)-1,1′-biphenyl (**3f**: R = OMe; R′ = Me; R″ = H)*

Yield 62%. M.p. (*n*-hexane) 91-92 °C; ^{1}H NMR: δ 7.34 (1H, td, $J = 7.5$, 1.8 Hz, H4′), 7.23 (1H, dd, $J = 8.1$, 7.9 Hz, H5), 7.11 (1H, dd, $J = 7.4$, 1.8 Hz, H6′), 7.03–

6.92 (2H, m, H5′, H3′), 6.88 (1H, dd, $J = 8.2$, 1.0 Hz, H4), 6.79 (1H, dd, $J = 7.5$, 1.1 Hz, H6), 3.85 (3H, s, CH_3O(C3)), 3.74 (3H, s, CH_3O(C2′)), 2.83–2.70 (1H, m, CH(C2)), 2.70–2.58 (1H, m, CH(C2)), 2.58–2.50 (2H, m, CH_2CO), 2.00 (3H, s, CH_3CO); ^{13}C-NMR: δ 209.12 (CO), 157.33 (q), 156.37 (q), 139.71 (q), 130.94 (C6′), 130.07 (q), 128.73 (C4′), 128.14 (q), 126.55 (C5), 122.62 (C6), 120.34 (C5′), 110.58 (C3′), 109.26 (C4), 55.29 (CH_3O), 55.26 (CH_3O), 43.28 (CH_2CO), 29.40 (CH_3CO), 22.19 (CH_2(C2)); IR (KBr, cm^{-1}): ν 1712; MS (EI, 70 eV): M$^+$ 284 (65), *m/z* 227 (52), 226 (38), 214 (33), 212 (34), 211 (35), 210 (27), 209 (100), 195 (38), 165 (39).

*4.2.15. 3,2′-Dimethoxy-2-(3-hydroxybut-1-enyl)-1,1′-biphenyl (**4f**: R = OMe; R′ = Me; R″ = H)*

Yield 3%. ^{1}H-NMR: δ 7.32 (1H, ddd, $J = 8.2$, 7.5, 1.8 Hz, H4′), 7.25 (1H, dd, $J = 7.4$, 1.8 Hz, H6′), 6.99 (1H, td, $J = 7.4$, 1.0 Hz, H5′), 6.95–6.80 (3H, m, H3′, H4, H6), 6.40 (1H, d, $J = 16.1$ Hz, =CH(C2)), 5.93–5.77 (1H, br m, =C*H*CH(OH)), 4.18 (1H, br quint, $J = 6.5$ Hz, C*H*(OH)), 3.88 (3H, s, CH_3O(C3)), 3.74 (3H, s, CH_3O(C2′)), 1.60 (1H, br s, OH), 1.08 (3H, br d, $J = 6.1$ Hz, C*H*$_3$CH(OH)); ^{13}C-NMR: δ 157.37 (q), 156.24 (q), 139.44 (q), 137.61 (=*C*HCH(OH)), 131.30 (C6′), 130.62 (q), 128.84 (q), 128.60 (C4′), 127.50 (C5), 124.20 (=CH(C2)), 123.09 (C6), 120.42 (C5′), 110.69 (C3′), 109.68 (C4), 69.75 (CH(OH)), 55.42 (2 CH_3O), 22.97 (*C*H$_3$CH(H)); MS (CI): M$^+$ 284.

*4.2.16. 3,2′-Dimethoxy-2-(3-oxobut-1-enyl)-1,1′-biphenyl (**5f**: R = OMe; R′ = Me; R″ = H)*

Yield 8%. M.p. (*n*-hexane) 82–83 °C. ^{1}H-NMR: δ 7.42–7.30 (3H, m, H4′, H5, =CH(C2) centred at 7.35, $J = 16.5$ Hz), 7.16 (1H, dd, $J = 7.4$, 1.8 Hz, H6′), 7.03 (1H, td, $J = 7.4$, 1.0 Hz, H5′), 6.99–6.94 (2H, m, H3′, H4), 6.91 (1H, dd, $J = 7.5$, 1.1 Hz, H6), 6.78 (1H, d, $J =$ 16.5 Hz, =CHCO), 3.93 (3H, s, CH_3O(C3)), 3.72 (3H, s, CH_3O(C2′)), 2.10 (3H, s, CH_3CO); ^{13}C-NMR: δ 200.10 (CO), 158.96 (q), 156.27 (q), 141.89 (q), 139.93 (=CH(C2)), 131.24 (C6′), 130.90 (=CHCO), 130.25 (C5), 129.41 (C4′), 129.33 (q), 123.26 (C6), 122.19 (q), 120.66 (C5′), 110.80 (C3′), 110.13 (C4), 55.48 (CH_3O), 55.44 (CH_3O), 26.54 (CH_3CO); IR (KBr, cm^{-1}): ν 1680; MS (EI, 70 eV): M$^+$ 282 (3), *m/z* 251 (58), 239 (100), 224 (37), 165 (26), 152 (18).

*4.2.17. 3,2′-Dimethoxycarbonyl-2-(3-oxobutyl)-1,1′-biphenyl (**3g**: R = CO$_2$Me; R′ = Me; R″ = H)*

Yield 93%. M.p. (MeOH) 97–98 °C; ^{1}H-NMR: δ 8.00 (1H, dd, $J = 7.8$, 1.5 Hz, H3′), 7.87 (1H, dd, $J = 7.7$, 1.6 Hz, H4), 7.54 (1H, td, $J = 7.5$, 1.5 Hz, H5′), 7.44 (1H, td, $J = 7.6$, 1.5 Hz, H4′), 7.26 (1H, dd, $J = 7.8$, 7.5 Hz, H5), 7.23–7.15 (2H, m, H6′, H6), 3.88 (3H, s, CH_3O_2C(C3)), 3.61 (3H, s, CH_3O_2C(C2′)), 3.08–2.96 (1H, m, CH(C2)), 2.91–2.79 (1H, m, CH(C2)), 2.65–2.41 (2H, m, CH_2CO), 1.97 (3H, s, CH_3CO); ^{13}C-NMR: δ 207.90 (CO), 168.17 (CO), 167.10 (CO), 143.10 (q), 141.79 (q), 139.79 (q), 132.57 (C6), 131.66 (C5′), 131.03 (C6′), 130.48 (C3′), 130.08 (q), 129.91 (C4), 127.73 (C4′), 125.34 (C5), 52.06 (CH_3O_2C(C3)), 51.87 (CH_3O_2C(C2′)), 44.13 (CH_2CO), 29.41 (CH_3CO), 25.30 (CH_2(C2)); IR (KBr, cm^{-1}): ν 1718; MS (EI, 70 eV): M$^+$ 340 (2), *m/z* 235 (23), 234 (100), 233 (33), 207 (30), 179 (32), 178 (42), 165 (27).

*4.2.18. 2-(1-Oxoethyl)-4-(2′-methoxycarbonylphenyl)indan-1-one (**6**) (enolic form stabilized by H-bridge)*

^{1}H-NMR: δ 8.03 (1H, dd, $J = 7.7$, 1.5 Hz, H3′), 7.83 (1H, dd, $J = 7.6$, 1.1 Hz, H7), 7.61 (1H, td, $J = 7.5$, 1.5 Hz, H5′), 7.51 (1H, td, $J = 7.6$, 1.5 Hz, H4′), 7.47 (1H, t, $J = 7.5$ Hz, H6), 7.36 (1H, dd, $J = 7.5$, 1.2 Hz, H5), 7.31 (1H, dd, $J = 7.5$, 1.4 Hz, H6′), 3.59 (3H, s, CH_3O_2C(C2′)), 3.28 (2H, s, CH_2), 2.46 (1H, br s, OH), 2.07 (3H, s, CH_3CO); ^{13}C-NMR: δ 191.24 (*C*OCH$_3$), 177.69 (=COH), 167.59 (CO_2CH_3), 145.58 (q), 140.26 (q), 139.55 (q), 137.90 (q), 132.46 (C5), 131.93 (C5′), 130.62 (C6′), 130.48 (C3′), 130.07 (q), 127.96 (C4′), 127.31 (C6), 122.16 (C7), 110.61 (q, =CCOCH$_3$), 52.06 (CH_3O_2C(C2′)), 29.51 (CH_2), 21.06 (CH_3CO); MS (EI, 70 eV): M$^+$ 308 (10), *m/z* 234 (100), 233 (35), 207 (31), 179 (28), 178 (40), 165 (25).

*4.2.19. 3,2′-Dimethyl-2-(3-oxo-3-phenylpropyl)-1,1′-biphenyl (**3h**: R = Me; R′ = Ph; R″ = H)*

Yield 53%. M.p. (*n*-hexane) 48–49 °C; ^{1}H-NMR: δ 7.64–7.58 (2H, m, H2″, H6″), 7.56–7.48 (1H, m, H4″), 7.41–7.18 (8H, m, H3″, H5″, H4′, H5′, H3′, H6′, H4, H5), 7.05–7.00 (1H, m, H6), 3.07–2.68 (4H, m, –CH_2CH_2–), 2.47 (3H, s, CH_3(C3)), 2.12 (3H, s, CH_3(C2′)); ^{13}C-NMR: δ 199.44 (CO), 141.66 (q), 141.47 (q), 136.93 (q), 136.43 (q), 136.16 (q), 135.82 (q), 132.85 (C4″), 130.09 (C3′), 129.62 (C4), 129.42 (C6′), 128.47 (C3″, C5″), 128.04 (C2″, C6″), 127.55 (C6), 127.32 (C4′), 125.99 (C5), 125.58 (C5′), 38.70 (CH_2CO), 25.64 (CH_2(C2)), 20.11 (CH_3(C2′)), 19.84 (CH_3(C3)); IR (KBr, cm^{-1}): ν 1686 ; MS (EI, 70 eV): M$^+$ 314 (8), *m/z* 296 (18), 194 (63), 179 (69), 178 (28), 165 (27), 105 (100), 77 (41).

*4.2.20. 3,2′-Dimethyl-2-(3-hydroxy-3-phenylprop-1-enyl)-1,1′-biphenyl (**4h**: R = Me; R′ = Ph; R″ = H)*

Yield 4%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.31–6.99 (12H, m, aromatic protons), 6.47 (1H, dd, $J = 16.1$, 0.8 Hz, =CH(C2)), 5.53, 5.51 (1H, two dd, $J = 16.1$, 6.6, $J = 16.1$, 6.8 Hz, =C*H*CH(OH)), 5.07 (1H, br d, C*H*(OH)), 2.40, 2.39 (3H, s, CH_3(C3)), 1.98, 1.96 (3H, two s, CH_3(C2′)), 1.61 (1H, br s, OH); ^{13}C-NMR: δ 142.41, 142.39, 141.94, 141.90, 140.96, 140.91, 136.68, 136.59, 136.10, 136.03, 135.60, 135.43, 135.21, 135.16, 129.98, 129.87, 129.82, 129.72, 129.18,

129.16, 128.35, 127.95, 127.91, 127.69, 127.54, 127.43, 127.01, 126.95, 126.71, 126.11, 125.44, 125.38, 75.26, 75.03, 21.04, 20.06, 20.04; MS (CI): M^+ 314.

*4.2.21. 3,2′-Dimethyl-2-(3-oxo-3-phenylprop-1-enyl)-1,1′-biphenyl (**5h**: R = Me; R′ = Ph; R″ = H)*

Yield 7%. MS (EI, 70 eV): M^+ 312 (2), *m/z* 207 (100), 206 (46), 192 (77), 191 (29), 105 (42), 77 (37).

*4.2.22. 3,2′-Diethyl-2-(3-oxo-3-phenylpropyl)-1,1′-biphenyl (**3i**: R = Et; R′ = Ph; R″ = H)*

Yield 51%. ^{1}H-NMR: δ 7.60–7.54 (2H, m), 7.54–7.47 (1H, m), 7.42–7.30 (4H, m), 7.30–7.18 (4H, m), 7.06–6.99 (1H, m), 3.05–2.89 (2H, m), 2.89–2.65 (4H, m), 2.50–2.31 (2H, m), 1.32 (3H, t, $J = 7.5$ Hz), 1.09 (3H, t, $J = 7.5$ Hz); ^{13}C-NMR: δ 199.52, 142.34, 141.81, 141.59, 141.04, 136.39, 136.19, 132.86, 129.61, 128.48, 128.33, 128.05, 127.75, 127.55, 125.99, 125.48, 39.63, 26.19, 25.84, 25.13, 15.55, 15.06; IR (neat, cm^{-1}): *v* 1682; MS (EI, 70 eV): M^+ 342 (2), *m/z* 222 (64), 207 (34), 193 (100), 179 (39), 178 (39), 165 (28), 105 (44), 77 (39).

*4.2.23. 3,2′-Diethyl-2-(3-hydroxy-3-phenylprop-1-enyl)-1,1′-biphenyl (**4i**: R = Et; R′ = Ph; R″ = H)*

Yield 4%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.40–6.90 (12H, m, aromatic protons), 6.50, 6.49 (1H, two dd, $J = 16.1$, 1.1 Hz), 5.47, 5.46 (1H, two dd, $J = 16.1$, 6.7 Hz), 5.05 (1H, br d, $J = 6.7$ Hz)), 2.80–2.61 (2H, m), 2.40–2.22 (2H, m), 1.58 (1H, br s), 1.29–1.15 (3H, m), 0.98 (3H, t, $J = 7.4$ Hz); MS (CI): M^+ 342.

*4.2.24. 3,2′-Diethyl-2-(3-oxo-3-phenylprop-1-enyl)-1,1′-biphenyl (**5i**: R = Et; R′ = Ph; R″ = H)*

Yield 5%. M^+ 340 (1), *m/z* 207 (100), 206 (35), 192 (37), 105 (49), 77 (33).

*4.2.25. 3,2′-Di-i-propyl-2-(3-oxo-3-phenylpropyl)-1,1′-biphenyl (**3j**: R = i-Pr; R′ = Ph; R″ = H)*

Yield 62%. M.p. (*n*-hexane): 63–64 °C; ^{1}H-NMR: δ 7.61–7.56 (2H, m, H2″, H6″), 7.54–7.48 (1H, m, H4″), 7.46–7.41 (2H, m, H3′, H5′*), 7.40–7.32 (3H, m, H3″, H5″, H4), 7.32–7.19 (3H, m, H5, H4′*, H6′), 7.02 (1H, dd, $J = 7.3$, 1.5 Hz, H6), 3.27 (1H, hept, $J = 7.8$ Hz, CH(C3)), 3.11–2.99 (2H, m, CH(C2), CH(CO)), 2.93–2.65 (3H, m, CH(C2), CH(CO), CH(C2′) centred at 2.72), 1.36 (3H, d, $J = 6.8$ Hz, CH_3CH(C3)), 1.33 (3H, d, $J = 6.8$ Hz, CH_3CH(C3)), 1.19 (3H, d, $J = 6.8$ Hz, CH_3CH(C2′)), 1.11 (3H, d, $J = 6.8$ Hz, CH_3CH(C2′)); ^{13}C-NMR: δ 199.47 (CO), 147.07, 146.55, 141.55 (q), 140.55 (q), 136.15 (q), 135.61 (q), 132.86 (C4″), 129.65 (C6′), 128.48 (C3″, C5″), 128.04 (C2″, C6″), 127.74 (C5′*), 127.60 (C6), 126.00 (C5), 125.62 (C3′), 125.31 (C4′*), 124.66 (C4), 40.25 (CH_2CO), 29.92 (CH(C2′)), 28.94 (CH(C3)), 25.22 (CH$_3$CH(C2′)), 25.02 (CH_2(2)), 24.76 (CH$_3$CH(C3)), 24.03 (CH$_3$CH(C3)), 22.79 (CH$_3$CH(C2′)); IR (KBr, cm^{-1}): *v* 1685; MS (EI, 70 eV): M^+ 370 (5), *m/z* 250 (22), 237 (17), 235 (33), 207 (100), 193 (19), 179 (22), 178 (17), 165 (14), 105 (33), 77 (19).

*4.2.26. 3,2′-Di-i-propyl-2-(3-hydroxy-3-phenylprop-1-enyl)-1,1′-biphenyl (**4j**: R = i-Pr; R′ = Ph; R″ = H)*

Yield 3%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.33–7.25 (4H, m, H4′, H4, H3′, H5), 7.24–7.19 (3H, m, H4″, H3″, H5″), 7.18–7.09 (1H, m, H5′), 7.07–7.01 (2H, m, H6′, H6), 6.99–6.92 (2H, m, H2″, H6″), 6.54, 6.52 (1H, dd, $J = 16.0$, 1.0 Hz, =CH(C2)), 5.52–5.40 (1H, m, =CHCH(OH)), 5.10–5.03 (1H, br m, CH(OH)), 3.26, 3.25 (1H, hept, $J = 6.9$ Hz, CH(C3)), 2.69, 2.68 (1H, hept, $J = 6.9$ Hz, CH(C2′)), 1.60 (1H, br s, OH), 1.29–1.20 (6H, m, $(CH_3)_2$CH(C3)), 1.06, 1.04, 1.03, 0.99 (6H, d, $J = 6.9$ Hz, $(CH_3)_2$CH(C2′)); ^{13}C-NMR: δ 146.74, 146.65 (C3), 146.19 (C2′), 142.28, 142.25 (C1″), 141.02 (C1′), 140.83, 140.80 (C1), 137.19, 137.13 (=CH(CHOH)), 134.89, 134.84 (C2), 130.34, 130.32 (C6′), 128.48, 128.46 (=CH(C2)), 128.33 (C3″, C5″), 127.58, 127.50 (C6), 127.38, 127.36 (C4″), 127.32, 127.27 (C4′), 127.73, 126.67 (C5), 126.22, 126.18 (C2″, C6″), 125.32, 125.18 (C3′), 125.07, 125.00 (C5′), 123.81 (C4), 74.98, 74.82 (CHOH), 29.84, 29.81, 29.76 (CH(C3), CH(C2′)), 25.06 (CH_3CH(C2′)), 23.80, 23.75, 23.64, 23.57 ((CH_3)$_2$CH(C3)), 22.69 ((CH_3)$_2$CH(C2′); MS (CI): M^+ 370.

*4.2.27. 3,2′-Di-i-propyl -2-(3-oxo-3-phenylprop-1-enyl)-1,1′-biphenyl (**5j**: R = i-Pr; R′ = Ph; R″ = H)*

Yield 6%. MS (EI, 70 eV): M^+ 368 (2), *m/z* 207 (100), 206 (31), 193 (39), 105 (47).

*4.2.28. 3,2′-Dimethyl-2-(2-methyl-3-oxobutyl)-1,1′-biphenyl (**3k**: R = Me; R′, R″ = Me)*

Yield 33%. A 1:1 mixture of two stereoisomers. ^{1}H-NMR: δ 7.29–7.12 (12H, m), 7.00–6.92 (2H, m), 3.04–2.95 (1H, m), 2.71–2.51 (2H, m), 2.51–2.32 (9H, m with two s at 2.39, 2.37), 2.06, 2.05 (6H, two s), 1.75, 1.65 (6H, two s), 0.86, 0.80 (6H, two d, $J = 6.7$ Hz); ^{13}C-NMR: δ 212.23, 212.21, 141.96, 141.91, 141.55, 141.48, 137.13, 137.11, 135.99, 135.91, 135.78, 135.57, 130.09, 130.07, 130.03, 129.79, 129.66, 128.03, 127.90, 127.33, 127.28, 126.11, 126.02, 125.55, 125.45, 47.36, 46.63, 32.13, 32.01, 28.04, 27.99, 20.74, 20.65, 20.11, 19.92, 14.94, 14.87; IR (neat, cm^{-1}): *v* 1712; MS (EI, 70 eV): M^+ 266 (4), *m/z* 248 (55), 233 (61), 195 (100), 180 (62), 179 (78), 178 (50), 165 (72).

*4.2.29. 3,2′-Di-i-propyl-2-(2-methyl-3-oxobutyl)-1,1′-biphenyl (**3l**: R = i-Pr; R′, R″ = Me)*

Yield 36%. A 1:1 mixture of two stereoisomers indicated as A and B. ^{1}H-NMR: δ 7.43–7.28 (6H, m, H3′, H4′, H4 (A,B)), 7.28–7.19 (4H, m, H5, H5′ (A, B)), 7.16, 7.11 (2H, two dd, $J = 7.5$, 1.5 Hz, H6′ (A, B)), 6.98, 6.96 (2H, two partly overlapping dd, $J = 7.3$, 1.6 Hz, H6

(A, B)), 3.33–3.16 (2H, m, CH(C3) (A, B)), 3.05–2.96 (1H, m, CH(C2), A), 2.74–2.55 (4H, m, CH_2(C2) B, CH(C2) A, CH(C2′) A), 2.54–2.39 (3H, m, CH(CH_3) (A, B), CH(C2′) B), 1.74, 1.60 (6H, two s, CH_3CO (A, B)), 1.33, 1.28, 1.23, 1.19 (12H, four d, $J = 6.8$ Hz, CH_3CH(C3) (A, B)), 1.24, 1.20, 1.07, 1.01 (12H, four d, $J = 6.8$ Hz, CH_3CH(C2′) (A, B)), 0.87, 0.79 (6H, two d, $J = 6.7$ Hz, CH_3CH (A, B)); ^{13}C-NMR: δ 212.11, 212.05 (CO), 147.85, 147.81 (C3), 146.71, 146.32 (C2′), 141.82, 141.73 (C1), 140.60, 140.47 (C1′), 134.24, 134.16 (C2), 130.23, 129.95 (C6′), 127.94, 127.89 (C6), 127.79, 127.69 (C4′), 126.25, 126.05 (C5), 125.47, 125.45 (C3′), 125.24, 125.18 (C5′), 124.55, 124.42 (C4), 47.39, 46.96 ($CHCH_3$), 31.00, 30.82 (CH_2(C2)), 29.92, 29.87 (CHC(2′)), 29.16, 29.11 (CH(C3)), 28.18, 28.00 (CH_3CO), 25.61, 25.52, 24.47, 22.51 ((CH_3)$_2$CH(C2′)), 25.26, 23.92, 22.97, 22.47 ((CH_3)$_2$CH(C3)), 14.55, 14.43 (CH_3CH); IR (neat, cm^{-1}): 1714 v; MS (EI, 70 eV): M$^+$ 322 (3), *m/z* 235 (40), 207 (100), 193 (33), 179 (27), 178 (29), 167 (65), 165 (28).

*4.2.30. 3,2′-Dimethoxycarbonyl-2-(2-methyl-3-oxobutyl)-1,1′-biphenyl (**3m**: R = CO_2Me; R′, R″ = Me)*

Yield 54%. A 1:1 mixture of two stereoisomers indicated as A and B. ^{1}H-NMR: δ 8.02, 7.99 (2H, two dd, $J = 7.8$, 1.5 Hz, H3′ (A, B)), 7.81, 7.79 (2H, two dd, $J = 7.6$, 1.7 Hz, H4 (A, B)), 7.55 (2H, td, $J = 7.5$, 1.5 Hz, H5′ (A, B)), 7.45 (2H, td, $J = 7.6$, 1.5 Hz, H4′ (A, B)), 7.31, 7.17 (6H, m, H6′, H5, H6 (A, B)), 3.90, 3.89 (6H, two s, CH_3O_2C(C3) (A, B)), 3.61, 3.60 (6H, two s, CH_3O_2C(C2′) (A, B)), 3.39 (1H, dd, $J = 13.5$, 4.4 Hz, CH(C2) A), 3.10 (1H, dd, $J = 13.8$, 6.6 Hz, CH(C2) B), 2.99 (1H, dd, $J = 13.8$, 7.5 Hz, CH(C2) B), 2.71 (1H, dd, $J = 13.5$, 9.7 Hz, CH(C2) A), 2.57–2.42 (2H, m, CH(CH_3) (A, B)), 1.87, 1.78 (6H, two s, CH_3CO (A, B)), 0.79, 0.73 (6H, two d, $J = 6.9$ Hz, CH_3(CH) (A, B)); ^{13}C-NMR: δ 201.67, 201.56 (CO), 168.90, 168.77 (CH_3O_2C(C3)), 167.22, 167.18 (CH_3O_2C(C2′)), 143.19, 143.00 (C1), 141.84, 141.76 (C1′), 138.20, 138.09 (C2), 132.92, 132.73 (C6), 131.74, 131.44 (C6′), 131.61 (C5′), 131.34, 131.13 (C3), 130.49, 130.40 (C3′), 130.39, 130.11 (C2′), 129.65, 129.61 (C4), 127.69, 127.66 (C4′), 125.51, 125.43 (C5), 52.09 (CH_3O_2C(C3)), 51.86 (CH_3O_2C(C2′)), 47.80, 47.59 (CH(CH_3)), 32.51, 32.04 (CH_2(C2)), 28.03, 27.79 (CH_3CO), 15.73, 14.96 (CH_3CH); MS (EI, 70 eV): M$^+$ 354 (12), *m/z* 280 (23), 279 (23), 248 (100), 247 (50), 219 (39), 207 (25), 191 (32), 178 (22), 165 (45).

4.2.31. Reaction of o-iodotoluene with 3-buten-2-ol in the presence of Ag_2CO_3

The reaction was carried out according to the general procedure using Ag_2CO_3 (498 mg, 1.80 mmol) in place of K_2CO_3. 4-(2-Methylphenyl)-3-buten-2-ol was obtained in 82% yield.

^{1}H-NMR: δ 7.46–7.42 (1H, m), 7.20–7.12 (3H, m), 6.78 (1H, dd, $J = 15.8$, 1.0 Hz), 6.15 (1H, dd, $J = 15.8$, 6.4 Hz), 4.51 (1H, quint d, $J = 6.4$, 1.1 Hz), 2.35 (3H, s), 1.60 (1H, br s), 1.39 (3H, d, $J = 6.4$ Hz); ^{13}C-NMR: δ 135.7, 135.5, 134.9, 130.3, 127.5, 127.2, 126.1, 125.6, 69.2, 23.5, 19.8; MS (CI): M$^+$ 162.

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