Synthesis of Benzannulated Spiroketals Using an Oxidative Radical Cyclization

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Abstract: The synthesis of both mono and bisbenzannulated spiroketals using an oxidative radical cyclization approach is investigated. Although unsuccessful in uncovering a novel route toward bisbenzannulated spiroketals, the oxidative radical cyclization does facilitate a new approach to monobenzannulated spiroketals such as those found in berkelic acid and in the chaetoquadrins.

Key words: spiroketals, berkelic acid, chaetoquadrin, radical cyclization, cross-metathesis

Spiroketals are a common structural element in several natural products of medicinal and environmental importance.[1] One such set of compounds, the rubromycins (Figure 1), are a class of natural antibiotics that display a broad range of biological activity[2] including inhibition of human telomerase as exemplified by β-rubromycin (**2**) and γ-rubromycin (**3**) (IC_{50} 3.06 ± 0.85 μM and 2.64 ± 0.09 μM, respectively). Intriguingly, α-rubromycin (**1**), derived from ring-opening of the spiroketal core of β-rubromycin (**2**), exhibits much lower inhibition of telomerase (IC_{50} >200 μM) than other members of the family, implying that the bisbenzannulated spiroketal core is an essential structural unit for inhibition of telomerase.[3] Structurally related to the rubromycins is heliquinomycin (**4**), an inhibitor of DNA helicase.[4]

Upon initial consideration, the acid-catalyzed cyclization of a diphenolic precursor appears to offer a straightforward route toward the synthesis of the bisbenzannulated spiroketal core of the aforementioned rubromycin family of antibiotics **2**–**4**. However, difficulties in executing this classical spirocyclization protocol have been reported by numerous research groups[5] during synthetic efforts toward this family of natural products. The reasons for these difficulties were ascertained through a series of detailed model studies by Kozlowski[5b] and Reißig,[5c] who showed independently that the presence of the electron-withdrawing moieties on the isocoumarin fragment significantly reduce the nucleophilicity of the phenolic hydroxy group, a key factor in hindering the key spiroketalization step, and hence formation of benzofuran (α-rubromycin type) products.[5b,c] Because of these difficulties in assembling the bisbenzannulated spiroketal core, only three successful syntheses have been achieved to date. The aglycon of (±)-heliquinomycin (**4**) by Danishefsky[5a] in which spiroketalization of a hemiketal took place under Mitsunobu conditions, the total synthesis of (±)-γ-rubromycin (**3**) by Kita[6] that utilized a double aromatic Pummerer-type reaction to effect spiroketalization, and our own formal synthesis of (±)-γ-rubromycin (**3**) which involved the spirocyclization of a carefully chosen diphenolic ketone precursor.[7]

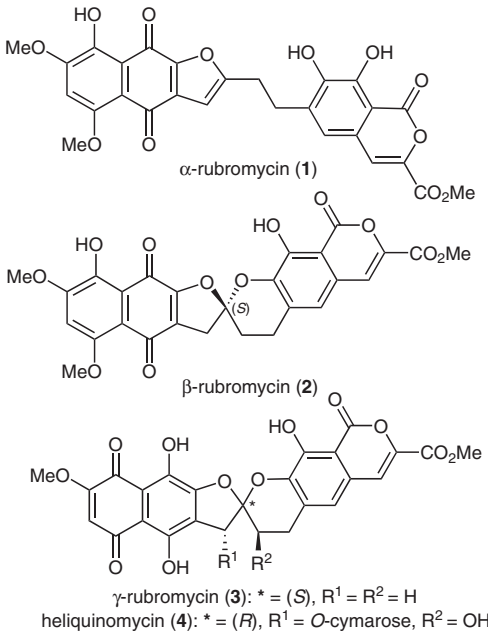

Figure 1 The rubromycin family of natural products

Despite our formal synthesis featuring an acid-catalyzed spiroketalization, its success hinged on the delicate balancing of the electronic properties of the substituents present on the naphthazarin and isocoumarin fragments present in the spiroketalization precursor.[7]

Several published model studies towards the bisbenzannulated spiroketal core of the rubromycins feature acid-catalyzed spiroketalization steps,[8] but numerous alternative methods have been disclosed, including intramolecular alkyne hydroalkoxylations[9] and cycloaddition-type approaches.[8d,10] Despite these worthwhile advances, alternative synthetic methods for the efficient construction of bisbenzannulated spiroketals related to the rubromycins would be a welcome addition to the synthetic repertoire.

Our research group has a long-standing interest in the synthesis of aliphatic spiroketals using the oxidative radical

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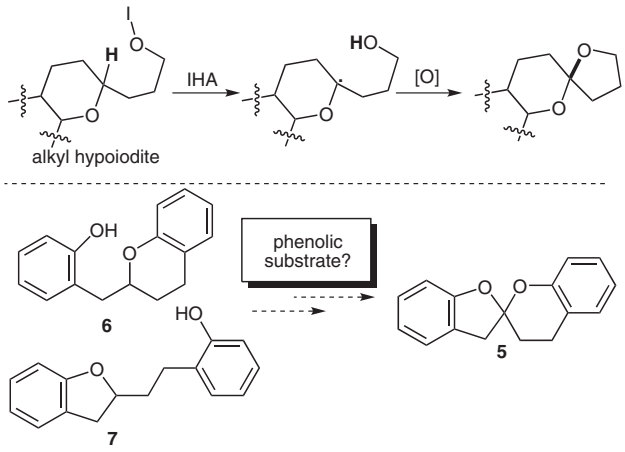
cyclization of cyclic ethers containing a hydroxyalkyl side chain (Scheme 1).[11] Due to the inherently mild nature of this cyclization protocol, we set out to investigate if this strategy could be successfully applied to the synthesis of the bisbenzannulated spiroketal core of the rubromycins (Scheme 1). This previously unexplored transformation would provide a worthy alternative to the troublesome acid-catalyzed spirocyclization commonly encountered during the synthesis of the spiroketal core **5** of the rubromycin family of antibiotics.

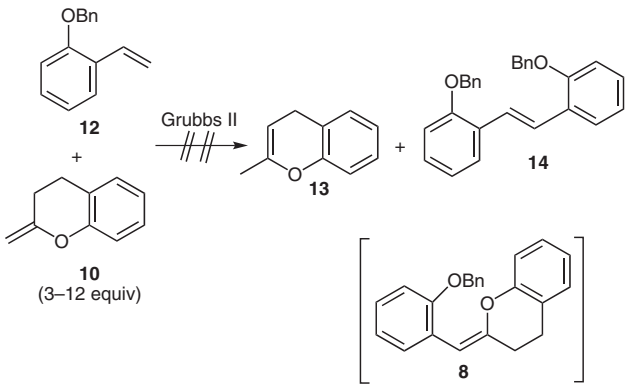


Scheme 1 Synthesis of spiroketals by oxidative radical cyclization (IHA = intramolecular hydrogen abstraction)

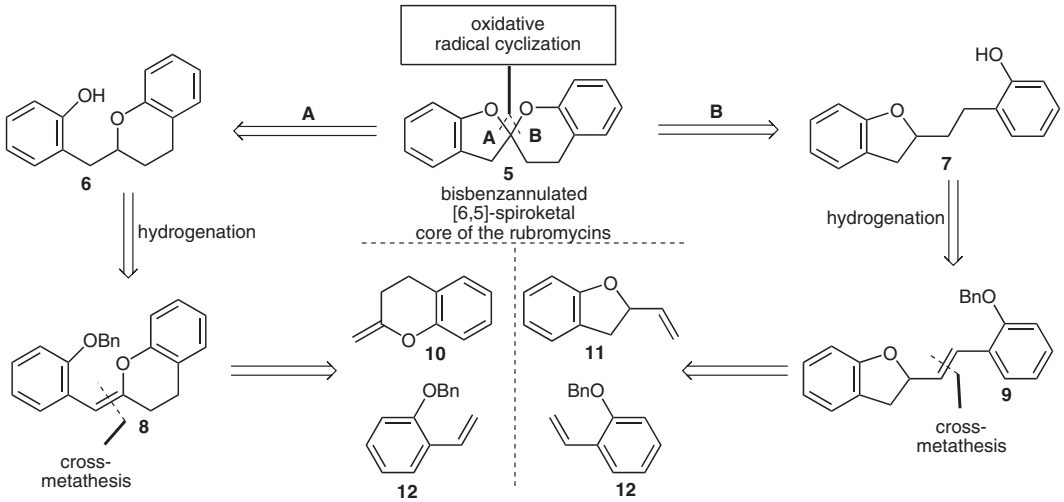
Our initial attention focused on the model bisbenzannulated spiroketal core **5** of the rubromycins (Scheme 2). The proposed oxidative radical cyclization approach allows for the [6,5]-spiroketal to be assembled by two distinct pathways; formation of the five-membered ring by cyclization of the chroman-tethered phenol **6** (path **A**), or formation of the six-membered ring by cyclization of the dihydrobenzofuran-tethered phenol **7** (path **B**). Both cyclization precursors **6** and **7** were envisaged to be accessible via hydrogenation of **8** or **9**, respectively. In turn, **8** and **9** are accessible via the cross-metathesis between enol ether **10** (path **A**) or dihydrobenzofuran **11** (path **B**) with the common *ortho*-substituted styrene **12** (Scheme 2).

It was presumed that formation of the five-membered ring of the [6,5]-spiroketal **5** would require an intramolecular hydrogen abstraction to occur through a more favorable six-membered transition state,[11] and thus we focused our initial attention on path **A**. The synthesis of the cross-metathesis coupling partners **10** and **12** was conducted as follows: styrene **12** was prepared on a large scale by Wittig methylenation of salicylaldehyde followed by benzylation,[12] and enol ether **10** was prepared from dihydrocoumarin using the reported Tebbe procedure.[13]

As enol ether **10** is categorized[14] as a type III alkene,[15] it was employed in excess with respect to styrene **12** (Type II) during the cross-metathesis process (Scheme 3). Disappointingly, despite subjecting styrene **12** and enol ether **10** to a large variety of cross-metathesis conditions with Grubbs' second-generation catalyst, no heterodimer **8** was observed. Only the isomerized product, 2-methylchromene (**13**) and the homodimer **14** were ever isolated, despite employing enol ether **10** in vast excess (up to 12 equivalents) and using a variety of solvents and temperatures. The main contributing factor to the failure of this reaction was the facile isomerization of enol ether **10**, even



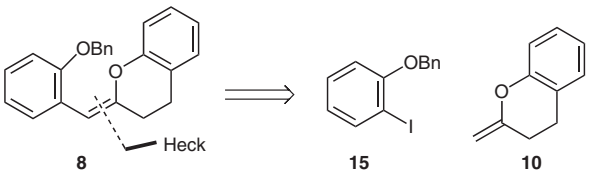
Scheme 3 Failed cross-metathesis



Scheme 2 Retrosynthesis of the bisbenzannulated spiroketal **5**

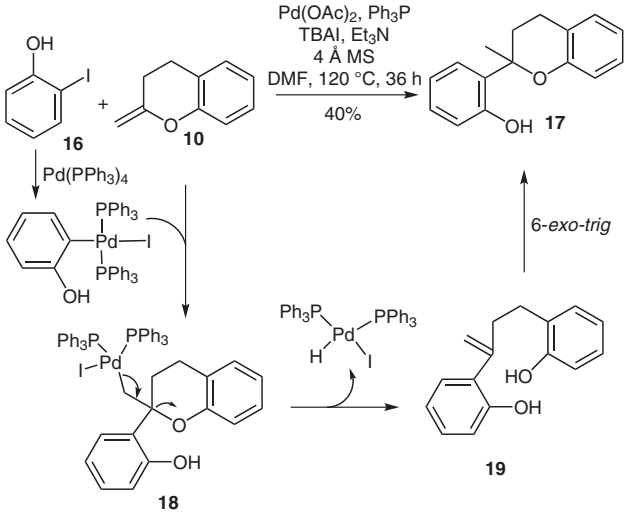
when conducting the cross-metathesis reaction in base-washed glassware.

With the cross-metathesis route failing, we opted to employ a Heck coupling strategy to construct the key model cyclization precursor **8** (Scheme 4).



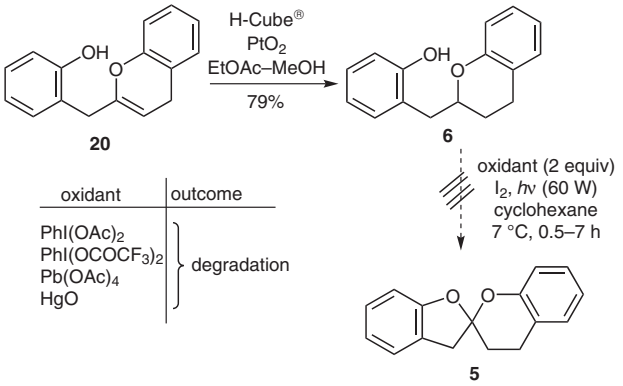
Scheme 4 Heck coupling strategy

With enol ether **10** already in hand, its attempted Heck coupling with the protected iodophenol **15** was investigated. However, no coupled product was ever observed, presumably due to steric hindrance restricting the initial oxidative addition step. Unperturbed, the Heck coupling of **10** with 2-iodophenol (**16**) was examined. Upon subjecting compounds **10** and **16** to standard Heck conditions, the chroman **17** was isolated as the sole product in moderate yield. Despite not forming the desired product **8**, the outcome of this reaction did demonstrate some interesting chemistry. A similar result had been previously disclosed on a related glycoside system[16] and can be attributed to the undesired regiochemical outcome of the initial addition to form the palladium σ-complex **18**. Alkoxide elimination then gives diol **19** which undergoes 6-*exo*-trig cyclization giving chroman **17** (Scheme 5).



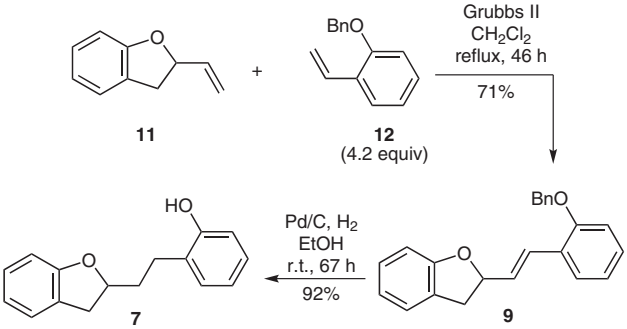
Scheme 5 Unexpected formation of chroman **17**

At this stage of our work, unrelated studies in our group resulted in the serendipitous formation of the chromene **20**.[17] Although only produced on small scale as an undesired by-product, passing a solution of **20** over Adams' catalyst through an H-Cube® hydrogenation apparatus provided sufficient quantities of chroman-tethered phenol **6** to attempt the desired oxidative radical cyclization. However, despite subjecting **6** to the standard oxidative radical cyclization conditions[11] with a variety of oxidants including diacetoxyiodobenzene [$PhI(OAc)_2$], bis(trifluoroacetoxy)iodobenzene [$PhI(OCOCF_3)_2$], lead tetraacetate [$Pb(OAc)_4$] or mercuric oxide (HgO),[11,18] only degradation was observed in all cases, and no bisbenzannulated spiroketal **5** was ever observed (Scheme 6).



Scheme 6 Failed oxidative radical cyclization

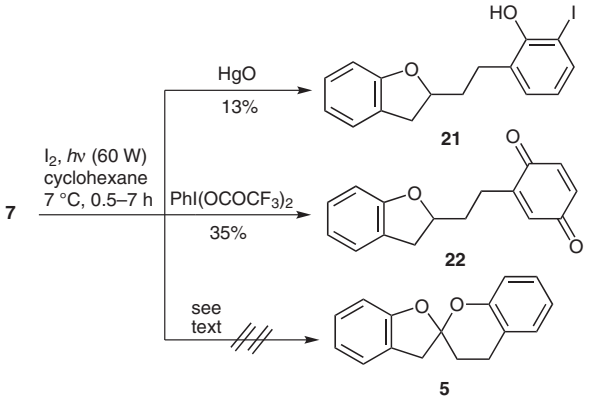
With the failure of the oxidative radical spiroketalization of **6** using path **A**, attention turned to forming the six-membered ring of the bisbenzannulated spiroketal core (Scheme 2, path **B**). Thus, the dihydrobenzofuran coupling partner **11** was synthesized from phenol in two steps using the procedure reported by Stoltz.[19] The monosubstituted nature of **11** indicated a type I status in cross-metathesis reactions,[14] and therefore, a relatively large excess of the styrene **12** was employed. After much experimentation, heating a mixture of dihydrobenzofuran **11**, styrene **12** (4.2 equivalents) and Grubbs' second-generation catalyst (2.6 mol%) in dichloromethane at reflux for 46 hours delivered the cross-metathesis product **9** in a 71% yield. Smooth hydrogenolysis with concomitant double bond reduction provided the key cyclization precursor **7** in excellent yield (Scheme 7).



Scheme 7 Synthesis of cyclization precursor **7**

Next, the key radical cyclization could be attempted. Irradiating a cyclohexane solution of phenol **7** in the presence of diacetoxyiodobenzene and iodine gave a complex mixture of products, even at 0 °C. Replacing diacetoxyiodobenzene with lead tetraacetate as the oxidant also gave complex mixtures from which no spiroketal **5** could be de-

tected. The use of mercuric oxide in the oxidative radical spiroketalization protocol resulted in a cleaner reaction, but disappointingly, only small amounts of the iodide **21** were isolated, arising from electrophilic iodination of the aromatic ring. The use of bis(trifluoroacetoxy)iodobenzene also resulted in a relatively clean reaction, however the only product isolated was the quinone **22** in moderate yield. The oxygen gained in the quinone product **22** presumably originates from the trifluoroacetate anion followed by hydrolysis during workup (Scheme 8).



Scheme 8 Attempted oxidative radical cyclizations

The disappointing finding that phenols **6** and **7** were unsuitable substrates for the oxidative radical cyclization was attributed to either their reduced nucleophilicity or the increased stabilization of the phenoxy radical by the aromatic ring preventing the key intramolecular hydrogen abstraction (IHA) step. Nevertheless, we sought to employ our cross-metathesis–oxidative radical cyclization approach to the synthesis of monobenzannulated spiroketals, thus offering a novel route to this key moiety.[1a] Such natural products possessing a monobenzannulated spiroketal include the agarwood component aquilarinoside A (**23**),[20] the extremophile-derived (–)-berkelic acid (**24**),[21,22] a potent matrix metalloprotease-3 (MMP) inhibitor (GI_{50} 1.87 μM), and chaetoquadrin A (**25**), a member of the chaetoquadrin family which exhibit promising monoamine oxidase (MAO) inhibitory properties[23] (Figure 2). Several novel approaches to this ring system have been reported.[24]

Thus, our retrosynthetic strategy to access various monobenzannulated spiroketals is outlined in Scheme 9 and is based on our earlier proposed route to access bisbenzannulated spiroketals. It was envisaged that monobenzannulated spiroketals **26**–**30** could be synthesized by oxidative radical cyclization of alcohols **31**–**35**, which in turn could be formed by concomitant hydrogenation of the alkene and hydrogenolysis of the benzyl group in alkenes **36**–**40**. Each of the alkenes **36**–**40** could be assembled via cross-metathesis of the appropriate heterocyclic coupling partner **11** or **41** with the appropriate alkene **42**–**44** (Scheme 9). This convergent approach should allow for the synthesis of monobenzannulated [5,5]-, [6,5]- and [6,6]-spiroketals by simple alteration of the alkyl

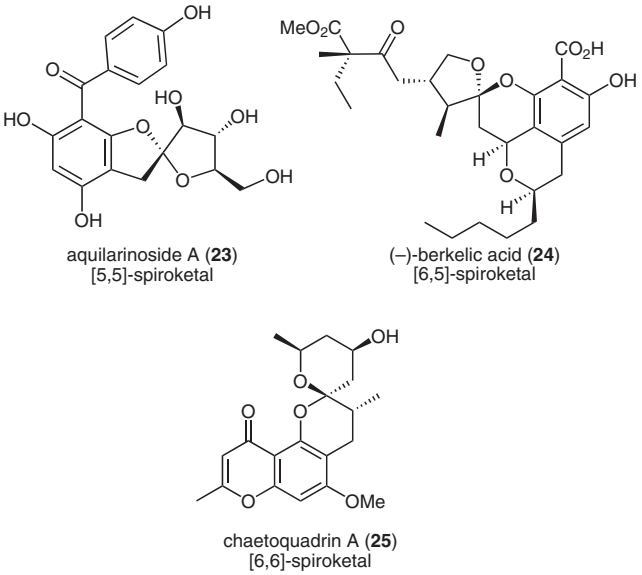
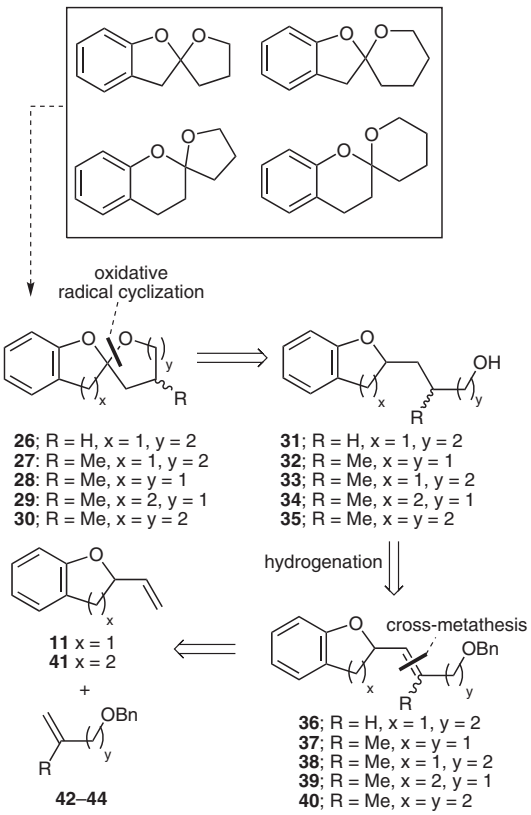


Figure 2 Examples of natural products containing a monobenzannulated spiroketal

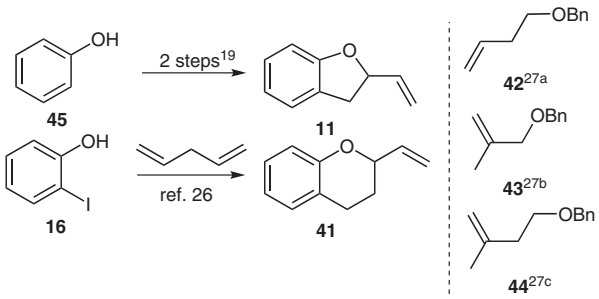
chain length of the heterocyclic alkenes **11** or **41**, or the aliphatic alcohol coupling partner **42**–**44** (Scheme 9). The full details of this study[25] are provided herein, providing a strategy that is readily amenable to analogue production.

The synthesis of the two heterocyclic alkenes **11** and **41** was undertaken. Heterocyclic alkene **11** was readily available from phenol (**45**),[19] and alkene **41** was obtained by the palladium-catalyzed annulation of 2-iodophenol (**16**)



Scheme 9 Retrosynthesis of monobenzannulated spiroketals

with 1,4-pentadiene.[26] The alkene coupling partners **42**–**44**[27] were obtained by benzylation of the commercially available alcohol precursors under standard conditions (Scheme 10).

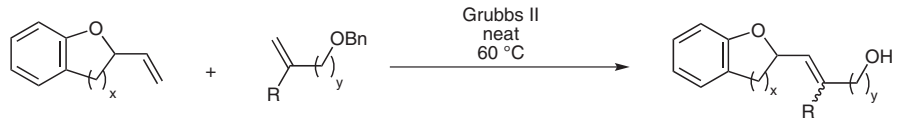


Scheme 10 Cross-metathesis coupling partners

With the appropriate starting materials in hand, attention was turned to the cross-metathesis step (Table 1). Not surprisingly, cross-metathesis of **11** with alkene **42** only afforded a low yield of heterodimer **36**, as both **11** and **42** are classified as type I alkenes (Table 1, entry 1).[14] As a result of this observation, disubstituted type III alkenes **43** and **44** were envisioned to be more suitable coupling partners for heterocyclic alkenes **11** and **41**. This was indeed the case and it was found that heating a neat mixture of **11** (one equivalent) and alkene **43** (four equivalents) in the presence of Grubbs' second-generation catalyst (5 mol%) provided the best yield of the desired heterodimer **37** as an inconsequential mixture of *E*/*Z* isomers (Table 1, entry 2).

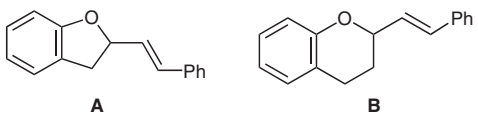
Based on this result, the synthesis of heterodimers **38**–**40** could thus be carried out in a similar fashion in moderate yields. Careful monitoring of the reaction time for each individual example was necessary to minimize the formation of homodimeric products (Table 1). Thus, compound

Table 1 Cross-Metathesis



Entry	Heterocyclic alkene	Alkene	Time (h)	Product	Yield (%)	(*E*/*Z*) ratio	Notes
1	**11**	**42**	48	**36**	19	1:0	[a]
2	**11**	**43**	37	**37**	57	4:1	[b,c]
3	**11**	**44**	48	**38**	58	2.1:1	[c,d]
4	**41**	**43**	70	**39**	51	3.5:1	[e,f]
5	**41**	**44**	14	**40**	38	1.1:1	–

[a] A 7% yield of heterocycle dimer and 16% yield of alcohol dimer were obtained.
[b] A 41% yield of heterocycle dimer was obtained.
[c] Product **A** was observed.
[d] A 30% yield of heterocycle dimer was obtained.
[e] A 30% yield of heterocycle dimer was obtained.
[f] Product **B** was observed.

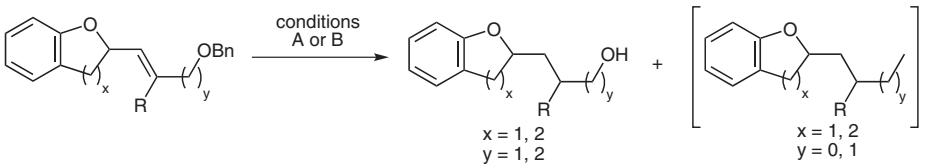


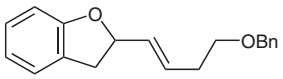
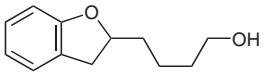
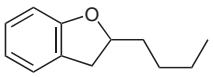
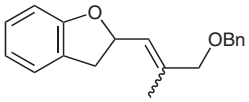
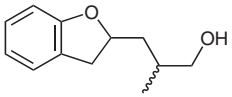
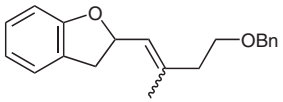
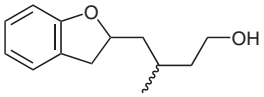
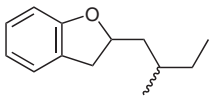
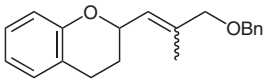
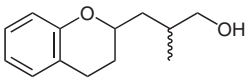
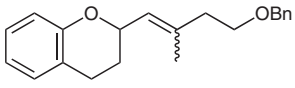
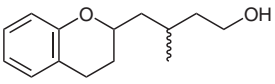
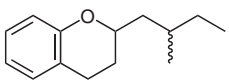
38 was obtained from the alkene coupling partners **11** and **44**, **39** from **41** and **43**, and **40** from **41** and **44**, respectively (Table 1, entries 3–5). Heterodimers **37**–**40** were all produced as inconsequential mixtures of *E*/*Z* isomers which were nearly always accompanied by the formation of the homodimer of the heterocyclic alkene (Table 1).

Next, hydrogenation of the cross-metathesis adducts was conducted using heterodimer **36** as our initial substrate (Table 2). Thus, hydrogenation of **36** over Pearlman's catalyst in methanol (conditions **A**) afforded the desired product **31**, but in poor yield. Much to our surprise, we also observed trace amounts of the hydrogenolysis product **46** (Table 2, entry 1), and even more puzzlingly, this over-reduction was only observed in the longer chain cross-metathesis adducts **36**, **38** and **40** (Table 2, entries 1, 3 and 5).[28] The over-reduction could be eliminated by conducting the hydrogenation with 10% palladium on carbon in ethyl acetate (conditions **B**). The shorter chain cross-metathesis adducts **37** and **39** underwent smooth hydrogenation with Pearlman's catalyst to give the desired aliphatic alcohols **32** and **34**, respectively (Table 2, entries 2 and 4).

With the spiroketalization precursors **31**–**35** in hand, the key oxidative radical cyclization was attempted (Table 3). Thus, to a solution of **31** in cyclohexane was added iodine and diacetoxyiodobenzene at 5 °C. The resulting solution was maintained at this temperature for two hours whilst being irradiated with a desk lamp (60 W). Gratifyingly,

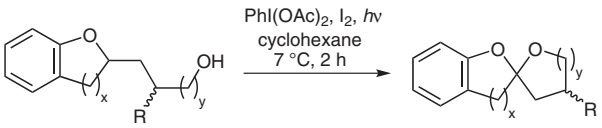
Table 2 Hydrogenation Conditions[a]

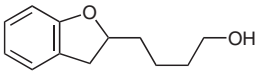
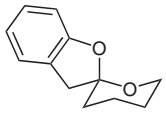
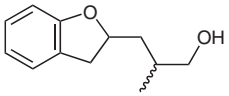
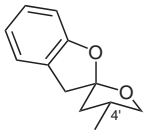
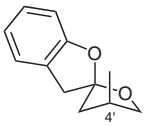
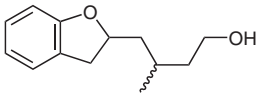
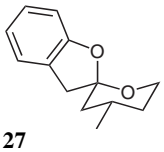
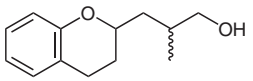
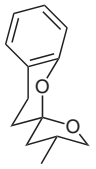
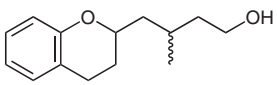
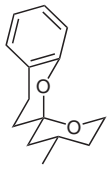


Entry	Substrate	Hydrogenation conditions, product(s), yield (%)		
1	 **36** (*E*/*Z* = 100:0)		 **31**	 **46**
		A	44	4
		B	52	0
2	 **37** (*E*/*Z* = 4:1)		 **32** (dr = 1:1)	
		A	83	
3	 **38** (*E*/*Z* = 2.1:1)		 **33** (dr = 1:1)	 **47** (dr = 1:1)
		A	40	~10%
		B	100	0
4	 **39** (*E*/*Z* = 3.5:1)		 **34** (dr = 1:1)	
		A	76	
5	 **40** (*E*/*Z* = 1.1:1)		 **35** (dr = 1:1)	 **48** (dr = 1:1)
		A	37	63
		B	63	0

[a] Conditions A: H_2, $Pd(OH)_2/C$, MeOH, r.t., 2.5 h. Conditions B: H_2, Pd/C, EtOAc, r.t., 3.5 h.

Table 3 Oxidative Radical Cyclization

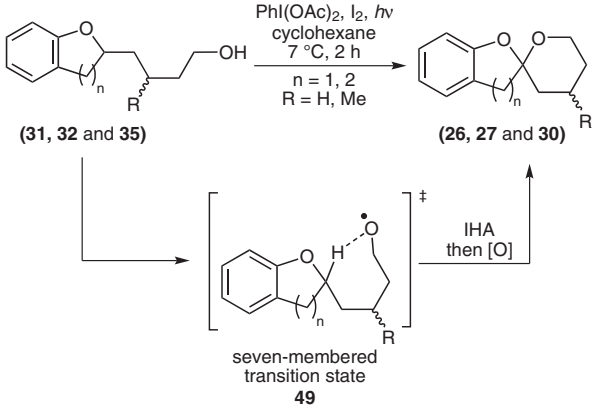


Entry	Spiroketalization precursor	Product	Yield (%)	dr
1	 **31**	 **26**	40	–
2	 **32** (dr = 1:1)	 **28a** (major) +  **28b** (minor)	42	1:0
3	 **33** (dr = 1:1)	 **27**	73	1.4:1
4	 **34** (dr = 1:1)	 **29a** (major) +  **29b** (minor)	92	1.4:1
5	 **35** (dr = 1:1)	 **30**	58	1:0

the desired monobenzannulated spiroketal **26** was obtained in moderate yield (Table 3, entry 1). Spiroketal **26** was isolated as a single racemic conformer wherein the C–O bond of the five-membered ring adopts an axial position with respect to the six-membered ring.

The methyl substituted precursors **32–35** were subjected to the same spiroketalization conditions, delivering spiroketals **27–30** in variable yields. Higher yields were observed for the formation of the five-membered rings (**28** and **29**) compared to their six-membered counterparts (**26**, **27** and **30**). This was attributed to the fact that the intramolecular hydrogen abstraction proceeds through an unfavored seven-membered transition state, **49** when forming six-membered rings (Scheme 11).

With spiroketals **28** and **29**, two inseparable racemic diastereomers were observed for each spiroketal. With respect to diastereomeric spiroketals **28a** and **28b** (Figure 3), it was found that the methyl group at C-4′ in spiroketal **28a** was more upfield than the corresponding methyl group in **28b** where it occupied a position *syn* to the oxygen atom of the dihydrobenzofuran moiety. Similarly, the resonance for H-4′ in spiroketal **28a** was further



Scheme 11 Oxidative radical cyclization

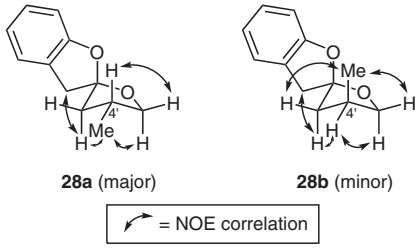


Figure 3 NOE correlations observed for spiroketal **28**

downfield than that for H-4′ in **28b** due to H-4′ in **28a** being *syn* to the oxygen atom of the dihydrobenzofuran moiety. Based on this and NOE evidence, spiroketal **28a** was assigned as the major diastereomer with the methyl group adopting a pseudoequatorial position (Figure 3). A similar rationale was used to assign the major and minor diastereomers of the [6,5]-spiroketal **29**.

Surprisingly, spiroketals **27** and **30** were obtained as a single racemic diastereomer. It was established that the methyl substituent adopted an equatorial position on the six-membered ring, and the corresponding spiroketal bearing a methyl group in the axial position was not observed. Presumably, once spiroketal formation had taken place, ring-opening and ring-closure resulted in formation of the thermodynamically favored spiroketal in which the methyl group was equatorial and the C–O bond of the five-membered ring was axial with respect to the six-membered ring, thus gaining maximum stability from the anomeric effect. Therefore, the formation of two racemic diastereomers for each of spiroketals **28** and **29** can be rationalized by the fact that the anomeric effect is weaker in five-membered ring systems (spiroketals **28** and **29**) than in six-membered ring systems (spiroketals **27** and **30**).[29]

Unfortunately, as neither the diastereomeric mixtures of spiroketals **28a**,**b** nor **29a**,**b** were separable by chromatography, subjecting the minor diastereomer to the reaction conditions was not possible and we were unable to unequivocally confirm that equilibration did occur in this case. It is equally feasible that the transition state for formation of these products simply minimizes diaxial interactions, which in the [6,5] and [5,5] systems is not as destabilizing, and thus the formation of two diastereomers is observed for **28** and **29**.

In conclusion, we have investigated the synthesis of both mono and bisbenzannulated spiroketals using a mild oxidative radical cyclization approach. Although this strategy proved elusive to provide a novel route toward bisbenzannulated spiroketals, it did offer a new approach to monobenzannulated spiroketals such as those observed in (–)-berkelic acid (**24**). Studies toward the synthesis of the monobenzannulated spiroketal natural products **23**–**25** and analogues thereof, using this methodology are ongoing.

All reactions were carried out in oven-dried or flame-dried glassware under a nitrogen atmosphere unless otherwise stated. Analytical thin-layer chromatography was performed using 0.2 mm Kieselgel F254 (Merck) silica plates and compounds were visualized under 365 nm UV irradiation followed by staining with either alkaline permanganate or ethanolic vanillin solution. Column chromatography was carried out using 0.063–0.1 mm silica gel. IR spectra were obtained using a Perkin–Elmer Spectrum One Fourier Transform IR spectrometer with a universal attenuated total refractance (ATR) attachment installed. Absorption maxima are expressed as wavenumbers (cm^{-1}). NMR spectra were recorded as indicated on either a Bruker DRX-400 spectrometer operating at 400 MHz for ^1H nuclei and 100 MHz for ^{13}C nuclei, or on a Bruker Avance 300 spectrometer operating at 300 MHz and 75 MHz for ^1H and ^{13}C nuclei, respectively. Chemical shifts are reported in parts per million (ppm) relative to the tetramethylsilane peak recorded at $\delta = 0.00$ ppm in $CDCl_3$–TMS solvent, the residual chloroform peak at $\delta = 7.25$ ppm or the residual acetone peak at $\delta = 2.05$ ppm. ^1H NMR data are reported as chemical shift (δ), relative integral, multiplicity, coupling constant (J in Hz) and assignment. The ^{13}C NMR values were referenced to the residual chloroform peak at $\delta = 77.0$ ppm or the residual acetone peak at $\delta = 29.8$ ppm. ^{13}C NMR data are reported as chemical shift (δ) and assignment. Assignments were made with the aid of DEPT 135, COSY, NOESY and HSQC experiments. Atom-numbering is shown in Figure 4 for compounds **26**–**30**. High-resolution mass spectra were recorded on a VG-70SE mass spectrometer at a nominal accelerating voltage of 70 eV. H-Cube® continuous hydrogenation equipment (Thompson Scientific) used a flow rate of 1 $mL \cdot min^{-1}$, a block temperature of 20 °C and pressure of 10 bar.

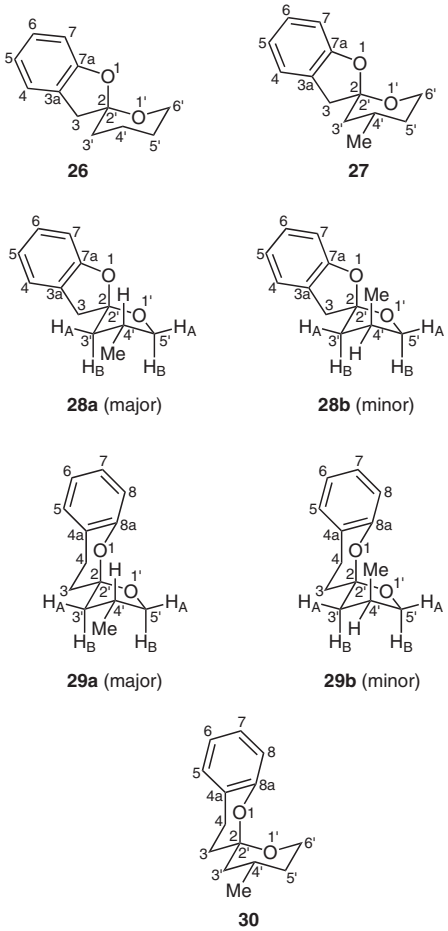


Figure 4 Numbering of atoms for compounds **26**–**30**

Cross-Metathesis; General Procedure A

Grubbs II catalyst (5 mol%) was added to a mixture of heterocyclic alkene **11** or **41** and alkene **42**, **43** or **44** (4 or 6 equiv) at r.t. and the neat reaction mixture was heated at 60 °C under N_2 for 14–70 h. After cooling to r.t., purification by column chromatography on silica gel (hexanes–CH_2Cl_2, 1:1, then 100% CH_2Cl_2) gave the heterodimeric product.

Hydrogenation/Hydrogenolysis; General Procedure B

Conditions A

$Pd(OH)_2$ [20 wt% Pd (dry basis) on carbon, 5–26 mg] was added to a soln of heterodimer in MeOH (1–2 mL). H_2 was bubbled through the reaction mixture at r.t. for 2.5–5 h after which the mixture was filtered through Celite®. The catalyst was washed with EtOAc (5 × 10 mL) and the filtrate was concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexanes–EtOAc, 3:1) to give the alcohol product.

Conditions B

As above, except Pd/C (10 wt%, 6–14 mg) and EtOAc (1–2 mL) were used as catalyst and solvent, respectively.

Oxidative Radical Cyclization; General Procedure C

A mixture of alcohol (1 equiv), $PhI(OAc)_2$ (2 equiv) and I_2 (2.25–2.28 equiv) in cyclohexane (1 mL per 0.012 mmol of alcohol substrate) was degassed with Ar at r.t. for 15 min. The resulting soln was cooled in an ice-H_2O bath (5 °C) and irradiated with a desk lamp (60 W) for 2–3 h. The soln was diluted with Et_2O (10 mL), then sat. aq $Na_2S_2O_3$ soln (10 mL) and sat. aq $NaHCO_3$ soln (10 mL) were added. After separation of both phases, the aq phase was extracted with Et_2O (4 × 15 mL). The organic phases were combined, dried over anhyd $MgSO_4$, filtered and the solvents concentrated in vacuo. The crude product was purified by column chromatography on silica gel (100% *n*-pentane, then *n*-pentane–Et_2O, 12:1) to give the spiroketal product.

The following compounds were prepared according to reported literature procedures: 2-methylenechroman (**10**),[13] (±)-2-ethenyl-2,3-dihydrobenzofuran (**11**),[19] 1-(benzyloxy)-2-ethenylbenzene (**12**),[12] 1-(benzyloxy)-2-iodobenzene (**15**),[30] (±)-2-ethenylchroman (**41**),[26] [(but-3-enyloxy)methyl]benzene (**42**),[27a] {[(2-methylprop-2-enyl)oxy]methyl}benzene (**43**),[27b] {[(3-methylbut-3-enyl)oxy]methyl}benzene (**44**).[27c] 2-Methylchromene (**13**) is a known compound[31] and was identified from its spectroscopic data.

2-(2-Methylchroman-2-yl)phenol (17)

To a base-washed, oven-dried, thick-walled sealed tube containing freshly degassed DMF (5 mL) were added 4 Å MS (200 mg), TBAI (1.26 mmol, 465 mg), Et_3N (1.26 mmol, 175 μL), enol ether **10** (31 mg, 0.21 mmol), aryl iodide **16** (0.42 mmol, 131 mg), $Pd(OAc)_2$ (10 mol%, 0.021 mmol, 5 mg) and Ph_3P (10 mol%, 0.021 mmol, 6 mg). The reaction mixture was covered with a blanket of Ar, the tube tightly sealed and placed on a sand bath pre-heated to 120 °C, and the contents stirred vigorously for 36 h. The reaction mixture was cooled, diluted with H_2O (20 mL) and extracted with EtOAc (3 × 20 mL). The combined organic extracts were washed with brine (2 × 20 mL), dried ($MgSO_4$), filtered and concentrated in vacuo. Purification by column chromatography on silica gel (hexanes–EtOAc, 3:1) gave the title compound.

Pale-yellow oil; yield: 20 mg, 0.083 mmol (40%).

IR (neat): 3299, 3100, 2928, 2830, 1684, 1658, 1630, 1577, 1479, 1461, 1456, 1379, 1229, 1176, 1100, 1020, 922, 731, 695 cm^{-1}.

^1H NMR (300 MHz, $CDCl_3$): δ = 1.72 (s, 3 H, Me), 2.10–2.20 (m, 1 H, 3-H_b), 2.58–2.90 (m, 3 H, 3-H_a, 4-H_a, 4-H_b) 6.84–6.93 (m, 4 H, Ar-H), 7.03–7.19 (m, 4 H, Ar-H), 8.25 (s, 1 H, OH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 22.2 (CH_2), 27.6 (Me), 31.2 (CH_2), 81.3 (C), 117.0 (CH), 117.9 (CH), 119.8 (CH), 121.6 (CH), 125.6 (CH), 127.5 (CH), 127.9 (C), 129.2 (CH), 129.7 (CH), 152.0 (C), 155.6 (C), (1 × C not observed).

MS (EI, 70 eV): *m*/*z* (%) = 263 (100) [M + Na^+], 241 (10), 209 (9), 147 (8), 121 (10).

HRMS (EI): *m*/*z* [M + Na^+] calcd for $C_{16}H_{16}NaO_2$: 263.1040; found: 263.1043.

2-(Chroman-2-ylmethyl)phenol (6)

Alkene **20** (10 mg, 0.04 mmol) was dissolved in EtOAc (4 mL) and MeOH (4 mL) before hydrogenation employing a H-Cube® continuous hydrogenation apparatus (Thompson Scientific) using a flow rate of 1 mL·min^{-1}, a block temperature of 20 °C and pressure of 10 bar. The solvent was removed in vacuo and the resulting oil was purified via preparatory thin layer chromatography (hexanes–EtOAc, 4:1) to afford the title compound.

Colorless oil; yield: 8 mg, 0.03 mmol (79%).

IR (neat): 2926, 2857, 1595, 1231, 752 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.94–2.17 (m, 2 H, 3-H_2), 2.77–2.93 (m, 2 H, 2″-H_2), 3.09 (br s, 1 H, OH), 3.25–3.31 (m, 1 H, 4-H_a), 4.71–4.80 (m, 1 H, 4-H_b), 6.81–6.90 (m, 3 H, Ar-H), 7.08–7.23 (m, 4 H, Ar-H), 7.31–7.52 (m, 1 H, Ar-H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 25.9 (CH_2, C-4), 35.4 (CH_2, C-3), 36.3 (CH_2, C-2″), 82.2 (CH, C-2), 109.5, 116.1, 120.6, 120.9, 125.1, 127.6, 128.0, 130.5 (8 × CH, C-5, C-6, C-7, C-8, C-3‴, C-4‴, C-5‴, C-6‴), 140.7, 149.9, 154.1, 156.9 (4 × C, C-4a, C-8a, C-1‴, C-2‴).

MS (EI, 70 eV): *m*/*z* (%) = 263 (3) [M + Na^+], 237 (5), 174 (100), 146 (35).

HRMS (EI): *m*/*z* [M + Na^+] calcd for $C_{16}H_{16}NaO_2$: 263.1040; found: 263.1048.

(±)-(*E*)-2-[2-(Benzyloxy)styryl]-2,3-dihydrobenzofuran (9)

Grubbs II catalyst (3 mg, 0.004 mmol, 2.6 mol%) and a soln of styrene **12** (119 mg, 0.57 mmol) in CH_2Cl_2 (2.5 mL) were added to neat alkene **11** (20 mg, 0.14 mmol) under N_2 at r.t. The reaction mixture was heated under reflux at 50 °C for 46 h after which it was concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexanes–CH_2Cl_2, 4:1, then 1:1) to give the title compound.

Yellow oil; yield: 32 mg, 0.097 mmol (71%).

IR (neat): 3066, 3033, 2925, 2854, 1688, 1649, 1629, 1598, 1479, 1461, 1451, 1379, 1293, 1229, 1162, 1099, 1015, 909, 733, 696 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 3.06 (dd, *J* = 15.6, 7.8 Hz, 1 H, 3-H_a), 3.41 (dd, *J* = 15.6, 9.2 Hz, 1 H, 3-H_b), 5.09 (s, 2 H, OC*H*$_2$Ph), 5.35 (dddd, *J* = 8.3, 8.3, 8.3, 1.0 Hz, 1 H, 2-H), 6.40 (dd, *J* = 15.9, 7.6 Hz, 1 H, OCHC*H*=CH), 6.79–6.86 (m, 2 H, 5-H, 7-H), 6.90–6.94 (m, 2 H, 3′-H, 5′-H), 7.08–7.22 (m, 4 H, OCHCH=C*H*, 4-H, 4′-H, 6-H), 7.31–7.43 (m, 5 H, OCH$_2$*Ph*), 7.48 (dd, *J* = 7.5, 1.2 Hz, 1 H, 6′-H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 36.3 (CH_2, C-3), 70.3 (CH_2, O*C*H$_2$Ph), 84.1 (CH, C-2), 109.4 (CH, C-5 or C-7), 112.5 (CH, C-3′ or C-5′), 120.3 (CH, C-5 or C-7), 121.0 (CH, C-3′ or C-5′), 124.8 (CH, C-6), 125.6 (C, C-1′), 126.8 (C, C-3a), 127.1 (CH, C-6′), 127.2 (2 × CH, C-2″, C-6″), 127.3 (CH, OCHCH=*C*H), 127.9 (CH, C-4″), 128.0 (CH, C-4), 128.5 (2 × CH, C-3″, C-5″), 128.9 (CH, OCH*C*H=CH), 129.0 (CH, C-4′), 137.0 (C, C-1″), 156.0 (C, C-2′), 159.4 (C, C-7a).

MS (EI, 70 eV): *m*/*z* (%) = 328 (16) [M$^+$], 237 (67), 221 (8), 209 (7), 197 (3), 189 (4), 178 (3), 165 (3), 144 (5), 131 (33), 119 (12), 107 (3), 91 (100), 77 (6), 65 (12), 51 (4), 39 (5).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{23}H_{20}O_2$: 328.1463; found: 328.1461.

(±)-2-[2-(2,3-Dihydrobenzofuran-2-yl)ethyl]phenol (7)

Pd/C (10 wt%, 84 mg) was added to a soln of alkene **9** (249 mg, 0.76 mmol) in EtOH (7 mL). The reaction mixture was evacuated and back-filled with H_2 (× 3, balloon), then stirred at r.t. under H_2 for 67 h after which it was filtered through Celite® and the catalyst washed with EtOAc (4 × 10 mL). The filtrates were combined and the solvents concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexanes–EtOAc, 9:1) to give the title compound.

Colorless oil; yield: 167 mg, 0.69 mmol (92%).

IR (neat): 3390, 3033, 2921, 2851, 1595, 1479, 1456, 1374, 1229, 1170, 1096, 1043, 1014 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.91–2.00 (m, 1 H, 2′-H_a), 2.06–2.15 (m, 1 H, 2′-H_b), 2.76–2.86 (m, 3 H, 1′-H, 3″-H_a), 3.20 (dd, *J* = 15.5, 8.9 Hz, 1 H, 3″-H_b), 4.72 (dddd, *J* = 8.2, 8.2, 8.2, 5.1 Hz, 1 H, 2″-H), 6.22 (br s, 1 H, OH), 6.77–6.86 (m, 4 H, 4-H, 5″-H, 6-H, 7″-H), 7.03–7.12 (m, 4 H, 3-H, 4″-H, 5-H, 6″-H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 25.9 (CH_2, C-1′), 35.4 (CH_2, C-3″), 36.2 (CH_2, C-2′), 82.2 (CH, C-2″), 109.5 (CH, C-6 or C-7″), 116.0 (CH, C-6 or C-7″), 120.6 (CH, C-4 or C-5″), 120.8 (CH, C-4 or C-5″), 125.0 (CH, C-4″), 126.8 (C, C-3″a), 127.1 (C, C-2), 127.6 (CH, C-5 or C-6″), 128.0 (CH, C-5 or C-6″), 130.4 (CH, C-3), 154.1 (C, C-1), 158.8 (C, C-7″a).

MS (EI, 70 eV): *m*/*z* (%) = 240 (46) [M$^+$], 145 (5), 133 (100), 131 (12), 119 (8), 107 (39), 105 (15), 103 (5), 91 (20), 77 (25), 65 (6), 51 (7), 39 (8).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{16}H_{16}O_2$: 240.1150; found: 240.1151.

(±)-2-[2-(2,3-Dihydrobenzofuran-2-yl)ethyl]-6-iodophenol (21)

A mixture of HgO (23 mg, 0.106 mmol) and I_2 (27 mg, 0.106 mmol) in cyclohexane (1.5 mL) was degassed with Ar at r.t. for 10 min. Next, a soln of phenol **7** (25 mg, 0.104 mmol) in cyclohexane (1.5 mL) was added. The reaction mixture was further degassed with Ar at r.t. for 5 min after which it was cooled in an ice-H_2O bath (7 °C) and irradiated with a desk lamp (60 W) for 3 h. The mixture was quenched with sat. aq $Na_2S_2O_5$ soln (10 mL), and Et_2O (20 mL) and sat. aq $NaHCO_3$ soln (10 mL) were added. After separation of both phases, the aq phase was extracted with Et_2O (4 × 15 mL). The organic phases were combined, dried over anhyd $MgSO_4$, filtered and the solvents concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexanes–Et_2O, 5:1) to give the title compound.

Pale-yellow oil; yield: 5 mg, 0.014 mmol (13%).

IR (neat): 3479, 2927, 2848, 1596, 1480, 1442, 1373, 1264, 1231, 1166, 1106, 1044, 1015 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.95–2.03 (m, 1 H, 2′-H_a), 2.07–2.17 (m, 1 H, 2′-H_b), 2.81–2.92 (m, 3 H, 1′-H, 3″-H_a), 3.29 (dd, *J* = 15.4, 8.9 Hz, 1 H, 3″-H_b), 4.73–4.80 (m, 1 H, 2″-H), 5.64 (s, 1 H, OH), 6.62 (t, *J* = 7.6 Hz, 1 H, 4-H), 6.79–6.85 (m, 2 H, 5″-H, 7″-H), 7.09–7.16 (m, 3 H, 3-H, 4″-H, 6″-H), 7.52 (d, *J* = 7.9 Hz, 1 H, 5-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 27.4 (CH_2, C-1′), 35.4 (CH_2, C-3″), 35.8 (CH_2, C-2′), 82.3 (CH, C-2″), 86.6 (C, C-6), 109.4 (CH, C-5″ or C-7″), 120.3 (CH, C-5″ or C-7″), 122.4 (CH, C-4), 125.0 (CH, C-4″), 126.8 (C, C-3″a), 128.0 (CH, C-6″), 128.3 (C, C-2), 130.9 (CH, C-3), 136.3 (CH, C-5), 152.8 (C, C-1), 159.3 (C, C-7″a).

MS (EI, 70 eV): *m*/*z* (%) = 366 (96) [M$^+$], 272 (1), 259 (52), 246 (2), 233 (24), 145 (7), 133 (100), 119 (14), 107 (29), 91 (27), 77 (24), 65 (10), 51 (16), 39 (12).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{16}H_{15}IO_2$: 366.0117; found: 366.0124.

(±)-2-[2-(2,3-Dihydrobenzofuran-2-yl)ethyl]cyclohexa-2,5-diene-1,4-dione (22)

A mixture of phenol **7** (26 mg, 0.108 mmol), $PhI(OCOCF_3)_2$ (93 mg, 0.216 mmol) and I_2 (62 mg, 0.244 mmol) in cyclohexane (9.0 mL) was degassed with Ar at r.t. for 10 min. The resulting soln was cooled in an ice-H_2O bath (7 °C) and irradiated with a desk lamp (60 W) for 2.5 h after which it was diluted with Et_2O (15 mL), then sat. aq $Na_2S_2O_3$ soln (12 mL) and sat. aq $NaHCO_3$ soln (12 mL) were added. After separation of both phases, the aq phase was extracted with Et_2O (4 × 15 mL). The organic phases were combined, dried over anhyd $MgSO_4$, filtered and the solvents concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexanes–Et_2O, 3:1) to give the title compound.

Orange oil; yield: 9.5 mg, 0.037 mmol (35%).

IR (neat): 3049, 2921, 2851, 1657, 1598, 1480, 1461, 1264, 1230 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.88–2.04 (m, 2 H, 2′-H), 2.55–2.63 (m, 1 H, 1′-H_a), 2.67–2.74 (m, 1 H, 1′-H_b), 2.90 (dd, *J* = 15.5, 7.4 Hz, 1 H, 3″-H_a), 3.33 (dd, *J* = 15.4, 9.0 Hz, 1 H, 3″-H_b), 4.77–4.84 (m, 1 H, 2″-H), 6.61 (s, 1 H, 3-H), 6.71–6.76 (m, 2 H, 5-H, 7″-H), 6.77 (d, *J* = 10.1 Hz, 1 H, 6-H), 6.83 (t, *J* = 7.2 Hz, 1 H, 5″-H), 7.10 (t, *J* = 7.7 Hz, 1 H, 6″-H), 7.15 (d, *J* = 7.2 Hz, 1 H, 4″-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.5 (CH_2, C-1′), 34.2 (CH_2, C-2′), 35.3 (CH_2, C-3″), 82.0 (CH, C-2″), 109.4 (CH, C-7″), 120.4 (CH, C-5″), 125.0 (CH, C-4″), 126.4 (C, C-3″a), 128.1 (CH, C-6″), 132.8 (CH, C-3), 136.4 (CH, C-5), 136.8 (CH, C-6), 148.7 (C, C-2), 159.2 (C, C-7″a), 187.3 (C, C-1), 187.6 (C, C-4).

MS (EI, 70 eV): *m*/*z* (%) = 254 (17) [M$^+$], 252 (7), 240 (1), 235 (1), 149 (4), 147 (8), 131 (100), 123 (14), 119 (6), 115 (4), 107 (16), 105 (7), 91 (18), 77 (13), 65 (7), 57 (7), 51 (7), 39 (11).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{16}H_{14}O_3$: 254.0943; found: 254.0942.

(±)-(*E*)-2-[4-(Benzyloxy)but-1-enyl]-2,3-dihydrobenzofuran (36)

According to general procedure A, the title compound was obtained from reaction of alkene **42** (200 mg, 1.233 mmol) and Grubbs II catalyst (9 mg, 0.011 mmol, 5 mol%) with alkene **11** (30 mg, 0.205 mmol) for 48 h.

Pale-yellow oil; yield: 11 mg, 0.039 mmol (19%).

IR (neat): 3032, 2923, 2853, 1598, 1558, 1479, 1460, 1361, 1229, 1172, 1097, 1027, 1015, 965, 910, 872, 747, 733, 697 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.41 (q, *J* = 6.6 Hz, 2 H, 3′-H), 2.98 (dd, *J* = 15.5, 8.0 Hz, 1 H, 3-H_a), 3.33 (dd, *J* = 15.4, 9.1 Hz, 1 H, 3-H_b), 3.54 (t, *J* = 6.7 Hz, 2 H, 4′-H), 4.51 (s, 2 H, OCH_2Ph), 5.15 (q, *J* = 8.1 Hz, 1 H, 2-H), 5.75 (dd, *J* = 15.1, 7.7 Hz, 1 H, 1′-H), 5.87 (dt, *J* = 15.3, 6.6 Hz, 1 H, 2′-H), 6.77 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.83 (t, *J* = 7.3 Hz, 1 H, 5-H), 7.10 (t, *J* = 7.8 Hz, 1 H, 6-H), 7.15 (d, *J* = 7.1 Hz, 1 H, 4-H), 7.26–7.34 (m, 5 H, OCH_2*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 32.6 (CH_2, C-3′), 36.1 (CH_2, C-3), 69.4 (CH_2, C-4′), 72.9 (CH_2, OCH_2Ph), 83.6 (CH, C-2), 109.3 (CH, C-7), 120.3 (CH, C-5), 124.8 (CH, C-4), 126.8 (C, C-3a), 127.6 (CH, C-4″), 127.7 (2 × CH, C-2″, C-6″), 128.0 (CH, C-6), 128.4 (2 × CH, C-3″, C-5″), 130.7 (CH, C-2′), 131.1 (CH, C-1′), 138.3 (C, C-1″), 159.3 (C, C-7a).

MS (EI, 70 eV): *m*/*z* (%) = 280 (8) [M$^+$], 189 (5), 174 (4), 171 (3), 159 (24), 146 (8), 131 (7), 119 (6), 115 (4), 107 (6), 91 (100), 77 (8), 65 (10), 55 (5), 51 (5), 41 (9).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{19}H_{20}O_2$: 280.1463; found: 280.1456.

(±)-(*E*/*Z*)-2-[3-(Benzyloxy)-2-methylprop-1-enyl]-2,3-dihydrobenzofuran (37)

According to general procedure A, reaction of alkene **43** (133 mg, 0.820 mmol) and Grubbs II catalyst (9 mg, 0.011 mmol, 5 mol%) with alkene **11** (30 mg, 0.205 mmol) for 37 h gave the title compound as a mixture of *E*/*Z* isomers in the ratio 4:1 (as determined by ^{1}H NMR spectroscopy). These isomers were separated for characterization purposes.

Clear oil; yield: 33 mg, 0.118 mmol (57%).

***E*-Isomer**

Viscous oil; yield: 26.4 mg, 0.094 mmol (46% of 57%).

IR (neat): 3031, 2916, 2848, 1596, 1479, 1461, 1377, 1354, 1228, 1096, 1071, 963, 909, 872, 731, 697 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.82 (s, 3 H, 2′-Me), 2.96 (dd, *J* = 15.3, 8.4 Hz, 1 H, 3-H$_a$), 3.37 (dd, *J* = 15.3, 8.9 Hz, 1 H, 3-H$_b$), 3.96 (s, 2 H, 3′-H), 4.50 (s, 2 H, OC*H*$_2$Ph), 5.51 (q, *J* = 8.6 Hz, 1 H, 2-H), 5.77 (d, *J* = 8.6 Hz, 1 H, 1′-H), 6.77 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.83 (t, *J* = 7.3 Hz, 1 H, 5-H), 7.10 (t, *J* = 7.8 Hz, 1 H, 6-H), 7.15 (d, *J* = 7.1 Hz, 1 H, 4-H), 7.25–7.34 (m, 5 H, OCH$_2$*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.3 (CH_3, 2′-Me), 36.5 (CH_2, C-3), 72.0 (CH_2, O*C*H$_2$Ph), 75.0 (CH_2, C-3′), 79.2 (CH, C-2), 109.4 (CH, C-7), 120.3 (CH, C-5), 124.8 (CH, C-4), 126.6 (CH, C-1′), 126.9 (C, C-3a), 127.6 (CH, C-4″), 127.7 (2 × CH, C-2″, C-6″), 128.0 (CH, C-6), 128.4 (2 × CH, C-3″, C-5″), 137.2 (C, C-2′), 138.2 (C, C-1″), 159.3 (C, C-7a).

MS (EI, 70 eV): *m*/*z* (%) = 280 (9) [M$^+$], 189 (2), 175 (4), 161 (4), 159 (7), 145 (3), 131 (17), 119 (3), 115 (3), 107 (5), 91 (100), 77 (6), 65 (7), 55 (5), 51 (4), 39 (8).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{19}H_{20}O_2$: 280.1463; found: 280.1463.

***Z*-Isomer**

Pale-yellow oil; yield: 6.6 mg, 0.024 mmol (11% of 57%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.88 (d, *J* = 1.0 Hz, 3 H, 2′-Me), 2.94 (dd, *J* = 15.5, 8.2 Hz, 1 H, 3-H$_a$), 3.30 (dd, *J* = 15.5, 8.9 Hz, 1 H, 3-H$_b$), 4.06 (d, *J* = 11.8 Hz, 1 H, 3′-H$_a$), 4.19 (d, *J* = 11.9 Hz, 1 H, 3′-H$_b$), 4.51 (s, 2 H, OC*H*$_2$Ph), 5.48 (q, *J* = 8.7 Hz, 1 H, 2-H), 5.66 (d, *J* = 9.0 Hz, 1 H, 1′-H), 6.76 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.83 (t, *J* = 7.3 Hz, 1 H, 5-H), 7.10 (t, *J* = 7.8 Hz, 1 H, 6-H), 7.14 (d, *J* = 7.3 Hz, 1 H, 4-H), 7.26–7.36 (m, 5 H, OCH$_2$*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.7 (CH_3, 2′-Me), 36.7 (CH_2, C-3), 68.6 (CH_2, C-3′), 72.1 (CH_2, O*C*H$_2$Ph), 78.7 (CH, C-2), 109.4 (CH, C-7), 120.3 (CH, C-5), 124.8 (CH, C-4), 126.9 (C, C-3a), 127.7 (CH, C-4″), 127.8 (2 × CH, C-2″, C-6″), 128.0 (CH, C-6), 128.4 (2 × CH, C-3″, C-5″), 128.7 (CH, C-1′), 137.5 (C, C-2′), 138.1 (C, C-1″), 159.3 (C, C-7a).

(±)-(*E*/*Z*)-2-[4-(Benzyloxy)-2-methylbut-1-enyl]-2,3-dihydrobenzofuran (38)

According to general procedure A, reaction of alkene **44** (217 mg, 1.231 mmol) and Grubbs II catalyst (9 mg, 0.011 mmol, 5 mol%) with alkene **11** (30 mg, 0.205 mmol) for 48 h gave the title compound as a mixture of *E*/*Z* isomers in the ratio 2.1:1 (as determined by ^{1}H NMR spectroscopy). These isomers were separated for characterization purposes.

Clear oil; yield: 35 mg, 0.119 mmol (58%).

***E*-Isomer**

Clear oil; yield: 23.7 mg, 0.081 mmol (39% of 58%).

IR (neat): 3029, 2920, 2853, 1674, 1596, 1478, 1460, 1379, 1361, 1228, 1097, 961, 870, 747, 697 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.80 (s, 3 H, 2′-Me), 2.39 (td, *J* = 6.7, 2.6 Hz, 2 H, 3′-H), 2.93 (dd, *J* = 15.4, 7.7 Hz, 1 H, 3-H$_a$), 3.33 (dd, *J* = 15.4, 8.1 Hz, 1 H, 3-H$_b$), 3.60 (t, *J* = 6.9 Hz, 2 H, 4′-H), 4.51 (s, 2 H, OC*H*$_2$Ph), 5.44–5.52 (m, 2 H, 1′-H, 2-H), 6.76 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.83 (t, *J* = 7.3 Hz, 1 H, 5-H), 7.10 (t, *J* = 7.7 Hz, 1 H, 6-H), 7.15 (d, *J* = 7.2 Hz, 1 H, 4-H), 7.25–7.33 (m, 5 H, OCH$_2$*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.1 (CH_3, 2′-Me), 36.6 (CH_2, C-3), 39.4 (CH_2, C-3′), 68.6 (CH_2, C-4′), 72.9 (CH_2, O*C*H$_2$Ph), 79.6 (CH, C-2), 109.4 (CH, C-7), 120.2 (CH, C-5), 124.8 (CH, C-4), 126.0 (CH, C-1′), 127.1 (C, C-3a), 127.56 (CH, C-4″), 127.64 (2 × CH, C-2″, C-6″), 128.0 (CH, C-6), 128.4 (2 × CH, C-3″, C-5″), 138.2 (C, C-2′), 138.4 (C, C-1″), 159.4 (C, C-7a).

MS (EI, 70 eV): *m*/*z* (%) = 294 (15) [M$^+$], 203 (10), 185 (17), 173 (33), 160 (10), 145 (8), 131 (9), 119 (5), 107 (12), 91 (100), 81 (8), 71 (10), 57 (16), 41 (13).

HRMS (EI): *m*/*z* [M$^+$] calcd for $C_{20}H_{22}O_2$: 294.1620; found: 294.1626.

***Z*-Isomer**

Pale-yellow oil; yield: 11.3 mg, 0.038 mmol (19% of 58%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.81 (d, *J* = 1.2 Hz, 3 H, 2′-Me), 2.39 (ddd, *J* = 13.4, 6.6, 6.6 Hz, 1 H, 3′-H$_a$), 2.62 (ddd, *J* = 13.4, 7.5, 7.6 Hz, 1 H, 3′-H$_b$), 2.89 (dd, *J* = 15.5, 8.3 Hz, 1 H, 3-H$_a$), 3.23 (dd, *J* = 15.5, 8.7 Hz, 1 H, 3-H$_b$), 3.54 (ddd, *J* = 9.1, 7.2, 7.2 Hz, 1 H, 4′-H$_a$), 3.60 (ddd, *J* = 9.2, 5.8, 7.4 Hz, 1 H, 4′-H$_b$), 4.51 (d, *J* = 12.1 Hz, 1 H, OC*H*$_a$H$_b$Ph), 4.55 (d, *J* = 12.1 Hz, 1 H, OCH$_a$*H*$_b$Ph), 5.47 (q, *J* = 8.7 Hz, 1 H, 2-H), 5.55 (d, *J* = 8.7 Hz, 1 H, 1′-H), 6.75 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.82 (td, *J* = 7.5, 0.8 Hz, 1 H, 5-H), 7.07–7.12 (m, 2 H, 4-H, 6-H), 7.26–7.35 (m, 5 H, OCH$_2$*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.0 (CH_3, 2′-Me), 32.9 (CH_2, C-3′), 36.6 (CH_2, C-3), 68.6 (CH_2, C-4′), 73.0 (CH_2, O*C*H$_2$Ph), 79.5 (CH, C-2), 109.3 (CH, C-7), 120.2 (CH, C-5), 124.7 (CH, C-4), 126.9 (CH, C-1′), 127.2 (C, C-3a), 127.57 (CH, C-4″), 127.61 (2 × CH, C-2″, C-6″), 127.9 (CH, C-6), 128.4 (2 × CH, C-3″, C-5″), 138.1 (C, C-2′), 138.4 (C, C-1″), 159.4 (C, C-7a).

(±)-(*E*/*Z*)-2-[3-(Benzyloxy)-2-methylprop-1-enyl]chroman (39)

According to general procedure A, reaction of alkene **43** (122 mg, 0.75 mmol) and Grubbs II catalyst (8 mg, 0.009 mmol, 5 mol%) with alkene **41** (30 mg, 0.19 mmol) for 70 h gave the title compound as a mixture of *E*/*Z* isomers in the ratio 3.5:1 (as determined by ^{1}H NMR spectroscopy). These isomers were separated for characterization purposes.

Clear oil; yield: 28 mg, 0.095 mmol (51%).

***E*-Isomer**

Clear oil; yield: 21.8 mg, 0.074 mmol (40% of 51%).

IR (neat): 3060, 3027, 2923, 2850, 1581, 1522, 1487, 1455, 1231, 1094, 1068, 1045, 750, 735, 697 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.77 (s, 3 H, 2′-Me), 1.83–1.93 (m, 1 H, 3-H$_{ax}$), 2.01 (dddd, *J* = 16.5, 5.9, 3.0, 3.0 Hz, 1 H, 3-H$_{eq}$), 2.79 (dt, *J* = 16.6, 4.4 Hz, 1 H, 4-H$_{eq}$), 2.91 (ddd, *J* = 16.6, 10.8, 6.0 Hz, 1 H, 4-H$_{ax}$), 3.97 (s, 2 H, 3′-H), 4.50 (s, 2 H, OC*H*$_2$Ph), 4.81 (td, *J* = 9.0, 2.5 Hz, 1 H, 2-H), 5.68 (d, *J* = 7.8 Hz, 1 H, 1′-H), 6.81–6.85 (m, 2 H, 6-H, 8-H), 7.04–7.10 (m, 2 H, 5-H, 7-H), 7.27–7.35 (m, 5 H, OCH$_2$*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.4 (CH_3, 2′-Me), 24.5 (CH_2, C-4), 27.8 (CH_2, C-3), 72.0 (CH_2, O*C*H$_2$Ph), 72.5 (CH, C-2), 75.3

(CH_2, C-3′), 116.9 (CH, C-6 or C-8), 120.1 (CH, C-6 or C-8), 121.7 (C, C-4a), 126.7 (CH, C-1′), 127.2 (CH, C-7), 127.6 (CH, C-4″), 127.7 (2 × CH, C-2″, C-6″), 128.4 (2 × CH, C-3″, C-5″), 129.5 (CH, C-5), 136.4 (C, C-2′), 138.3 (C, C-1″), 154.7 (C, C-8a).

MS (EI, 70 eV): *m*/*z* (%) = 294 (11) [M^+], 235 (4), 217 (7), 199 (3), 187 (6), 174 (6), 160 (10), 145 (8), 131 (8), 107 (68), 91 (100), 81 (8), 77 (11), 65 (9), 44 (8), 41 (8).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{20}H_{22}O_2$: 294.1620; found: 294.1612.

Z-Isomer

Pale-yellow oil; yield: 6.2 mg, 0.021 mmol (11% of 51%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.82–1.91 (m, 1 H, 3-H_{ax}), 1.89 (s, 3 H, 2′-Me), 1.92–1.99 (m, 1 H, 3-H_{eq}), 2.75 (dt, *J* = 16.4, 4.4 Hz, 1 H, 4-H_{eq}), 2.83 (ddd, *J* = 16.6, 10.9, 5.9 Hz, 1 H, 4-H_{ax}), 4.05 (d, *J* = 11.8 Hz, 1 H, 3′-H_a), 4.16 (d, *J* = 11.7 Hz, 1 H, 3′-H_b), 4.47 (d, *J* = 11.9 Hz, 1 H, OC$H_a$$H_b$Ph), 4.51 (d, *J* = 11.9 Hz, 1 H, OC$H_a$$H_b$-Ph), 4.74 (td, *J* = 9.2, 2.1 Hz, 1 H, 2-H), 5.58 (d, *J* = 8.5 Hz, 1 H, 1′-H), 6.79–6.85 (m, 2 H, 6-H, 8-H), 7.03–7.10 (m, 2 H, 5-H, 7-H), 7.27–7.36 (m, 5 H, OCH_2*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.7 (CH_3, 2′-Me), 24.5 (CH_2, C-4), 28.2 (CH_2, C-3), 68.6 (CH_2, C-3′), 71.97 (CH, C-2), 71.99 (CH_2, O*C*H_2Ph), 116.9 (CH, C-6 or C-8), 120.1 (CH, C-6 or C-8), 121.7 (C, C-4a), 127.2 (CH, C-7), 127.6 (CH, C-4″), 127.7 (2 × CH, C-2″, C-6″), 128.4 (2 × CH, C-3″, C-5″), 128.6 (CH, C-1′), 129.5 (CH, C-5), 137.1 (C, C-2′), 138.2 (C, C-1″), 154.6 (C, C-8a).

(±)-(*E*/*Z*)-2-[4-(Benzyloxy)-2-methylbut-1-enyl]chroman (40)

According to general procedure A, reaction of alkene **44** (198 mg, 1.12 mmol) and Grubbs II catalyst (8 mg, 0.009 mmol, 5 mol%) with alkene **41** (30 mg, 0.19 mmol) for 14 h gave the title compound as a mixture of *E*/*Z* isomers in the ratio 1.1:1 (as determined by ^{1}H NMR spectroscopy). These isomers were separated for characterization purposes.

Clear oil; yield: 22 mg, 0.071 mmol (38%).

***E*-Isomer**

Clear oil; yield: 11.5 mg, 0.037 mmol (20% of 38%).

IR (neat): 3060, 3028, 2920, 2851, 1670, 1581, 1487, 1455, 1361, 1230, 1103, 1069, 1043, 750, 734, 697 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.77 (s, 3 H, 2′-Me), 1.82–1.89 (m, 1 H, 3-H_{ax}), 1.94–2.00 (m, 1 H, 3-H_{eq}), 2.37 (ddd, *J* = 13.9, 6.9, 6.9 Hz, 1 H, 3′-H_a), 2.42 (ddd, *J* = 13.3, 6.7, 6.7 Hz, 1 H, 3′-H_b), 2.77 (dt, *J* = 16.4, 4.3 Hz, 1 H, 4-H_{eq}), 2.89 (ddd, *J* = 16.4, 10.9, 5.8 Hz, 1 H, 4-H_{ax}), 3.61 (t, *J* = 6.9 Hz, 2 H, 4′-H), 4.52 (s, 2 H, OCH_2Ph), 4.76 (td, *J* = 9.0, 2.0 Hz, 1 H, 2-H), 5.43 (d, *J* = 8.2 Hz, 1 H, 1′-H), 6.81–6.85 (m, 2 H, 6-H, H-8), 7.03–7.09 (m, 2 H, 5-H, 7-H), 7.26–7.34 (m, 5 H, OCH_2*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.1 (CH_3, 2′-Me), 24.7 (CH_2, C-4), 27.9 (CH_2, C-3), 39.5 (CH_2, C-3′), 68.7 (CH_2, C-4′), 72.8 (CH, C-2), 72.9 (CH_2, O*C*H_2Ph), 116.9 (CH, C-6 or C-8), 120.0 (CH, C-6 or C-8), 121.8 (C, C-4a), 125.9 (CH, C-1′), 127.2 (CH, C-7), 127.5 (CH, C-4″), 127.6 (2 × CH, C-2″, C-6″), 128.3 (2 × CH, C-3″, C-5″), 129.5 (CH, C-5), 137.2 (C, C-2′), 138.4 (C, C-1″), 154.9 (C, C-8a).

MS (EI, 70 eV): *m*/*z* (%) = 308 (11) [M^+], 235 (4), 217 (7), 199 (3), 187 (6), 174 (6), 160 (10), 145 (8), 131 (8), 107 (68), 91 (100), 81 (8), 77 (11), 65 (9), 44 (8), 41 (8).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{21}H_{24}O_2$: 308.1776; found: 308.1778.

***Z*-Isomer**

Clear oil; yield: 10.5 mg, 0.034 mmol (18% of 38%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.76–1.86 (m, 1 H, 3-H_{ax}), 1.82 (s, 3 H, 2′-Me), 1.90–1.96 (m, 1 H, 3-H_{eq}), 2.38 (ddd, *J* = 13.2, 6.5, 6.5 Hz, 1 H, 3′-H_a), 2.57 (ddd, *J* = 13.7, 7.1, 7.1 Hz, 1 H, 3′-H_b), 2.72 (dt, *J* = 16.6, 4.0 Hz, 1 H, 4-H_{eq}), 2.83 (ddd, *J* = 16.4, 11.0, 5.7 Hz, 1 H, 4-H_{ax}), 3.52–3.62 (m, 2 H, 4′-H), 4.51 (s, 2 H, OCH_2Ph), 4.75 (td, *J* = 9.3, 1.9 Hz, 1 H, 2-H), 5.46 (d, *J* = 8.4 Hz, 1 H, 1′-H), 6.78–6.84 (m, 2 H, 6-H, 8-H), 7.02–7.09 (m, 2 H, 5-H, 7-H), 7.27–7.33 (m, 5 H, OCH_2*Ph*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.0 (CH_3, 2′-Me), 24.7 (CH_2, C-4), 28.2 (CH_2, C-3), 33.1 (CH_2, C-3′), 68.6 (CH_2, C-4′), 72.6 (CH, C-2), 72.9 (CH_2, O*C*H_2Ph), 116.9 (CH, C-6 or C-8), 120.0 (CH, C-6 or C-8), 121.8 (C, C-4a), 126.8 (CH, C-1′), 127.1 (CH, C-7), 127.5 (CH, C-4″), 127.6 (2 × CH, C-2″, C-6″), 128.3 (2 × CH, C-3″, C-5″), 129.5 (CH, C-5), 137.5 (C, C-2′), 138.4 (C, C-1″), 154.9 (C, C-8a).

The cross-metathesis side products (±)-(*E*)-2-styryl-2,3-dihydrobenzofuran and (*E*)-2-styrylchroman (Table 1) were assigned according to comparison with the literature.[32]

(±)-4-(2,3-Dihydrobenzofuran-2-yl)butan-1-ol (31)[33]

According to general procedure B (conditions B), the title compound was obtained from reaction of Pd/C (10 wt%, 14 mg) with heterodimer **36** (33 mg, 0.118 mmol) in EtOAc (2 mL) for 4 h.

Pale-yellow oil; yield: 12 mg, 0.061 mmol (52%).

IR (neat): 3352, 2918, 2850, 1598, 1480, 1461, 1377, 1264, 1231, 1173, 1057, 1028, 1015, 869, 738 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.47–1.67 (m, 4 H, 2-H, 3-H), 1.70–1.77 (m, 1 H, 4-H_a), 1.81–1.92 (m, 1 H, 4-H_b), 2.86 (dd, *J* = 15.4, 7.8 Hz, 1 H, 3′-H_a), 3.28 (dd, *J* = 15.5, 8.9 Hz, 1 H, 3′-H_b), 3.68 (t, *J* = 6.2 Hz, 2 H, 1-H), 4.77 (tdd, *J* = 9.0, 7.4, 5.4 Hz, 1 H, 2′-H), 6.75 (d, *J* = 8.0 Hz, 1 H, 7′-H), 6.81 (td, *J* = 7.4, 0.8 Hz, 1 H, 5′-H), 7.09 (t, *J* = 7.8 Hz, 1 H, 6′-H), 7.14 (d, *J* = 7.3 Hz, 1 H, 4′-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.7 (CH_2, C-3), 32.6 (CH_2, C-2), 35.5 (CH_2, C-3′), 35.8 (CH_2, C-4), 62.8 (CH_2, C-1), 83.1 (CH, C-2′), 109.3 (CH, C-7′), 120.1 (CH, C-5′), 124.9 (CH, C-4′), 126.8 (C, C-3′a), 127.9 (CH, C-6′), 159.5 (C, C-7′a).

MS (EI, 70 eV): *m*/*z* (%) = 192 (65) [M^+], 174 (6), 159 (12), 145 (23), 133 (34), 131 (35), 119 (31), 107 (78), 92 (8), 91 (65), 39 (23), 85 (100), 77 (28), 65 (17), 51 (14), 41 (15).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{16}O_2$: 192.1150; found: 192.1156.

No ^{1}H NMR or ^{13}C NMR data were reported in the literature.[33]

(±)-3-(2,3-Dihydrobenzofuran-2-yl)-2-methylpropan-1-ol (32)

According to general procedure B (conditions A), reaction of $Pd(OH)_2$ [20 wt% Pd (dry basis) on carbon, 5 mg] with heterodimer **37** (21 mg, 0.075 mmol) in MeOH (2 mL) for 2.5 h gave the title compound as a mixture of inseparable diastereomers in the ratio 1:1.

Pale-yellow oil; yield: 12 mg, 0.062 mmol (83%).

IR (neat): 3392, 3045, 2923, 2848, 1597, 1480, 1461, 1373, 1264, 1230, 1033 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.03 (d, *J* = 6.6 Hz, 3 H, 2-Me, 2-Me*), 1.54 (ddd, *J* = 13.6, 6.9, 3.5 Hz, 0.5 H, 3-H_a), 1.79 (t, *J* = 6.5 Hz, 1 H, 3-H_a*, 3-H_b*), 1.89–2.01 (m, 1.5 H, 2-H, 2-H*, 3-H_b), 2.85 (dd, *J* = 15.4, 7.9 Hz, 1 H, 3′-H_a, 3′-H_a*), 3.29 (dd, *J* = 14.9, 8.9 Hz, 0.5 H, 3′-H_b), 3.33 (dd, *J* = 13.2, 9.0 Hz, 0.5 H, 3′-H_b*), 3.51–3.59 (m, 2 H, 1-H, 1-H*), 4.86–4.95 (m, 1 H, 2′-H, 2′-H*), 6.75 (d, *J* = 7.9 Hz, 1 H, 7′-H, 7′-H*), 6.83 (t, *J* = 7.3 Hz, 1 H, 5′-H, 5′-H*), 7.10 (t, *J* = 7.6 Hz, 1 H, 6′-H, 6′-H*), 7.15 (d, *J* = 7.2 Hz, 1 H, 4′-H, 4′-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.0, 17.2 (2 × CH_3, 2-Me), 32.8, 33.7 (2 × CH, C-2), 35.9, 36.4 (2 × CH_2, C-3′), 39.6, 40.7 (2 × CH_2,

C-3), 67.6, 68.4 (2 × CH_2, C-1), 81.4, 81.8 (2 × CH, C-2′), 109.35, 109.39 (2 × CH, C-7′), 120.3, 120.4 (2 × CH, C-5′), 124.91, 124.93 (2 × CH, C-4′), 126.8 (2 × C, C-3′a), 128.0 (2 × CH, C-6′), 159.1, 159.3 (2 × C, C-7′a).

MS (EI, 70 eV): *m*/*z* (%) = 192 (14) [M^+], 174 (1), 161 (4), 159 (6), 145 (4), 133 (14), 131 (10), 119 (15), 115 (3), 107 (25), 105 (6), 91 (30), 85 (100), 77 (11), 65 (8), 57 (19), 51 (7), 41 (16), 39 (14).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{12}H_{16}O_2$: 192.1150; found: 192.1156.

(±)-4-(2,3-Dihydrobenzofuran-2-yl)-3-methylbutan-1-ol (33)

According to general procedure B (conditions B), reaction of Pd/C (10 wt%, 14 mg) with heterodimer **38** (11 mg, 0.037 mmol) in EtOAc (1 mL) for 3.5 h gave the title compound as a mixture of inseparable diastereomers in the ratio 1:1.

Yellow oil; yield: 7.7 mg, 0.037 mmol (100%).

IR (neat): 3364, 2925, 2848, 1597, 1480, 1460, 1378, 1264, 1230, 1053, 1015 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.01 (d, *J* = 6.8 Hz, 1.5 H, 3-Me), 1.03 (d, *J* = 6.9 Hz, 1.5 H, 3-Me*), 1.42–1.55 (m, 1.5 H, 2-H_a, 2-H_a*, 4-H_a), 1.60–1.69 (m, 1.5 H, 2-H_b, 2-H_b*, 4-H_a*), 1.72–1.82 (m, 0.5 H, 4-H_b*), 1.87–1.99 (m, 1.5 H, 3-H, 3-H*, 4-H_b), 2.83 (dd, *J* = 15.1, 7.7 Hz, 0.5 H, 3′-H_a), 2.84 (dd, *J* = 15.3, 7.9 Hz, 0.5 H, 3′-H_a*), 3.29 (dd, *J* = 15.3, 8.3 Hz, 0.5 H, 3′-H_b), 3.30 (dd, *J* = 15.4, 7.1 Hz, 0.5 H, 3′-H_b*), 3.67–3.79 (m, 2 H, 1-H, 1-H*), 4.84–4.92 (m, 1 H, 2′-H, 2′-H*), 6.75 (d, *J* = 8.0 Hz, 1 H, 7′-H, 7′-H*), 6.82 (t, *J* = 7.3 Hz, 1 H, 5′-H, 5′-H*), 7.10 (t, *J* = 7.8 Hz, 1 H, 6-H, 6′-H*), 7.15 (d, *J* = 7.2 Hz, 1 H, 4′-H, 4′-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.6, 20.1 (2 × CH_3, 3-Me), 26.67, 26.69 (2 × CH, C-3), 35.8, 36.2 (2 × CH_2, C-3′), 39.6, 40.2 (2 × CH_2, C-2), 43.3, 43.7 (2 × CH_2, C-4), 60.85, 60.90 (2 × CH_2, C-1), 81.4, 81.6 (2 × CH, C-2′), 109.3, 109.4 (2 × CH, C-7′), 120.2 (2 × CH, C-5′), 124.9 (2 × CH, C-4′), 126.8, 126.9 (2 × C, C-3′a), 127.9 (2 × CH, C-6′), 159.4, 159.5 (2 × C, C-7′a).

MS (EI, 70 eV): *m*/*z* (%) = 206 (31) [M^+], 185 (4), 173 (8), 159 (6), 149 (9), 145 (10), 133 (48), 119 (31), 107 (80), 99 (100), 91 (64), 81 (37), 69 (21), 55 (33), 41 (40).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{13}H_{18}O_2$: 206.1307; found: 206.1312.

(±)-3-(Chroman-2-yl)-2-methylpropan-1-ol (34)

According to general procedure B (conditions A), reaction of $Pd(OH)_2$ [20 wt% Pd (dry basis) on carbon, 26 mg] with heterodimer **39** (28 mg, 0.095 mmol) in MeOH (2 mL) for 5 h gave the title compound as a mixture of inseparable diastereomers in the ratio 1:1.

Light-brown oil; yield: 15 mg, 0.073 mmol (76%).

IR (neat): 3362, 2924, 2872, 1581, 1487, 1456, 1380, 1231, 1107, 1039, 751 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 1.00 (d, *J* = 6.8 Hz, 1.5 H, 2-Me), 1.01 (d, *J* = 6.9 Hz, 1.5 H, 2-Me*), 1.44 (ddd, *J* = 14.3, 7.5, 2.9 Hz, 0.5 H, 3-H_a), 1.68–1.72 (m, 1 H, 3-H_a*, 3-H_b*), 1.74–1.87 (m, 1.5 H, 3-H_b, 3′-H_{ax}, 3′-H_{ax}*), 1.93–2.02 (m, 2 H, H-2, H-2*, 3′-H_{eq}, 3′-H_{eq}*), 2.75 (ddd, *J* = 16.6, 5.7, 3.4 Hz, 1 H, 4′-H_{eq}, 4′-H_{eq}*), 2.81–2.92 (m, 1 H, 4′-H_{ax}, 4′-H_{ax}*), 3.50–3.61 (m, 2 H, 1-H, 1-H*), 4.07–4.18 (m, 1 H, 2′-H, 2′-H*), 6.78 (d, *J* = 8.1 Hz, 1 H, 8′-H, 8′-H*), 6.83 (t, *J* = 7.4 Hz, 1 H, 6′-H, 6′-H*), 7.03–7.09 (m, 2 H, 5′-H, 5′-H*, 7′-H, 7′-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.2, 17.3 (2 × CH_3, 2 × 2-Me), 24.7 (2 × CH_2, C-4′), 27.8, 28.4 (2 × CH_2, C-3′), 32.4, 33.3 (2 × CH, C-2), 38.9, 39.9 (2 × CH_2, C-3), 67.7, 68.5 (2 × CH_2, C-1), 73.9, 74.4 (2 × CH, C-2′), 116.7 (2 × CH, C-8′), 120.20, 120.24 (2 × CH, C-6′), 121.98, 122.01 (2 × C, C-4′a), 127.2 (2 × CH, C-7′), 129.6 (2 × CH, C-5′), 154.6, 154.7 (2 × C, C-8′a).

MS (EI, 70 eV): *m*/*z* (%) = 206 (1) [M^+], 185 (7), 149 (5), 147 (6), 133 (5), 131 (7), 121 (11), 111 (6), 105 (11), 92 (11), 83 (18), 77 (19), 69 (33), 57 (85), 55 (64), 43 (100), 38 (5).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{13}H_{18}O_2$: 206.1307; found: 206.1311.

(±)-4-(Chroman-2-yl)-3-methylbutan-1-ol (35)

According to general procedure B (conditions B), reaction of Pd/C (10 wt%, 6 mg) with heterodimer **40** (7 mg, 0.023 mmol) in EtOAc (1 mL) for 3.5 h gave the title compound as a mixture of inseparable diastereomers in the ratio 1:1.

Pale-yellow oil; yield: 3.13 mg, 0.014 mmol (63%).

IR (neat): 3359, 2925, 2848, 1582, 1488, 1456, 1379, 1264, 1232, 1105, 1048, 735, 703 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.99 (d, *J* = 6.2 Hz, 1.5 H, 3-Me), 1.00 (d, *J* = 6.2 Hz, 1.5 H, 3-Me*), 1.30–1.38 (m, 0.5 H, 4-H_a*), 1.42–1.83 (m, 4.5 H, 2-H, 2-H*, 3′-H_{ax}, 3′-H_{ax}*, 4-H_a*, 4-H_b, 4-H_b*), 1.89–2.06 (m, 2 H, 3-H, 3-H*, 3′-H_{eq}, 3′-H_{eq}*), 2.74 (dt, *J* = 16.2, 4.3 Hz, 1 H, 4′-H_{eq}, 4′-H_{eq}*), 2.81–2.90 (m, 1 H, 4′-H_{ax}, 4′-H_{ax}*), 3.67–3.78 (m, 2 H, 1-H, 1-H*), 4.05–4.13 (m, 1 H, 2′-H, 2′-H*), 6.77–6.84 (m, 2 H, 6′-H, 6′-H*, 8′-H, 8′-H*), 7.02–7.09 (m, 2 H, 5′-H, 5′-H*, 7′-H, 7′-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.7, 20.3 (2 × CH_3, 3-Me), 24.7, 24.8 (2 × CH_2, C-4′), 25.9, 26.2 (2 × CH, C-3), 27.6, 28.2 (2 × CH_2, C-3′), 39.6, 40.3 (2 × CH_2, C-2), 42.5, 42.8 (2 × CH_2, C-4), 60.9, 61.0 (2 × CH_2, C-1), 73.7, 74.0 (2 × CH, C-2′), 116.7 (2 × CH, C-6′ or C-8′), 120.0 (2 × CH, C-6′ or C-8′), 122.0 (2 × C, C-4′a), 127.1 (2 × CH, C-7′), 129.5 (2 × CH, C-5′), 154.9 (2 × C, C-8′a).

MS (EI, 70 eV): *m*/*z* (%) = 220 (50) [M^+], 185 (11), 173 (4), 167 (4), 159 (4), 149 (12), 147 (9), 133 (40), 131 (10), 120 (39), 107 (100), 105 (15), 95 (30), 91 (14), 85 (14), 77 (18), 71 (23), 69 (21), 57 (32), 55 (24), 43 (29), 39 (10).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{20}O_2$: 220.1463; found: 220.1465.

(±)-2-(2-Methylbutyl)chroman (48)

According to general procedure B (conditions A), reaction of $Pd(OH)_2$ [20 wt% Pd (dry basis) on carbon, 20 mg] with heterodimer **40** (38 mg, 0.123 mmol) in MeOH (2 mL) for 2.5 h gave the title compound as a mixture of inseparable diastereomers in the ratio 1:1.

Yellow oil; yield: 15.9 mg, 0.078 mmol (63%).

IR (neat): 2954, 2922, 2869, 2848, 1582, 1488, 1456, 1377, 1299, 1271, 1232, 1108, 1067, 1046, 991, 887 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.90 (t, *J* = 7.4 Hz, 1.5 H, 4′-H), 0.91 (t, *J* = 7.4 Hz, 1.5 H, 4′-H*), 0.937 (d, *J* = 6.6 Hz, 1.5 H, 2′-Me), 0.943 (d, *J* = 6.3 Hz, 1.5 H, 2′-Me*), 1.17–1.49 (m, 2.5 H, 1′-H_a, 3′-H, 3′-H*), 1.51–1.81 (m, 3.5 H, 3-H_{ax}, 3-H_{ax}*, 1′-H_a*, 1′-H_b, 1′-H_b*, 2′-H, 2′-H*), 1.92–2.02 (m, 1 H, 3-H_{eq}, 3-H_{eq}*), 2.74 (ddd, *J* = 16.5, 5.6, 3.5 Hz, 1 H, 4-H_{eq}, 4-H_{eq}*), 2.84 (ddd, *J* = 16.6, 11.0, 5.7 Hz, 0.5 H, 4-H_{ax}), 2.85 (ddd, *J* = 16.6, 11.2, 5.6 Hz, 0.5 H, 4-H_{ax}*), 4.04–4.10 (m, 1 H, 2-H, 2-H*), 6.77–6.83 (m, 2 H, 6-H, 6-H*, 8-H, 8-H*), 7.02–7.08 (m, 2 H, 5-H, 5-H*, 7-H, 7-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 11.17, 11.24 (2 × CH_3, C-4′), 18.9, 19.6 (2 × CH_3, 2′-Me), 24.7, 24.8 (2 × CH_2, C-4), 27.6, 28.2 (2 × CH_2, C-3), 29.3, 30.0 (2 × CH_2, C-3′), 30.5, 30.9 (2 × CH, C-2′), 42.2, 42.5 (2 × CH_2, C-1′), 73.7, 74.3 (2 × CH, C-2), 116.77, 116.79 (2 × CH, C-6 or C-8), 119.8 (2 × CH, C-6 or C-8), 122.1 (2 × C, C-4a), 127.1 (2 × CH, C-7), 129.5 (2 × CH, C-5), 155.08, 155.10 (2 × C, C-8a).

MS (EI, 70 eV): *m/z* (%) = 204 (7) [M$^+$], 203 (8), 165 (7), 120 (16), 105 (27), 89 (27), 71 (13).

HRMS-FAB: *m/z* [M$^+$] calcd for $C_{14}H_{20}O$: 204.1514; found: 204.1521.

(±)-3′,4′,5′,6′-Tetrahydro-3*H*-spiro(benzofuran-2,2′-pyran) (26)[9]

According to general procedure C, the title compound was obtained from reaction of $PhI(OAc)_2$ (34 mg, 0.106 mmol) and I_2 (30 mg, 0.118 mmol) with alcohol **31** (10 mg, 0.052 mmol) in cyclohexane (4.3 mL) for 2.5 h.

Colorless oil; yield: 4 mg, 0.021 mmol (40%).

IR (neat): 2923, 2848, 1598, 1479, 1461, 1366, 1239, 1089, 1071, 1046, 867, 809, 793, 771, 746, 707 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.60–1.73 (m, 2 H, 5′-H_{ax}, 5′-H_{eq}), 1.75–1.80 (m, 1 H, 4′-H_{eq}), 1.88 (dd, *J* = 13.6, 4.5 Hz, 1 H, 3′-H_{eq}), 1.98–2.08 (m, 2 H, 3′-H_{ax}, 4′-H_{ax}), 3.05 (d, *J* = 16.2 Hz, 1 H, 3-H_a), 3.11 (d, *J* = 16.2 Hz, 1 H, 3-H_b), 3.72 (dddd, *J* = 11.4, 4.3, 2.0, 2.0 Hz, 1 H, 6′-H_{eq}), 4.08 (td, *J* = 11.7, 2.9 Hz, 1 H, 6′-H_{ax}), 6.81–6.88 (m, 2 H, 5-H, 7-H), 7.11–7.17 (m, 2 H, 4-H, 6-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.7 (CH_2, C-4′), 24.7 (CH_2, C-5′), 34.1 (CH_2, C-3′), 42.7 (CH_2, C-3), 62.8 (CH_2, C-6′), 109.6 (C, C-2), 109.7 (CH, C-7), 120.6 (CH, C-5), 125.0 (CH, C-4), 126.0 (C, C-3a), 127.9 (CH, C-6), 158.2 (C, C-7a).

MS (EI, 70 eV): *m/z* (%) = 190 (1) [M$^+$], 120 (2), 118 (3), 85 (65), 83 (100), 47 (33), 37 (11).

HRMS (EI): *m/z* [M$^+$] calcd for $C_{12}H_{14}O_2$: 190.0994; found: 190.0991.

No ^{1}H NMR or ^{13}C NMR data were reported in the literature.[9]

(±)-4′-Methyl-3′,4′,5′,6′-tetrahydro-3*H*-spiro(benzofuran-2,2′-pyran) (27)

According to general procedure C, the title compound was obtained from reaction of $PhI(OAc)_2$ (53 mg, 0.165 mmol) and I_2 (47 mg, 0.185 mmol) with a 1:1 mixture of diastereomeric alcohols **33** (17 mg, 0.082 mmol) in cyclohexane (6.9 mL) for 3 h.

Pale-yellow oil; yield: 7 mg, 0.034 mmol (42%).

IR (neat): 2946, 2925, 2869, 1597, 1479, 1461, 1377, 1238, 1216, 1121, 1096, 1084, 1034, 869, 826, 810, 791, 776, 747, 706 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.98 (d, *J* = 6.6 Hz, 3 H, 4′-Me), 1.33 (qd, *J* = 12.8, 4.9 Hz, 1 H, 5′-H_{ax}), 1.47 (dd, *J* = 13.1, 12.5 Hz, 1 H, 3′-H_{ax}), 1.64 (dtd, *J* = 13.2, 3.8, 1.9 Hz, 1 H, 5′-H_{eq}), 2.03 (ddd, *J* = 13.4, 3.8, 1.8 Hz, 1 H, 3′-H_{eq}), 2.08–2.24 (m, 1 H, 4′-H_{ax}), 3.05 (d, *J* = 16.3 Hz, 1 H, 3-H_a), 3.12 (d, *J* = 16.3 Hz, 1 H, 3-H_b), 3.74 (ddd, *J* = 11.4, 4.9, 1.5 Hz, 1 H, 6′-H_{eq}), 4.06 (ddd, *J* = 13.0, 11.3, 2.4 Hz, 1 H, 6′-H_{ax}), 6.80 (d, *J* = 7.9 Hz, 1 H, 7-H), 6.85 (td, *J* = 7.4, 0.9 Hz, 1 H, 5-H), 7.10–7.17 (m, 2 H, 4-H, 6-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.1 (CH_3, 4′-Me), 26.2 (CH, C-4′), 33.3 (CH_2, C-5′), 42.5 (CH_2, C-3′), 42.8 (CH_2, C-3), 62.6 (CH_2, C-6′), 109.7 (CH, C-7), 109.8 (C, C-2), 120.6 (CH, C-5), 124.9 (CH, C-4), 126.0 (C, C-3a), 127.9 (CH, C-6), 158.2 (C, C-7a).

MS (EI, 70 eV): *m/z* (%) = 204 (100) [M$^+$], 203 (5), 189 (60), 145 (3), 134 (10), 131 (21), 121 (5), 115 (4), 107 (29), 97 (70), 91 (12), 78 (41), 69 (16), 55 (15), 51 (12), 41 (30).

HRMS (EI): *m/z* [M$^+$] calcd for $C_{13}H_{16}O_2$: 204.1150; found: 204.1146.

(±)-4′-Methyl-4′,5′-dihydro-3*H*,3′*H*-spiro(benzofuran-2,2′-furan) (28a and 28b)

According to general procedure C, reaction of $PhI(OAc)_2$ (37 mg, 0.115 mmol) and I_2 (33 mg, 0.130 mmol) with a 1:1 mixture of diastereomeric alcohols **32** (11 mg, 0.057 mmol) in cyclohexane (4.8 mL) for 2 h gave the title compound as a mixture of inseparable major (**28a**) and minor* (**28b**) diastereomers in the ratio 1.4:1.

Pale-yellow oil; yield: 8 mg, 0.042 mmol (73%).

IR (neat): 2954, 2924, 2855, 1598, 1479, 1462, 1377, 1241, 1120, 1082, 1010, 830, 779, 747, 706 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.13 (d, *J* = 6.8 Hz, 3 H, 4′-Me), 1.20 (d, *J* = 6.6 Hz, 2.1 H, 4′-Me*), 1.73 (dd, *J* = 12.9, 10.1 Hz, 1 H, 3′-H_B), 2.12 (dd, *J* = 13.6, 6.0 Hz, 0.7 H, 3′-H_A*), 2.38 (dd, *J* = 13.4, 9.4 Hz, 0.7 H, 3′-H_B*), 2.45–2.54 (m, 0.7 H, 4′-H*), 2.51 (dd, *J* = 12.9, 7.0 Hz, 1 H, 3′-H_A), 2.69–2.82 (m, 1 H, 4′-H), 3.23–3.32 (m, 3.4 H, 3-H, 3-H*), 3.56 (t, *J* = 8.0 Hz, 1 H, 5′-H_B), 3.68 (t, *J* = 8.2 Hz, 0.7 H, 5′-H_A*), 4.13 (t, *J* = 7.9 Hz, 0.7 H, 5′-H_B*), 4.25 (t, *J* = 8.0 Hz, 1 H, 5′-H_A), 6.76 (d, *J* = 8.4 Hz, 1 H, 7-H), 6.79 (d, *J* = 8.9 Hz, 0.7 H, 7-H*), 6.85 (t, *J* = 7.4 Hz, 1.7 H, 5-H, 5-H*), 7.11 (t, *J* = 7.9 Hz, 1.7 H, 6-H, 6-H*), 7.16 (d, *J* = 7.4 Hz, 1.7 H, 4-H, 4-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.7 (CH_3, 4′-Me), 18.0 (CH_3, 4′-Me*), 32.3 (CH, C-4′), 32.9 (CH, C-4′*), 39.0 (CH_2, C-3), 40.1 (CH_2, C-3*), 44.6 (CH_2, C-3′*), 45.2 (CH_2, C-3′), 75.3 (CH_2, C-5′*), 75.5 (CH_2, C-5′), 109.4 (CH, C-7), 109.5 (CH, C-7*), 118.6 (C, C-2*), 118.7 (C, C-2), 120.46 (CH, C-5), 120.51 (CH, C-5*), 124.49 (CH, C-4*), 124.53 (CH, C-4), 125.7 (C, C-3a), 125.8 (C, C-3a*), 127.89 (CH, C-6*), 127.94 (CH, C-6), 157.7 (C, C-7a), 158.0 (C, C-7a*).

MS (EI, 70 eV): *m/z* (%) = 190 (30) [M$^+$], 175 (9), 134 (4), 131 (6), 107 (21), 85 (66), 83 (100), 78 (10), 47 (42), 37 (21).

HRMS (EI): *m/z* [M$^+$] calcd for $C_{12}H_{14}O_2$: 190.0994; found: 190.0990.

(±)-4′-Methyl-4′,5′-dihydro-3′*H*-spiro(chroman-2,2′-furan) (29a and 29b)

According to general procedure C, reaction of $PhI(OAc)_2$ (41 mg, 0.127 mmol) and I_2 (36 mg, 0.142 mmol) with a 1:1 mixture of diastereomeric alcohols **34** (13 mg, 0.063 mmol) in cyclohexane (5.25 mL) for 3 h gave the title compound as a mixture of inseparable major (**29a**) and minor* (**29b**) diastereomers in the ratio 1.4:1.

Yellow oil; yield: 11.9 mg, 0.058 mmol (92%).

IR (neat): 2957, 2928, 2872, 1582, 1490, 1455, 1364, 1219, 1134, 1094, 1034, 1013, 838, 751 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.10 (d, *J* = 6.9 Hz, 3 H, 4′-Me), 1.18 (d, *J* = 6.9 Hz, 2.1 H, 4′-Me*), 1.52 (dd, *J* = 12.7, 9.2 Hz, 1 H, 3′-H_B), 1.91 (dd, *J* = 13.4, 7.1 Hz, 0.7 H, 3′-H_A*), 1.99–2.06 (m, 3.4 H, 3-H, 3-H*), 2.20 (dd, *J* = 13.3, 9.5 Hz, 0.7 H, 3′-H_B*), 2.37 (dd, *J* = 12.6, 7.5 Hz, 1 H, 3′-H_A), 2.41–2.49 (m, 0.7 H, 4′-H*), 2.68–2.84 (m, 2.7 H, 4-H_{eq}, 4-H_{eq}*, 4′-H), 3.00–3.08 (m, 1.7 H, 4-H_{ax}, 4-H_{ax}*), 3.51 (t, *J* = 7.5 Hz, 1 H, 5′-H_B), 3.64 (t, *J* = 8.6 Hz, 0.7 H, 5′-H_A*), 4.05 (t, *J* = 7.9 Hz, 0.7 H, 5′-H_B*), 4.21 (t, *J* = 8.0 Hz, 1 H, 5′-H_A), 6.76 (d, *J* = 8.0 Hz, 1 H, 8-H), 6.79 (d, *J* = 8.0 Hz, 0.7 H, 8-H*), 6.84 (t, *J* = 7.5 Hz, 1 H, 6-H), 6.85 (t, *J* = 7.4 Hz, 0.7 H, 6-H*), 7.05–7.10 (m, 3.4 H, 5-H, 5-H*, 7-H, 7-H*).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.6 (CH_3, 4′-Me*), 18.3 (CH_3, 4′-Me), 22.4 (CH_2, C-4*), 22.7 (CH_2, C-4), 30.4 (CH_2, C-3), 30.6 (CH_2, C-3*), 32.0 (CH, C-4′), 33.2 (CH, C-4′*), 45.4 (CH_2, C-3′*), 45.6 (CH_2, C-3′), 74.6 (CH_2, C-5′*), 75.1 (CH_2, C-5′), 107.2 (2 × C, C-2, C-2*), 117.0 (CH, C-8), 117.1 (CH, C-8*), 120.3 (CH, C-6), 120.5 (CH, C-6*), 121.7 (C, C-4a), 121.8 (C, C-4a*), 127.15 (CH, C-7*), 127.18 (CH, C-7), 129.08 (CH, C-5), 129.10 (CH, C-5*), 153.0 (C, C-8a), 153.1 (C, C-8a*).

MS (EI, 70 eV): *m/z* (%) = 204 (100) [M$^+$], 189 (53), 187 (9), 174 (7), 159 (16), 148 (23), 131 (45), 120 (27), 115 (8), 107 (94), 98 (19), 91 (88), 83 (33), 77 (27), 69 (13), 57 (28), 55 (27), 40 (44).

HRMS (EI): *m/z* [M$^+$] calcd for $C_{13}H_{16}O_2$: 204.1150; found: 204.1153.

(±)-4′-Methyl-3′,4′,5′,6′-tetrahydrospiro(chroman-2,2′-pyran) (30)

According to general procedure C, the title compound was obtained from reaction of $PhI(OAc)_2$ (53 mg, 0.165 mmol) and I_2 (47 mg, 0.185 mmol) with a 1:1 mixture of diastereomeric alcohols **35** (18 mg, 0.082 mmol) in cyclohexane (6.8 mL) for 3 h.

Pale-yellow oil; yield: 10.3 mg, 0.047 mmol (58%).

IR (neat): 2926, 2869, 1583, 1492, 1455, 1372, 1244, 1216, 1172, 1142, 1110, 1088, 1038, 837, 751 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 0.97 (d, *J* = 6.6 Hz, 3 H, 4′-Me), 1.23 (t, *J* = 13.0 Hz, 1 H, 3′-H_{ax}), 1.28 (qd, *J* = 13.1, 4.8 Hz, 1 H, 5′-H_{ax}), 1.62 (dtd, *J* = 13.2, 3.7, 1.9 Hz, 1 H, 5′-H_{eq}), 1.82 (td, *J* = 13.3, 6.2 Hz, 1 H, 3-H_{ax}), 1.90 (ddd, *J* = 13.3, 3.9, 1.8 Hz, 1 H, 3′-H_{eq}), 1.96 (ddd, *J* = 13.5, 6.5, 2.1 Hz, 1 H, 3-H_{eq}), 2.18–2.31 (m, 1 H, 4′-H_{ax}), 2.62 (ddd, *J* = 16.2, 6.1, 2.1 Hz, 1 H, 4-H_{eq}), 3.03 (ddd, *J* = 16.3, 13.0, 6.5 Hz, 1 H, 4-H_{ax}), 3.63 (ddd, *J* = 11.0, 5.2, 1.4 Hz, 1 H, 6′-H_{eq}), 3.81 (ddd, *J* = 12.9, 11.4, 2.4 Hz, 1 H, 6′-H_{ax}), 6.83 (dd, *J* = 8.2, 0.8 Hz, 1 H, 8-H), 6.87 (td, *J* = 7.4, 1.2 Hz, 1 H, 6-H), 7.06 (d, *J* = 7.6 Hz, 1 H, 5-H), 7.10 (t, *J* = 8.1 Hz, 1 H, 7-H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.1 (CH_2, C-4), 22.2 (CH_3, 4′-Me), 24.8 (CH, C-4′), 31.9 (CH_2, C-3), 33.9 (CH_2, C-5′), 43.4 (CH_2, C-3′), 61.7 (CH_2, C-6′), 96.3 (C, C-2), 116.9 (CH, C-8), 120.5 (CH, C-6), 122.7 (C, C-4a), 127.0 (CH, C-7), 129.2 (CH, C-5), 152.3 (C, C-8a).

MS (EI, 70 eV): *m*/*z* (%) = 218 (1) [M^+], 203 (1), 107 (5), 97 (30), 91 (78), 83 (32), 77 (30), 69 (47), 57 (77), 55 (80), 41 (100).

HRMS (EI): *m*/*z* [M^+] calcd for $C_{14}H_{18}O_2$: 218.1307; found: 218.1305.

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