Synthesis of New Cardanol and Cardol Derivatives by Allylation and Regioselective Cyclocarbonylation Reactions

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Received 28 August 2002

Abstract: Palladium acetate [$Pd(OAc)_2$] and 1,4-bis(diphenylphosphino)butane (dppb) catalyse cyclocarbonylation of allylic cardanol and cardol derivatives to give regioselectively 7-membered ring lactones in good yields. One of the compounds prepared exhibits excellent antioxidant properties.

Key words: allylations, carbonylations, cardanol, cardol, lactones, palladium

The chemistry of renewable organic raw materials for the production of new commercial materials is of topical importance and deserves the attention both of academic and industrial research. Industrial grade cardanol, as a yellow oil, is obtained by vacuum distillation of pollutant, dark, tar-like, and partially polymerised 'cashew nut shell liquid' (CNSL), the international name of the alkyl phenolic oil contained in the spongy mesocarp of the cashew nut shell (*Anacardium occidentale* L.). This oil derives as by-product from the most diffused roasted mechanical processes of the cashew industry in view of the high edible value of the kernels.[1,2] CNSL represents nearly 25% of the total nut weight and its world-wide production (Africa, Asia, and South America being the main producer areas) is estimated to be about 300 000 tons per year. Therefore, CNSL represents an alternative, sustainable, low-cost, and largely available natural resource. Indeed, the distilled cardanol is mainly a mixture of 3-*n*-pentadecylphenol (**1**) in which the aliphatic side-chain may be saturated, mono-olefinic (8), di-olefinic (8, 11), and tri-olefinic (8, 11, 14), with an average value of two double bonds per molecule, together with a minor amount of cardol (3-*n*-pentadecylresorcinol) and methyl cardol (2-methyl-5-*n*-pentadecylresorcinol). Hydrogenation of the double bonds in the side-chain of distilled cardanol leads to 3-*n*-pentadecylphenol (**1**) of good industrial grade.

In previous papers, some of us reported the synthesis and industrial utilizations of cardanol derivatives as fine chemicals and intermediates, additives for lubricants and diesel engine fuels, pour-point depressants, antioxidants and stabilizers, flame retardants, resins, inks, and hydrorepellents.[3]

Our interest for the cyclocarbonylation reactions, mainly devoted to the synthesis of lactones and lactams, prompted us to examine the possibility to obtain new allylated and cyclocarbonylated cardanol and cardol derivatives as suitable precursors for the production of fine chemicals (anti-oxidants, polymeric precursors, etc.) by regioselective cyclocarbonylation process catalysed by the $Pd(OAc)_2$-1,4-bis(diphenylphosphino)butane (dppb) system.

Previously some of us showed that 2-allylphenol in toluene can undergo cyclocarbonylation reaction in the presence of the homogeneous catalytic system $Pd(OAc)_2$–dppb and $CO–H_2$ (1:1) to produce the seven membered ring lactone as the major product.[4,5]

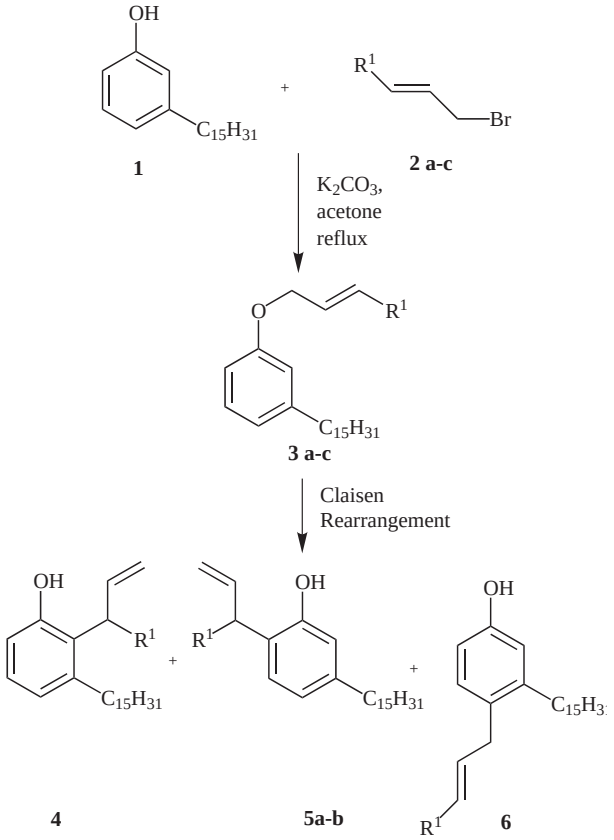
When the same reaction is carried out in dichloromethane the five-membered ring lactone was the main product of the reaction. Now, we report here that the cyclocarbonylation of some allylic cardanol and cardol derivatives occurs under relatively mild conditions, in high yields, affording the seven membered ring lactone as the major product.[4]

3-*n*-Pentadecylphenol (**1**) in acetone reacted with allylic bromides **2a**–**c** in the presence of potassium carbonate to give the allylic derivatives **3a**–**c** and then compounds **4**,**5a**,**b**,**6** by means of Claisen rearrangement. When 3-*n*-pentadecylphenol (**1**) was reacted with allyl bromide (**2a**) a mixture of two isomers **4** and **5a** was formed in equimolar amounts. In the reaction with 1-bromo-2-butene (**2b**), selective formation of product **5b** was observed, whereas in the reaction of 3-*n*-pentadecylphenol (**1**) with cinnamyl bromide (**2c**) the sole formation of pure product **6** was observed (Scheme 1).

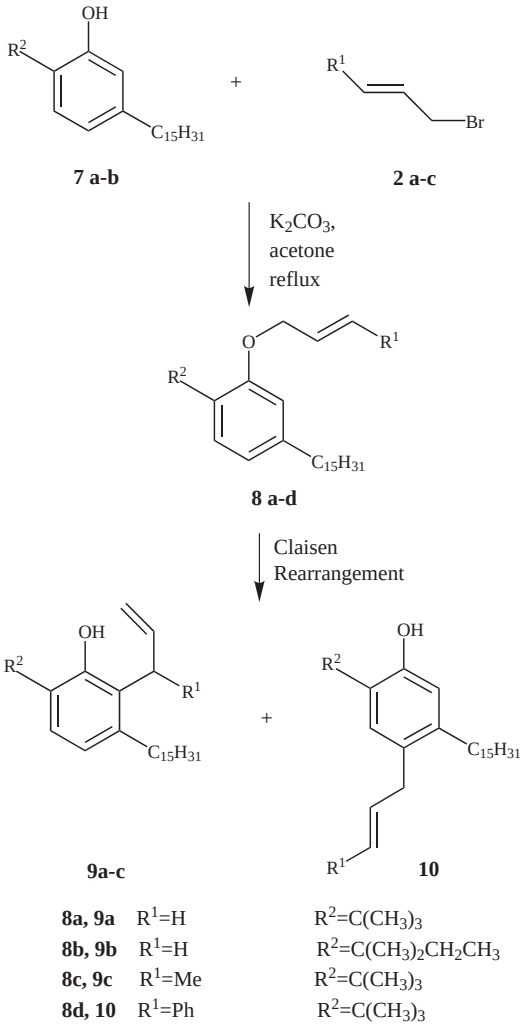
2-*tert*-Butyl-5-*n*-pentadecylphenol (**7a**) and the 2-*tert*-amyl-5-*n*-pentadecylphenol (**7b**) gave the same reaction with allylic bromides **2a**–**c** with formation of the ethers **8a**–**d**. Then these compounds were treated under Claisen conditions affording only pure compounds **9a**–**c** and **10**. In the case of the reaction of 2-*tert*-butyl-5-*n*-pentadecylphenol (**7a**) with cinnamyl bromide (**2c**) only *para* substituted phenol derivative **10** was formed, presumably due to the steric hindrance (Scheme 2).

Synthesis 2002, No. 18, Print: 19 12 2002.
Art Id.1437-210X,E;2002,0,18,2749,2755,ftx,en;P04502SS.pdf.

ISSN 0039-7881



Scheme 1



Scheme 2

Allylpentadecylphenol derivatives **4** and **5a**, as a mixture, underwent cyclocarbonylation reactions to give the cyclocarbonylated compounds **11** and **12** (Scheme 3, path a). The same allylphenol derivatives **4** and **5a** reacted again with allyl bromide to form the ethers mixture **13** and **14** and after Claisen rearrangement the bis-allylpentadecylphenol **15**.

Cyclocarbonylation reaction of **15** gave a mixture of two compounds impossible to separate by chromatography, but GC–MS analysis showed the same molecular weight and similar fragmentation pattern and could be ascribed to two isomeric seven-membered, cyclocarbonylated compounds **16** and **17** (Scheme 3, path b).

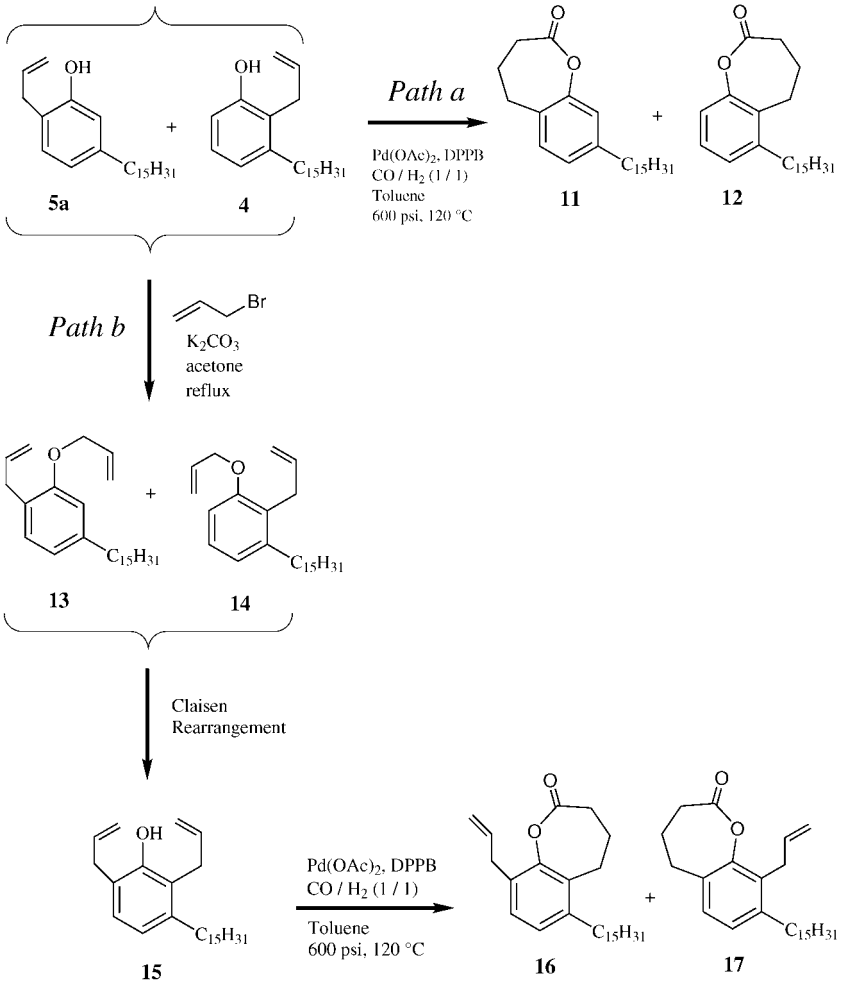
2-*tert*-Butyl-6-allyl-5-*n*-pentadecylphenol (**9a**) and 2-*tert*-amyl-6-allyl-5-*n*-pentadecylphenol (**9b**) were reacted in toluene in the presence of the same catalytic system and afforded the cyclocarbonylated compounds **18a**,**b**, respectively (Scheme 4).

No influence at all was observed due to the presence of a bulky substituent in the *ortho* position of the phenolic hydroxyl. Recently, we also investigated the double-carbonylation reactions of bis-allyl derivatives of cardol using the homogeneous catalytic system Pd $(OAc)_2$–dppb under relatively mild conditions, for the preparation of various bis-lactones.[6] As an extension of the double-carbonylation reactions previously reported, we applied analogous reactions to 5-*n*-pentadecylresorcinol (**19**) showing two phenolic OHs in *meta* positions of the benzene ring.

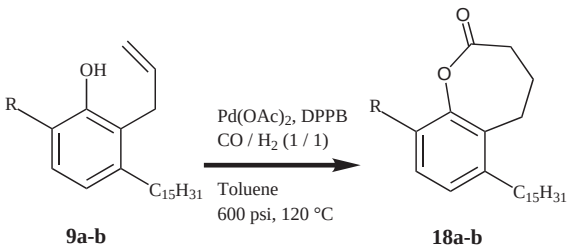
5-*n*-Pentadecylresorcinol (**19**) reacted with two equivalents of allyl bromide (**2a**) to afford symmetric diallyl ether **20** that gave double Claisen rearrangment to resorcinol derivative **21**. This last compound was then treated with the homogeneous catalytic system Pd $(OAc)_2$–dppb and $CO–H_2$ (1:1) and the corresponding bis-lactone **22** was formed (Scheme 5).

In agreement with our previous paper,[7] we determined by kinetic measurements (inhibition rate constants k_{inh} $M^{-1}s^{-1}$) the antioxidant properties of some allylic derivatives (**9a**,**c**) in comparison both with other cardanol derivatives and commercial antioxidants (Table 1).

As can be seen, 3-*n*-pentadecylphenol (hydrogenated cardanol) **1** exhibits an antioxidant activity similar to those of **23** and **25** (Irganox 1076, Anox PP 18) . As expected, the introduction of a *tert*-butyl group in the *ortho* position to the hydroxy function of **1** determines a higher antioxidant



Scheme 3

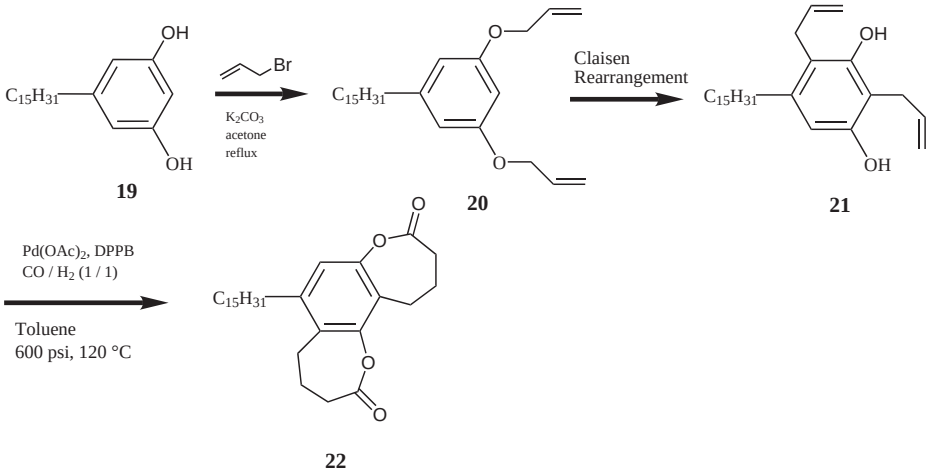


Scheme 4

Table 1 Inhibition Rate Constants for Some Cardanol Derivatives And Commercial Antioxidants

Item	Compound	$k_{inh}/10^4$
23	2,6-di-*tert*-butyl-4-methylphenol (BHT)[7]	2.6
24	2,6-di-*tert*-butyl-4-methoxyphenol (DB-HA)[7]	14
25	octadecyl-3-(3,5-di-*tert*-butyl-4-hydroxy-phenyl)propionate	1.5
1	3-*n*-pentadecylphenol[7]	1.6
7a	2-*tert*-butyl-5-*n*-pentadecylphenol[7]	3.2
9a	2-allyl-3-*n*-pentadecyl-6-*tert*-butylphenol	1.7
9c	2-(1-methylallyl)-3-*n*-pentadecyl-6-*tert*-butylphenol	8.7

activity of **7a** due to the steric hindrance of the *tert*-butyl group. The introduction of the allylic group in the second *ortho* position of **7a** does not increase the antioxidant activity of **9a** probably due to the modest steric hindrance of the allyl group, while the introduction of the 1-methylallyl group in the same position remarkably enhances the antioxidant activity of **9c** in respect to that of the starting compound **7a**. Due the low volatility, phenolic antioxidants with long alkyl side-chains are very important in the antioxidative stabilization of some polymers because of the high temperatures at which the reticulation process is carried out (ca. 300 °C). It is noteworthy that **9c** shows an inhibition rate constant appreciably higher than that of the commercial product **25**, largely used for the stabilization of polymeric materials.[8,9]



Scheme 5

In conclusion, the palladium acetate–dppb system catalyses the cyclocarbonylation of allyl derivatives of 3-*n*-pentadecylphenol and 3-*n*-pentadecylresorcinol, in the reported reaction conditions, to give selectively 7-membered ring lactones in relatively good yields. We have described the preparation of various representative examples of ethers and relevant Claisen rearrangment products, as well as cyclocarbonylation reactions applied to cardanol and cardol derivatives to mark the increasing importance attached to the production of new organic materials starting from renewable organic resources. In addition, the compound **9c** showed an interesting antioxidant activity promising for practical utilization.

Most chemicals were used as obtained from commercial sources. $Pd(OAc)_2$ and dppb are commercially available while allylphenol derivatives were prepared according to literature procedures.[6] Toluene was dried and distilled from sodium under nitrogen. Mps were taken on an electro thermal apparatus. ^1H and ^{13}C NMR spectra were recorded on a Bruker AC-200 or NMR Varian 400 at r.t. and chemical shifts are reported relative to Me_4Si. IR and MS spectra were performed, respectively, on a Jasco FTIR instrument and a Hewlett-Packard GC/Mass MSD 5971 instrument. Petroleum ether refers to the fraction with bp 40–60 °C.

Cyclocarbonylation Reactions; General Procedure

Palladium acetate (0.01 mmol) and dppb (0.04 mmol) were dissolved in anhyd toluene (5 mL) and the allyl phenol derivative (1 mmol) was added. The autoclave was purged three times with CO and pressurised with CO and H_2. The reaction mixture was heated with stirring for 24 h at 100 °C (oil bath temperature). The reaction mixture was cooled to r.t., the solution was concentrated, and the residue was extracted with Et_2O. The lactones were purified by chromatography (petroleum ether and Et_2O).

1-Allyloxy-3-*n*-pentadecylbenzene (3a)

Yield: 95%; oil.

IR (neat): 3026, 2921, 1600, 1584 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.5 Hz, 3 H, CH_3), 1.15–1.60 (m, 26 H, CH_2), 2.57 (t, *J* = 7.5 Hz, 2 H, $ArCH_2$), 4.50–4.55 (m, 2 H, OCH_2), 5.24–5.47 (m, 2 H, $=CH_2$), 5.97–6.17 (m, 1 H, CH=C), 6.69–6.79 (m, 3 H, Ar), 7.13–7.22 (m, 1 H, Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.12, 22.70, 29.32, 29.36, 29.52, 29.51, 29.70, 31.36, 31.92, 36.01, 68.68, 111.57, 115.01, 117.51, 121.03, 129.10, 133.47, 144.62, 158.58.

EIMS: *m*/*z* (%) = 344 (M^+, 19), 161 (12), 148 (100), 147 (46), 133 (44), 107 (35), 91 (16), 57 (9), 43 (23), 41 (32).

Anal. Calcd for $C_{24}H_{40}O$ (344.57): C, 83.66; H, 11.70. Found: C, 83.75; H, 11.71.

1-But-2-enyloxy-3-*n*-pentadecylbenzene (3b)

Yield: 90%; oil

IR (neat): 3028, 2944, 1665, 1621 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.98 (t, *J* = 6.9 Hz, 3 H, CH_3), 1.29 (s, 26 H, CH_2), 1.78 (d, *J* = 6.2 Hz, 3 H, CH_3), 2.58 (t, *J* = 7.8 Hz, 2 H, $ArCH_2$), 4.48 (d, *J* = 5.8 Hz, 2 H, OCH_2), 5.85 (m, 1 H, =CH), 6.07 (m, 1 H, =CH), 6.69–6.75 (m, 3 H, Ar), 7.15–7.25 (m, 1 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.25, 18.48, 23.72, 29.78, 29.82, 30.26, 30.45, 30.90, 32.25, 34.13, 120.75, 126.80, 131.65, 135.65, 142.01, 155.62.

EIMS: *m*/*z* (%) = 358 (M^+, 13), 357 (70), 217 (52), 203 (100).

Anal. Calcd for $C_{25}H_{42}O$ (358.61): C, 83.73; H, 11.81. Found: C, 83.61; H, 11.65.

1-*n*-Pentadecyl-3-(3-phenylallyloxy)benzene (3c)

Yield: 87%; oil.

IR (neat): 3029, 2930, 1612, 1582 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.89 (t, *J* = 7.2 Hz, 3 H, CH_3), 1.15–1.68 (m, 26 H, CH_2), 2.60 (t, *J* = 7.6 Hz, 2 H, $ArCH_2$), 4.70 (d, *J* = 6.0 Hz, 2 H, OCH_2), 6.44 (d, *J* = 16.0 Hz, 1 H, =CH), 6.75 (d, *J* = 16.0 Hz, 1 H, =CH), 6.78–6.90 (m, 3 H, Ar), 7.13–7.22 (m, 1 H, Ar), 7.25–7.55 (m, 5 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.36, 22.94, 29.61, 29.77, 29.83, 29.94, 31.62, 32.17, 36.28, 68.76, 111.87, 115.34, 121.36, 124.91, 126.81, 128.14, 128.81, 129.41, 133.13, 136.77, 144.93, 158.89.

EIMS: *m*/*z* (%) = 420 (M^+, 5), 368 (23), 285 (14), 257 (51), 236 (70), 185 (100).

Anal. Calcd for $C_{30}H_{44}O$ (420.68): C, 85.65; H, 10.54. Found: C, 85.48; H, 10.49.

2-Allyl-3-*n*-pentadecylphenol (4)
Yield: 50%; white solid; mp: 63–65 °C.

IR (neat): 3341, 3075, 2954, 1636, 1580 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.5 Hz, 3 H, CH_3), 1.11–1.75 (m, 26 H, CH_2), 2.60 (t, *J* = 7.7 Hz, 2 H, $ArCH_2$), 3.47–3.40 (m, 2 H, $ArCH_2$-allyl), 4.91 (br s, 1 H), 4.99–5.12 (m, 2 H, $=CH_2$), 5.89–6.09 (m, 1 H, CH=C), 6.66 (d, *J* = 7.7 Hz, 1 H, Ar), 6.77 (d, *J* = 7.7 Hz, 1 H, Ar), 7.04 (t, *J* = 7.7Hz, 1 H, Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.12, 22.70, 29.36, 29.52, 29.60, 29.66, 29.69, 30.33, 31.31, 31.93, 33.38, 113.40, 115.67, 122.07, 123.21, 127.11, 136.27, 142.81, 154.30.

EIMS: *m*/*z* (%) = 344 (M^+, 29), 161(11), 149(12), 148(100).

Anal. Calcd for $C_{24}H_{40}O$ (344.57): C, 83.66; H, 11.70. Found: C, 83.64; H, 11.60.

2-Allyl-5-*n*-pentadecylphenol (5a)
Yield: 50%; white solid; mp: 68–70 °C.

IR (neat): 3308, 3055, 2953, 2914, 1637, 1575 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 6.5 Hz, 3 H, CH_3), 1.00–1.70 (m, 26 H, CH_2), 2.52 (t, *J* = 7.2 Hz, 2 H, $ArCH_2$), 3.37 (d, *J* = 6.4 Hz, 2 H, Ar), 4.94 (br s, 1 H, OH, D_2O exch.), 5.04–5.21 (m, 2 H, $C=CH_2$), 5.90–6.11 (m, 1 H, CH=C), 6.63 (d, *J* = 1.5 Hz, 1 H, Ar), 6.70 (dd, *J* = 1.5, 7.6 Hz, 1 H, Ar), 6.99 (d, *J* = 7.6 Hz, 1 H, Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ =14.10, 22.69, 29.33, 29.36, 29.51, 29.60, 29.65, 29.67, 31.34, 31.92, 34.86, 35.5, 115.79, 116.26, 120.98, 122.26, 130.12, 136.67, 143.11, 153.90.

EIMS: *m*/*z* (%) = 344 (M^+, 37), 189 (3), 161(10), 149 (12), 148 (100).

Anal. Calcd for $C_{24}H_{40}O$ (344.57): C, 83.66; H, 11.70. Found: C, 83.69; H, 11.60.

2-(1-Methylallyl)-5-*n*-pentadecylphenol (5b)
Yield: 82%; white solid; mp: 46–48 °C.

IR (nujol): 3521, 3024, 2925, 1618, 1595 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 6.8 Hz, 3 H, CH_3), 1.30 (m, 26 H, CH_2), 1.41 (d, *J* = 6.8 Hz, 3 H, CH_3), 2.68 (t, *J* = 7.6 Hz, 2 H, $ArCH_2$), 3.90 (m, 1 H, CH), 5.27 (dd, *J* = 10.0, 1.2 Hz, 1 H, ArCH), 5.31 (dd, 1 H, *J* = 16.0, 1.2 Hz, 1 H, =CH), 5.87 (br s, 1 H, OH, D_2O exch.), 6.23 (ddd, *J* = 16.0, 10.0, 5.6 Hz, 1 H, =CH), 6.77 (d, *J* = 1.6 Hz, 1 H, Ar), 6.89 (dd, *J* = 7.6, 1.6 Hz, 1 H, Ar), 7.21(d, *J* = 7.6 Hz, 1 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.56, 19.36, 23.19, 29.92, 30.16, 30.25, 31.81, 32.46, 35.97, 37.28, 113.99, 116.42, 121.34, 127.99, 128.34, 142.77, 143.11, 153.70.

EIMS: *m*/*z* (%) = 358 (M^+, 29), 345 (5), 318 (3), 238 (5), 175 (11), 162 (100).

Anal. Calcd for $C_{25}H_{42}O$ (358.61): C, 83.73; H, 11.81. Found: C, 83.57; H, 11.64.

3-*n*-Pentadecyl-4-(3-phenylallyl)phenol (6)
Yield: 81%; white solid; mp: 62–64 °C.

IR (nujol): 3345, 2924, 1611, 1591 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.97 (t, *J* = 6.9 Hz, 3 H, CH_3), 1.41 (s, 26 H, CH_2), 2.65 (t, *J* = 7.7, 2 H, $ArCH_2$), 3.55 (d, *J* = 4.8 Hz, 2 H, $ArCH_2$), 5.50 (br s, 1 H, OH, D_2O exch), 6.35–6.46 (m, 2 H, =CH), 6.70 (dd, *J* = 8.0, 2.4 Hz, 1 H, Ar), 6.75 (d, *J* = 2.4 Hz, 1 H, Ar), 7.11 (d, *J* = 8.0 Hz, 1 H, Ar), 7.21–7.42 (m, 5 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.43, 23.09, 27.24, 29.72, 29.92, 30.05, 30.26, 31.28, 32.27, 33.24, 35.82, 113.16, 116.38, 126.36, 127.27, 128.76, 128.86, 130.01, 130.86, 131.07, 137.91, 143.02, 154.23.

EIMS: *m*/*z* (%) = 420 (M^+, 26), 316 (18), 223 (31), 209 (100).

Anal. Calcd for $C_{30}H_{44}O$ (420.68): C, 85,65; H, 10.54. Found: C, 85.48; H, 11.62.

2-Allyloxy-1-*tert*-butyl-4-*n*-pentadecylbenzene (8a)
Yield 80%; oil.

IR (neat): (3035, 2926, 1632,1595) cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.98 (t, *J* = 6.9 Hz, 3 H, CH_3), 1.0–1.70 [m, 26 H, CH_2, and 9 H, $C(CH_3)_3$], 2.54 (t, *J* = 6.7 Hz, 2 H, $ArCH_2$), 4.80–4.85 (m, 2 H, OCH_2), 5.25–5.40 (m, 2 H, $=CH_2$), 5.96–6.18 (m, 1 H, CH=C), 6.65–6.70 (m, 2 H), 7.17 (d, *J* = 8.0 Hz, 1 H Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.12, 22.70, 29.36, 29.49, 29.54, 29.61, 29.66, 29.70, 29.84, 31.40, 31.92, 34.52, 35.66, 68.78, 112.81, 116.80, 120.17, 126.40, 133.75, 135.47, 141.81, 157.25.

EIMS: *m*/*z* (%) = 400 (M^+, 20), 386 (30), 385 (100).

Anal. Calcd for $C_{28}H_{48}O$ (400.68): C, 83.93; H, 12.07. Found: C, 83.48; H, 11.82.

2-Allyloxy-1-(1,1-dimethylpropyl)-4-*n*-pentadecylbenzene (8b)
Yield 78%; oil.

IR (neat): 3035, 2926, 1632,1595 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.66 (t, *J* = 7.6 Hz, 3 H, CH_3) , 0,92 (t, *J* = 6.8 Hz, 3 H, CH_3), 1.23–1.43 (m, 30 H, CH_2), 1.57–1.66 (m, 2 H), 1.87 (q, *J* = 7.5 Hz, 2 H, CH_2), 2.59 (t, *J* = 7.5 Hz, 2 H, CH_2), 4.57–4.61 (m, 2 H, OCH_2), 5.28–5.32 (m, 1 H, =CH), 5.44–5.50 (m, 1 H, =CH), 6.08–6.16 (m, 1 H, =CH), 6.70 (d, *J* = 1.6 Hz, 1 H, Ar), 6.75 (dd, *J* = 1.6, 7.5 Hz, 1 H, Ar), 7.15 (d, *J* = 7.5 Hz, 1 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 9.58, 14.11, 22.69, 27.93, 29.37, 29.47, 29.55, 29.62, 29.67, 29.70, 29.87, 31.34, 31.93, 33.25, 35.66, 38.12, 68.89, 112.78, 116.74, 120.15, 127.4, 133.78, 133.85, 141.68, 157.28.

EIMS: *m*/*z* (%) = 414 (M^+, 5), 385 (100).

Anal. Calcd for $C_{28}H_{48}O$ (414.71): C, 83.99; H,12.15; Found: C, 83.90; H, 12.10.

2-But-2-enyloxy-1-*tert*-butyl-4-*n*-pentadecylbenzene (8c)
Yield: 77%; oil

IR (neat): 3035, 2926, 1632,1595 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.99 (t, *J* = 6.8 Hz, 3 H, CH_3), 1.48 [s, 9 H, $C(CH_3)_3$], 1.35–1.75 (m, 26 H, CH_2), 1.81 (d, *J* = 6.0 Hz, 3 H, CH_3), 2.64 (t, *J* = 7.8 Hz, 2 H, $ArCH_2$), 4.58 (d, *J* = 5.5 Hz, 2 H, OCH_2), 5.48–6.0 (m, 2 H, =CH), 6.70 (s, 1 H, Ar), 6.79 (d, *J* = 8.0 Hz, 1 H, Ar), 7.26 (d, *J* = 8.0 Hz, 1 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.58, 18.36, 23.16, 29.82, 30.15, 30.28, 31.86, 32.37, 34.93, 69.02, 113.09, 120.19, 126.56, 126.88, 129.11, 135.64, 141.89, 157.57.

EIMS: *m*/*z* (%) = 414 (M^+, 15), 399 (15), 360 (28), 345 (100).

Anal. Calcd for $C_{29}H_{50}O$ (414.72): C, 83.99; H, 12.15. Found: C, 85.47; H, 10.81.

1-*tert*-Butyl-4-*n*-pentadecyl-2-(3-phenylallyloxy)benzene (8d)
Yield: 79%; oil.

IR (neat): 3030, 2930, 1613, 1569 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.99 (t, *J* = 6.9 Hz, 3 H, CH_3), 1.37 (s, 26 H, CH_2), 1.52 [s, 9 H, $C(CH_3)_3$], 2.67 (t, *J* = 6.7 Hz, 2 H, $ArCH_2$), 4.82 (d, *J* = 5.4 Hz, 2 H, OCH_2), 6.55 (dt, *J* = 16, 5.4 Hz, 1

H, =CH), 6.83 (d, *J* = 7.6 Hz, 1 H, Ar), 6.84 (s, 1 H, Ar), 6.86 (d, *J* = 16 Hz, 1 H, =CH), 7.29 (d, *J* = 7.6 Hz, 1 H, Ar), 7.34 (d, *J* = 7.2 Hz, 1 H, Ar), 7.42 (t, *J* = 7.2 Hz, 2 H, Ar), 7.51 (d, *J* = 7.2 Hz, 2 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.66, 23.24, 29.91, 30.23, 30.43, 31.94, 32.45, 35.04, 69.09, 113.19, 120,55, 125.34, 126.64, 126.76, 128.04, 128.76, 132.48, 135.78, 136.90, 142.05, 157.54.

EIMS: *m*/*z* (%) = 476 (M^+, 22), 461 (11), 425 (16), 384 (18), 369 (55), 345 (39), 161 (50), 147 (100).

Anal. Calcd for $C_{34}H_{52}O$ (476.79): C, 85.65; H, 10.99. Found: C, 85.47; H, 10.83.

2-Allyl-6-*tert*-butyl-3-*n*-pentadecylphenol (9a)
Yield: 80%; oil.

IR (neat): 3345, 3030, 2930, 1613, 1591 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): 0.95 (t, *J* = 6.9 Hz, 3 H, CH_3), 1.00–1.16 (m, 26 H, CH_2), 1.48 [s, 9 H, $C(CH_3)_3$], 2.56 (t, *J* = 6.7 Hz, 2 H, $ArCH_2$), 3.42–3.45 (m, 2 H, $ArCH_2$), 5.18–5.20 (m, 2 H, $=CH_2$), 5.98–6.07 (m, 1 H, =CH), 7.09 (d, *J* = 5.5 Hz, 1 H, Ar), 7.12 (d, *J* = 5.5 Hz, 1 H, Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.12, 22.70, 29.37, 29.52, 29.60, 29.67, 29.69, 29.73, 29.78, 30.91, 31.32, 31.93, 33.68, 34.40, 116.65, 121.27, 123.07, 124.78, 134.33, 136.12, 139.83, 153.66.

EIMS: *m*/*z* (%) = 400 (M^+, 20), 386 (24), 385 (81), 203 (19) 189 (56), 161 (35), 147 (49), 57 (100).

Anal. Calcd for $C_{28}H_{48}O$ (400.68): C, 83.93; H, 12.07. Found: C, 83.47; H, 11.93.

2-Allyl-6-(1,1-dimethylpropyl)-3-*n*-pentadecylphenol (9b)
Yield: 85%; oil.

IR (neat): 3350, 3028, 2930, 1610, 1590 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.07 (d, *J* = 8.0 Hz, 1 H), 6.75 (d, *J* = 8.0 Hz, 1 H), 6.10–6.00 (m, 1 H), 5.23–5.11 (m, 3 H), 3.47 (d, *J* = 5.5 Hz, 2 H), 2.58 (t, *J* = 7.8 Hz, 2 H); 1.88 (quar, *J* = 7.5 Hz, 2 H), 1.56 (quint, *J* = 7.5 Hz, 2 H), 1.48–1.29 (m, 30 H), 0.92 (t, *J* = 6.7 Hz, 3 H), 0.69 (t, *J* = 7.5 Hz, 3 H).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 9.56, 14.01, 22.69, 27.89, 29.37, 29.52, 29.60, 29.66, 29.69, 29.72, 29.79, 30.85, 31.25, 31.93, 33.36, 33.66, 38.81, 116.44, 121.19, 122.85, 126.12, 132.53, 136.08, 139.77, 153.52.

EIMS: *m*/*z* (%) = 414 (M^+, 5), 386 (30), 385 (100).

Anal. Calcd for $C_{28}H_{48}O$ (414.71): C, 83.99; H,12.15. Found: C, 83.99; H, 12.15.

6-*tert*-Butyl-2-(1-methylallyl)-3-*n*-pentadecylphenol (9c)
Yield: 76%; white solid; mp 55–57 °C.

IR (nujol): 3533, 2956, 1649, 1612 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.96 (t, *J* = 6.8 Hz, 3 H,CH_3), 1.33 (s, 26 H, CH_2), 1.44 [s, 9 H, $C(CH_3)_3$], 1.52 (d, *J* = 6.9Hz, 3 H, CH_3), 2.62 (t, *J* = 7.5 Hz, 2 H, CH_2), 3.94 (dq, *J* = 6.8, 4.4 Hz, 1 H, ArCH), 5.46 (dd, *J* = 10.4, 2.4 Hz, 1 H, =CH), 5.48 (dd, *J* = 17.2, 2.4 Hz, 1 H, =CH), 5.78 (br s, 1 H, OH, D_2O exch.), 6.36 (ddd, *J* = 17.2, 10.4, 4.4 Hz, 1 H, =CH), 6.75 (d, *J* = 8.0 Hz, 1 H, Ar), 7.15 (d, *J* = 8.0 Hz, 1 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.41, 16.29, 22.99, 29.68, 29.83, 29.91, 30.01, 32.09, 32.24, 34.56, 35.81, 116.03, 121.59, 125.20, 127.91, 135.72, 139.40, 142.79, 154.81.

EIMS: *m*/*z* (%) = 414 (M^+, 58), 399 (100), 357 (45), 345 (18).

Anal. Calcd for $C_{29}H_{50}O$ (414.79): C, 83.99; H, 12.15. Found: C, 83.82; H, 11.79.

2-*tert*-Butyl-5-*n*-pentadecyl-4-(3-phenylallyl)phenol (10)
Yield: 85%; white solid; mp: 66–68 °C.

IR (nujol): 3510, 2925, 1653, 1599 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.15 (t, *J* = 7.0 Hz, 3 H, CH_3), 1.40 (s, 26 H, CH_2), 1.57 [s, 9 H, $C(CH_3)_3$], 2.67 (t, *J* = 7.8 Hz, 2 H, $ArCH_2$), 3.61 (d, *J* = 5.2 Hz, 2 H, $ArCH_2$), 4.72 (br s, 1 H, OH, D_2O exch), 6.41–6.55 (m, 2 H, =CH), 6.56 (s, 1 H, Ar), 7.21 (s, 1 H, Ar), 7.30 (d, *J* = 8.0 Hz, 1 H, Ar), 7.39 (t, *J* = 8.0 Hz, 2 H, Ar), 7.45 (d, *J* = 8.0 Hz, 2 H, Ar).

^{13}C NMR (100.64 MHz, $CDCl_3$): δ = 14.45, 23.08, 27.29, 29.77, 29.99, 30.09, 30.23, 31.35, 32.32, 32.61, 34.53, 36.41, 117.69, 126.40, 127.21, 128.76, 128.81, 129.60, 130.43, 130.64, 133.86, 138.09, 140.12, 152.82.

EIMS: *m*/*z* (%) = 476 (M^+, 27), 425 (30), 423 (33), 369 (31), 345 (100).

Anal. Calcd for $C_{34}H_{52}O$ (476.79): C, 85.65; H,10.99. Found: C, 85.60; H, 10.84.

8-*n*-Pentadecyl-4,5-dihydro-3*H*-benzo[*b*]oxepin-2-one (11)
Yield: 95%; white solid; mp 64–65 °C.

IR (neat): 3055, 2918, 2851, 1770 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.08 (d, *J* = 7.6 Hz, 1 H), 6.96 (dd, *J* = 1.5, 7.6 Hz, 1 H), 6.90 (d, *J* = 1.5 Hz, 1 H), 2.78 (t, *J* = 7.2 Hz, 2 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 2.47 (t, *J* = 7.2 Hz, 2 H), 2.16 (quint, *J* = 7.2 Hz, 2 H), 1.16–1.43 (m, 2 H), 1.40–1.15 (m, 24 H), 0.87 (t, *J* = 6.6 Hz, 3 H).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.10, 22.68, 29.30, 29.35, 29.50, 29.58, 29.65, 29.66, 29.69, 31.09, 31.78, 35.24, 125.11, 126.86, 128.02, 128.83, 143.46, 151.53, 171.61.

EIMS: *m*/*z* (%) = 372 (37), 317 (10), 176 (12), 175 (15), 121 (100).

Anal. Calcd for $C_{25}H_{40}O_2$ (372.58): C, 80.59; H, 10.82. Found: C, 85.60; H, 10.84.

6-*n*-Pentadecyl-4,5-dihydro-3*H*-benzo[*b*]oxepin-2-one (12)
Yield: 95%; white solid; mp 31–33 °C.

IR (neat): 3050, 2923, 2855, 1770, 1606, 1577 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.16 (t, *J* = 7.7 Hz, 1 H), 7.03 (d, *J* = 7.7 Hz, 1 H), 6.93 (d, *J* = 7.7 Hz, 1 H), 2.84 (t, *J* = 7.1 Hz, 2 H), 2.63 (t, *J* = 7.5 Hz, 2 H), 2.45 (t, *J* = 7.1 Hz, 2 H), 2.14 (quint, *J* = 7.1 Hz, 2 H), 1.65–1.15 (m, 26 H), 0.87 (t, *J* = 6.5 Hz, 3 H).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.09, 22.65, 23.32, 26.23, 29.32, 29.46, 29.53, 29.60, 29.63, 29.66, 31.08, 31.73, 31.89, 33.34, 117.04, 127.02, 127.29, 128.05, 141.81, 152.25, 171.78.

EIMS: *m*/*z* (%) = 372 (24), 344 (4), 317 (2), 199 (6), 176 (93), 175 (12), 147 (21), 121 (100).

Anal. Calcd for $C_{25}H_{40}O_2$ (372.58): C, 80.59; H, 10.82. Found: C, 85.60; H, 10.84.

9-*tert*-Butyl-6-*n*-pentadecyl-4,5-dihydro-3*H*-benzo[*b*]oxepin-2-one (18a)
Yield: 90%; oil.

IR (neat): 3050, 2923, 2855, 1770, 1606, 1577 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 6.5 Hz, 3 H). 1.00–1.60 [m, 35 H, 26 H CH_2, and 9 H $C(CH_3)_3$], 2.08 (quint, *J* = 7.0 Hz, 2 H), 2.39 (t, *J* = 7.0 Hz, 2 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 2.82 (t, *J* = 7.0 Hz, 2 H), 6.97 (d, *J* = 8.1 Hz, 1 H), 7.17 (d, *J* = 8.1 Hz, 1 H).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 13.10, 14.29, 20.99, 21.96, 22.73, 26.08, 28.28, 28.64, 28.99, 29.29, 29.53, 30.17, 30.91, 31.78, 32.10, 32.35, 33.20, 33.54, 36.08, 118.06, 123.44,125.57, 128.99, 134.74, 138.34, 137.43, 149.78, 170.96.

EIMS: *m*/*z* (%) = 428 (M^+, 25), 413 (100), 57(90), 121 (24), 135 (15), 161 (21), 177 (17), 203 (17).

Anal. Calcd for $C_{29}H_{48}O_2$ (428,69): C, 81.25; H, 11.29. Found: C, 81.25; H, 11.29.

9-(1,1-Dimethylpropyl)-6-*n*-pentadecyl-4,5-dihydro-3*H*-benzo[*b*]oxepin-2-one (18b)
Yield: 90%; oil.

IR (neat): 3019, 2924, 2854, 1761, 1456 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.64 (t, *J* = 7.5 Hz, 3 H) , 0.87 (t, *J* = 6.5 Hz, 3 H), 1.00–1.60 (m, 34 H), 2.08 (quint, *J* = 7.0 Hz, 2 H), 2.39 (t, *J* = 7.0 Hz, 2 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 2.82 (t, *J* = 7.0 Hz, 2 H), 6.97 (d, *J* = 8.2 Hz, 1 H), 7.12 (d, *J* = 8.2 Hz, 1 H).

^{13}C NMR ($CDCl_3$): δ = 9.93, 14.54, 15.69, 23.11, 23.94, 26.35, 28.52, 29.78, 29.91, 29.99, 30.07, 30.08, 30.10, 31.50, 32.02, 32.33, 33.55, 34.22, 38.43, 120.0 , 126.87, 129.15, 136.39, 139.74, 151.10, 172.38

EIMS: *m*/*z* (%) = 442 (M^+, 3) , 413 (100), 203 (82).

Anal. Calcd for $C_{30}H_{50}O_2$ (442.72): C, 81.39; H, 11.38. Found: C, 80.90; H, 10.99.

1,3-Bisallyloxy-5-*n*-pentadecylbenzene (20)
Yield: 80%; white solid; mp 48–52 °C.

IR (neat): 2923, 2852, 1594, 1457 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.90 (t, *J* = 6.8 Hz, 3 H, CH_3), 1.10–1.45 (m, 24 H), 1.48–1.67 (m, 2 H, CH_2), 2.56 (t, *J* = 7.5 Hz, 2 H), 4.41–4.58 (m, 4 H, 2 OCH_2), 5.15–5.42 (m, 4 H, $=CH_2$), 5.90–6.20 (m, 2 H, 2 CH=C), 6.22–6.38 (m, 3 H, Ar).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.09, 14.11, 22.68, 29.31, 29.35, 29.51, 29.58, 29.68, 31.21, 31.89, 31.92, 36.26, 68.77, 98.98, 107.44, 117.58, 133.36, 145.33, 159.57.

EIMS: *m*/*z* (%) = 400 (M^+, 12), 217, (18), 204 (100), 203 (63).

Anal. Calcd for $C_{27}H_{44}O_2$ (400.64): C, 80.94; H, 11.07. Found: C, 80.60; H, 10.99.

2,4-Diallyl-5-*n*-pentadecylbenzene-1,3-diol (21)
Yield: 70%; oil.

IR (neat): 3543, 2921, 2851, 1506, 1465 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.91 (t, *J* = 6.7 Hz, 3 H, CH_3), 1.02–1.46 (m, 24 H, CH_2), 1.50–1.70 (m, 2 H, CH_2), 2.58 (t, *J* = 7.9 Hz, 2 H), 3.39–3.60 (m, 4 H, $ArCH_2$), 4.95–5.30 (m, 5 H, OH, $=CH_2$), 5.97–6.10 (m, 2 H, CH=C), 6.30 (s, 1 H, OH).

EIMS: *m*/*z* (%) = 400 (M^+, 15), 217, (22), 204 (42), 203 (69), 201(25), 189 (100), 177 (57), 175 (73), 163 (94), 162 (88), 161 (84), 147 (31), 91 (15), 43 (44), 41 (27).

Anal. Calcd for $C_{27}H_{44}O_2$ (400.64): C, 80.94; H, 11.07. Found: C, 80.60; H, 10.99.

6-*n*-Pentadecyl-4,5,11,12-tetrahydro-3*H*,10*H*-1,8-dioxabenzo(1,2,3,4)dicycloheptene-2,9-dione (22)
Yield: 90%; oil.

IR (neat): 2921, 2851, 1765, 1591, 1454, 1407 cm^{-1}.

^1H NMR (200 MHz, $CDCl_3$): δ = 0.87 (t, *J* = 6.5 Hz, 3 H, CH_3), 1.05–1.67 (m, 26 H, CH_2), 2.00–2.92 (m, 14 H), 6.83 (s, 1 H).

^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 14.08, 22.65, 23.48, 23.97, 25.62, 26.06, 26.18, 26.28, 29.32, 29.42, 29.44, 29.51, 29.61, 29.65, 29.90, 31.03, 31.23, 31.36, 31.88, 31.99, 33.14, 118, 108, 133, 140.72, 150.72, 151.01, 171.18, 171.25.

EIMS: *m*/*z* (%) = 456 (M^+, 8), 260 (11), 205 (100).

Anal. Calcd for $C_{27}H_{44}O_2$ (456.66): C, 76.27; H, 9.71. Found: C, 76.20; H, 10.00.

Acknowledgement

This work was supported by financial assistance from the Consiglio Nazionale delle Ricerche (C.N.R.-Roma), the Ministero dell'Istruzione dell'Università e della Ricerca (M.I.U.R.-Roma), Consorzio I.N.C.A. (Venezia), the Università degli Studi di Lecce and the Università degli Studi di Urbino.

References

(1) (a) Tyman, J. H. P. *Synthetic and Natural Phenols*; Elsevier: Amsterdam, **1996**. (b) Tyman, J. H. P. *Chem. Soc. Rev.* **1979**, *8*, 499; and references cited therein.
(2) (a) Attanasi, O. A.; Buratti, S.; Filippone, P. *Chim. Ind. (Milano)* **1996**, *78*, 693. (b) Attanasi, O. A. *Chem. Today* **1983**, 11.
(3) (a) Attanasi, O. A.; Filippone, P.; Grossi, M. Ital. Patent 48737 A/85, **1985**. (b) Attanasi, O. A.; Filippone, P.; Grossi, M. Ital. Patent 47920 A/86, **1986**. (c) Attanasi, O. A.; Filippone, P.; Grossi, M. *Phosph. Sulf. Relat. Elem.* **1988**, *35*, 63. (d) Attanasi, O. A.; Filippone, P.; Balducci, S. *Gazz. Chim. Ital.* **1991**, *121*, 487. (e) Attanasi, O. A.; Filippone, P. Ital. Patent RM93A000605, **1993**. (f) Attanasi, O. A.; Buratti, S.; Filippone, P. *Org. Prep. Proced. Int.* **1995**, *27*, 645. (g) Attanasi, O. A.; Filippone, P. Ital. Patent PS95A000021, **1995**. (h) Coletta, M.; Filippone, P.; Fiorucci, C.; Marini, S.; Mincione, E.; Neri, V.; Saladino, R. *J. Chem Soc., Perkin Trans. 1* **2000**, 581. (i) Filippone, P.; Neri, V.; Mincione, E.; Saladino, R. *Tetrahedron*, in press.
(4) El-Ali, B.; Okuro, K.; Vasapollo, G.; Alper, H. *J. Am. Chem. Soc.* **1996**, *118*, 4264.
(5) Troisi, L.; Vasapollo, G.; El-Ali, B.; Mele, G.; Florio, S.; Capriati, V. *Tetrahedron Lett.* **1999**, *40*, 1771.
(6) Vasapollo, G.; Scarpa, A.; Mele, G.; Ronzini, L.; El-Ali, B. *Appl. Organomet. Chem.* **2000**, *14*, 739.
(7) Amorati, R.; Pedulli, G. F.; Valgimigli, L.; Attanasi, O. A.; Filippone, P.; Fiorucci, C.; Saladino, R. *J. Chem. Soc., Perkin Trans. 2* **2001**, 2142.
(8) Shlyapnikov, Yu. A.; Kiryushkin, S. G.; Mar'in, A. P. *Antioxidative Stabilization of Polymers*; Taylor & Francis: London, **1996**.
(9) Neri, C. *Chim. Ind. (Milano)* **1997**, *79*, 1223.