A Novel Approach Towards Dibenzylbutyrolactone Lignans Involving Heck and Radical Reactions: Application to (±)-Matairesinol Synthesis

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A highly regio- and stereoselective Heck reaction of iodo-arenes with vinylated malonates, generated in situ by fluoride-induced protiodesilylation of alkenylsilanols/disiloxanes to give functionalized styrenes and 1,4-diaryl-1-butenes has been developed. The dibenzylbutyrolactone lignan skeletons have been achieved from 1,4-diaryl-1-butenes by two routes involving diastereoselective radical cyclization as the key step. This strategy has successfully been applied in the synthesis of (±)-matairesinol.

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Introduction

Lignans constitute a class of natural products which have widespread occurrence in various plants.[1] The classification of lignans is based on their carbon skeleton as shown in Figure 1. Although having modest size and complexity, these molecules possess a great diversity of structures associated with significant pharmacological activities. The most common feature in these molecules is that the two aryl groups are separated by a C-4 unit (Figure 1). The synthesis of dibenzylbutyrolactone lignans has attracted added attention because of their immunoregulatory,[2] neuroprotective,[3] anticancer,[4] tumor[5] and HIV[6] properties. Besides these, dibenzylbutyrolactone lignans have also served as intermediates in the synthesis of other classes of lignans.[7]

A number of strategies[8] have been developed to achieve stereocontrolled synthesis of dibenzylbutyrolactone lignans including diastereoselective conjugate addition to butenol-ide,[9] alkylation of succinic acid derivatives/butanolide,[10] oxidative homocoupling[11] and radical reactions.[12] We envisaged the functionalized 1,4-diaryl-1-butene **1** (Scheme 1) as a potent precursor for the synthesis of dibenzylbutyrolactone lignans because they possess two aryl groups with a 1,4-relationship. The present strategy comprised the generation of **1** by Heck coupling of vinylated malonates with aryl iodides followed by regio- and stereoselective radical cyclization of intermediates **2** or **3** (X = S or Se) leading to the desired dibenzylbutyrolactones **4**. Herein, we present full details of our new approach to dibenzylbutyrolactones and

its application to the synthesis of (±)-matairesinol[13] (Figure 2). A communication on a part of this work has already been published.[14]
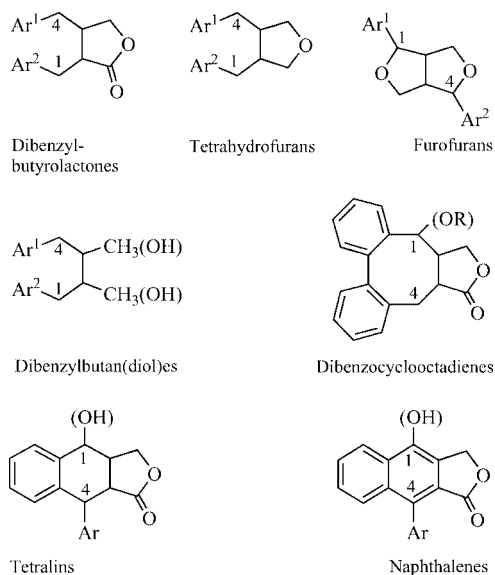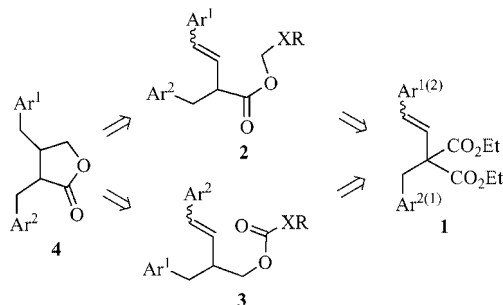

Figure 1. Classification of lignans.

Scheme 1. Retrosynthetic analysis of dibenzylbutyrolactones.

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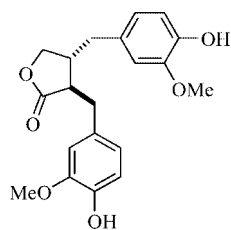
Figure 2. Structure of matairesinol.

Results and Discussion

Heck Reaction of Vinylated Malonates with Iodoarenes

In a recent publication, we reported[15] a general method for the preparation of 1-substituted alkenylsilanols **5**/disiloxanes **6** from the corresponding alkenyl(phenyl)silanes **7**[16] (Scheme 2) and their application in Hiyama–Denmark-type[17–20] cross-coupling reactions with iodoarenes. Our exploratory studies[15] on this cross-coupling reaction of a mixture of silanol **5a** and disiloxane **6a** with iodobenzene using [Pd(allyl)Cl]₂ as the catalyst and tetrabutylammonium fluoride (TBAF) or a combination of TBAF and tetrabutylammonium hydroxide (TBAOH)[20] as the promoter in various solvents gave a mixture of *ipso*-coupled 1-substituted styrene **8a**, vinylated malonate **9a**, formed due to protiodesilylation of silanes and the *cine*-coupled styrene derivative **10a** (Scheme 3).
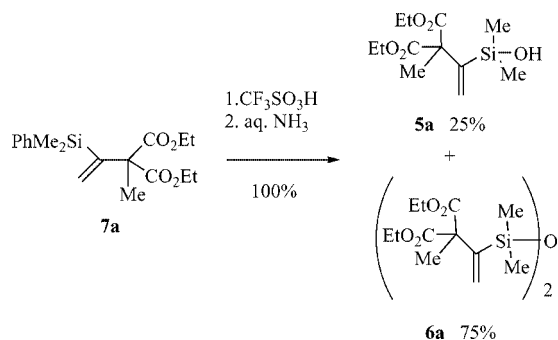
Scheme 2. Preparation of silanol/disiloxane **5a/6a**.

We looked into the details about the formation of the *cine*-coupled product and confirmed that it did not form by the direct cross-coupling[21] of the silanol **5a** or the disilox-
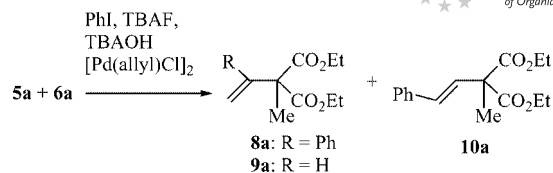
Scheme 3. Cross-coupling silanol/disiloxane **5a/6a** with iodobenzene.

ane **6a**. Under the coupling conditions, the silanes first undergo a rapid fluoride-induced protiodesilylation to yield the vinylated malonate **9a**, which then participates in a Heck reaction[22] with iodobenzene in the presence of [Pd(allyl)Cl]₂ to give **10a**.

Optimization of Heck Reaction Conditions

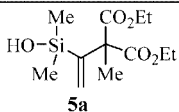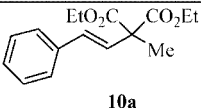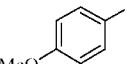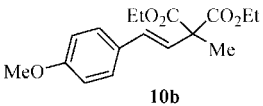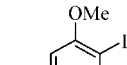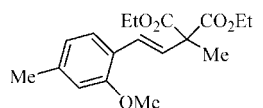Our present studies therefore aimed first to establish conditions for the *cine*-coupled product, namely **10a**, from the in situ generated terminal olefin **9a**. In general, conventional Heck reaction of aryl iodides proceeds smoothly with electron-deficient terminal alkenes.[22] However, electronically neutral or electron-rich alkenes in general do not serve as good partners for the coupling,[23] although some encouraging results have been reported recently by Lyapkalo et al.[24] using alkenyl nonalflates as coupling partners under ligand free palladium catalysis. In our initial cross-coupling studies, the reaction of **9a** (either pure or generated in situ) with iodobenzene was carried out under the conventional Heck conditions using Pd(OAc)₂/(*o*-Tol)₃P in the presence or absence of TBAF at 80 °C. The reaction was extremely slow with a conversion of <5% in both the cases even after 40 h. We next choose [Pd(allyl)Cl]₂ as the catalyst because of our previous[15] success with it in *ipso* cross-co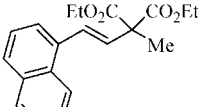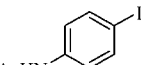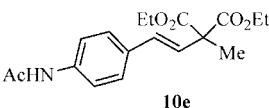upling reactions. Reaction of the silanes **5a/6a** with iodobenzene (1.5 equiv.), in the presence of TBAF (1.5 equiv.), TBAOH (1 equiv.) and [Pd(allyl)Cl]₂ at room temperature for 40 h provided the desired terminally substituted styryl product **10a** in 42% isolated yield. The coupling yield could not be improved by increasing the reaction temperature to 40–80 °C because of the formation of many by-products. It has been shown by Jeffery[25] that the addition of tetrabutylammonium salts enhances the yield of Heck products and allows the reaction to be performed in organic or aqueous media or in a combination of both. At this

Table 1. Optimization of *cine*-coupling conditions with silanol/disiloxane **5a/6a** and iodobenzene.[a]

Entry	Catalyst [equiv.]	Et₃N [equiv.]	TBACl [equiv.]	Ratio[b] of **10a/9a**	Yield of **10a** [%][c]
1	0.05	–	1.0	55:45	–[d]
2	0.05	1.5	1.0	75:25	61
3	0.05	1.0	1.0	82:18	68
4	0.05	0.75	1.0	90:10	75
5	0.05	0.5	1.0	85:15	70
6	0.03	0.75	1.0	50:50	–[d]
7	0.05	0.75	0.5	70:30	58
8	0.05	0.75	1.5	92:8	75

[a] The reactions were performed using 1 equiv. of the mixture of silanol **5a** and disiloxane **6a**, 1.5 equiv. of TBAF and 1.5 equiv. of iodobenzene, in DMF (1.33 M with respect to silanol) along with catalyst [Pd(allyl)Cl]₂, Et₃N and TBACl in appropriate quantities as mentioned at 80 °C for 40 h. [b] The ratio was determined by ¹H NMR spectroscopic analysis of the crude product. [c] Refers to the yield of spectroscopically pure product isolated after silica gel chromatography. [d] Products were not isolated.

Table 2. Synthesis of styryl derivatives **10** from silanol/disiloxane **5a/6a** and aryl iodides.

Entry	Silanol/disiloxane	Iodoarene	Product	Yield [%]
1	**5a** + disiloxane **6a**	(iodobenzene)	**10a**	75
2	**5a** + **6a**	(4-MeO-iodobenzene)	**10b**	75
3	**5a** + **6a**	(2-OMe-4-Me-iodobenzene)	**10c**	80
4	**5a** + **6a**	(1-iodonaphthalene)	**10d**	68
5	**5a** + **6a**	(4-AcHN-iodobenzene)	**10e**	72

stage, we, therefore, introduced tetrabutylammonium chloride (TBACl) as an additive in our coupling reaction and used Et_3N as a base in place of TBAOH. This modification dramatically improved the yield of desired product **10a**, and therefore, a study on optimization of the coupling conditions was performed by varying the proportions of reagents as shown in Table 1. Accordingly, the coupling was effected efficiently in the presence of TBACl (1 equiv.), Et_3N (0.75 equiv.), TBAF (1.5 equiv.) and [Pd(allyl)Cl]$_2$ (0.05 equiv.) with heating of the mixture at 80 °C for 40 h (Table 1, Entry 4). *cine*-Coupled product **10a** was obtained in 75% yield exclusively as the (*E*) isomer as judged from its ^{1}H NMR (*J* = 16 Hz) spectrum. There was no trace of its regioisomer **8a**. The scope of this coupling reaction was subsequently generalized with silanol **5a**/disiloxane **6a** and a few functionalized iodoarenes. The styryl derivatives **10a**–**e** were formed in very good yields and with excellent regio- and stereoselectivities. Regioisomeric olefinic products **8** and the (*Z*) isomers of styrenes **10** could not be detected in the crude reaction product as judged by ^{1}H NMR spectroscopy. The results are summarized in Table 2.

Heck Reaction Leading to 1,4-Diaryl-1-butenes

After successful development of Heck reaction conditions for the substituted styrene derivatives **10**, we focused our attention on the preparation of 1,4-diaryl-1-butenes **1**, as they are expected to serve as intermediates in the general synthesis of lignans and dibenzylbutyrolactone class in particular. In this context, we prepared the required benzylated silanol/disiloxanes **5b,c/6b,c** following our earlier described procedure[15] from alkenyl(phenyl)silanes **7b,c**[16] by using trifluoromethanesulfonic acid as shown in Scheme 4.

5b: R = Bn 50%
5c: R = 3-MeOC$_6$H$_4$CH$_2$− 45%

+

6b: R = Bn 50%
6c: R = 3-MeOC$_6$H$_4$CH$_2$− 55%
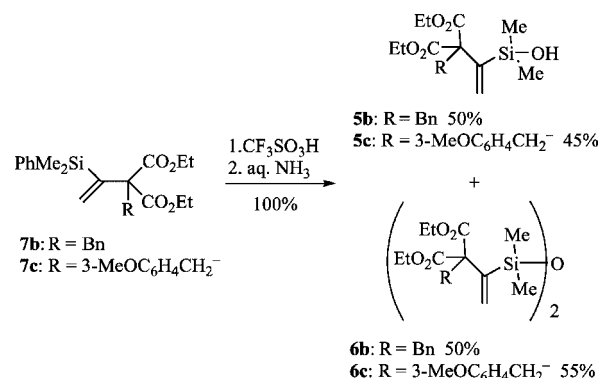
Scheme 4. Preparation of silanol/disiloxane embodied with substituted benzyl group.

Further, the synthesis of matairesinol required alkenylsilanol/disiloxane embodied with a substituted benzyl group. Alkenyl(phenyl)silane **7d**, required for this purpose was prepared with a slight modification of our previously reported[16] dimethylsulfonium methylide mediated one-pot olefination–alkylation procedure. Under the standard conditions, silylalkylidene malonate **11**[26] was treated with dimethylsulfonium methylide generated from the reaction using 1.2 equiv. of trimethylsulfonium iodide and 2.5 equiv. of sodium dimsylate in THF/DMSO (7:3), and the reaction was quenched with benzyl bromide **12**, which provided desired vinylsilane **7d** in 62% yield (Scheme 5). In the modified procedure, the ylide was generated using 3 equiv. of Me$_3$SI and *n*BuLi[27] in THF, and the yield of the reaction improved to 80%.
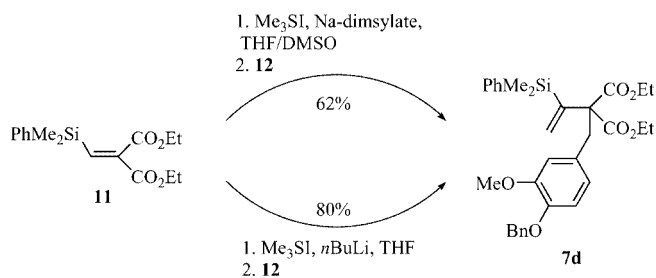
Scheme 5. Preparation of functionalized benzyl vinylsilane.

Scheme 7. Preparation of benzyl-substituted silanols/disiloxanes **5d/6d**.

The synthesis of bromide **12** has been reported in the literature[28] but we followed a different route starting from vanillin. For this, the hydroxy group of vanillin was protected as its 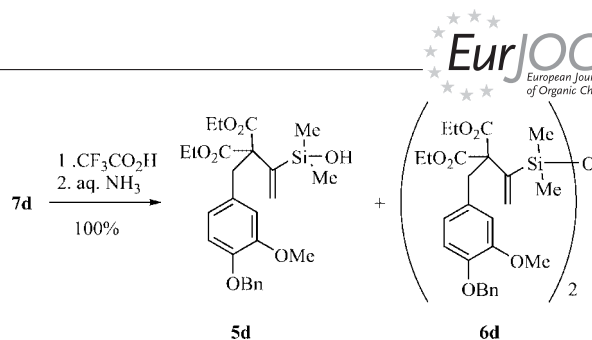benzyl ether **13** and was subjected to Cannizzaro reaction conditions to give acid **14** and alcohol **15** in very good yields. The alcohol was converted to benzyl bromide **12** using phosphorus tribromide (Scheme 6). This Cannizzaro method not only provided us with the precursor of **12** but also acid **14**, an intermediate for another component (vide infra) for the synthesis of (±)-matairesinol.


Scheme 6. Preparation of 4-benzyloxy-3-methoxybenzyl bromide.

In our previous experiments, we could selectively convert simple alkenyl(phenyl)silanes **7a–c** to the corresponding silanols/disiloxanes easily. Our next challenge was to selectively convert the phenylsilyl functionality to a silanol in a complex system like that of alkenyl(phenyl)silane **7d**. When vinylsilane **7d** was treated with trifluoromethanesulfonic acid in dichloromethane at –2 °C or even at lower temperatures, we did not obtain the desired silanol/disiloxane **5d/6d**, but the starting silane degraded to unknown byproducts. This degradation was presumably due to the noncompatibility of the benzyloxy group present therein to the reaction conditions. Fortunately, trifluoroacetic acid in dichloromethane at room temperature could selectively arylprotiodesilylate to give desired silanol **5d** associated with a trace amount of disiloxane **6d** (Scheme 7).

Although the yield of this arylprotiodesilylation reaction was excellent, it required longer reaction time for completion. In the course of this investigation we explored another

possibility for the synthesis of this type of functionalized disiloxanes. For this, silylidene malonate **11** was subjected to our alkenyl silanol preparation conditions[15] using CF$_3$SO$_3$H, which exclusively gave disiloxane **16** in nearly quantitative yield. Disiloxane **16** underwent a smooth dimethylsulfonium methylide mediated double olefination (Me$_3$SI + nBuLi) followed by double alkylation with benzyl bromide **12** in the same pot (Scheme 8) to give desired alkenyl disiloxane **6d** in very good yield.
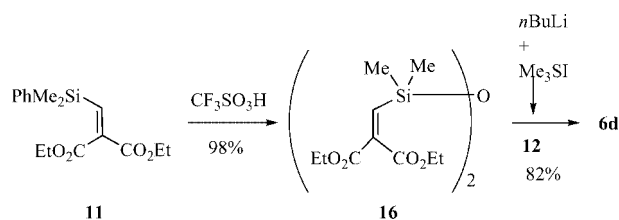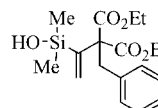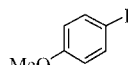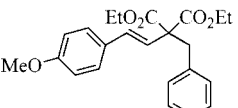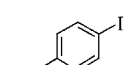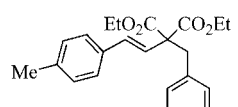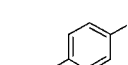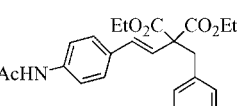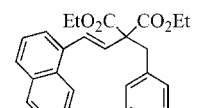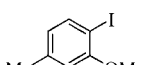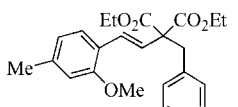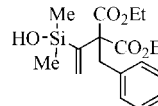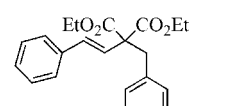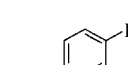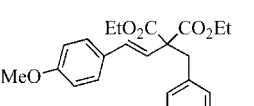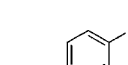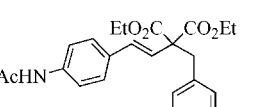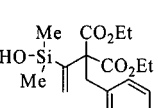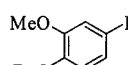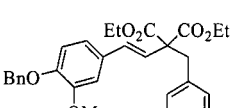
Scheme 8. Preparation of disiloxane **6d**.

Having developed the protocols for silanol/disiloxane containing functionalized benzyl groups and optimization of the *cine*-coupling (Table 1 and 2) with silanol/disiloxane, we studied the scope of this reaction with silanols **5b–d**/disiloxanes **6b–d** with a few functionalized iodoarenes as presented in Table 3. The *cine*-coupled products, i.e. (E)-1,4-diaryl-1-butenes **1a–i**, were obtained in very good yields again, with very high regio- and stereocontrol. The iodoarenes were either commercially available or prepared by following the literature procedures.[29] Iodoarene **17** required for the synthesis of diaryl butene **1i** was prepared in a few steps as depicted in Scheme 9. Carboxylic acid **14**, obtained from the Cannizzaro reaction (Scheme 6), was converted into Boc-protected aniline derivative **18**. Boc deprotection followed by a Sandmeyer reaction gave iodoarene **17** in moderate yield.
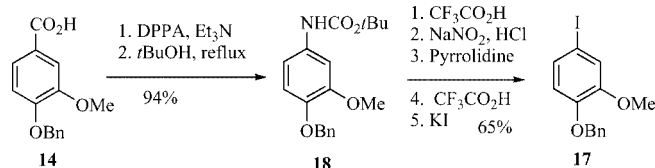
Scheme 9. Preparation of 4-benzyloxy-3-methoxy iodobenzene.

Table 3. Coupling of benzylated silanols/siloxanes with various iodoarenes.

Entry	Silanol/disiloxane	Iodoarene	Product	Yield [%]
1	**5b** + disiloxane **6b**	MeO—C₆H₄—I	**1a**	75
2	**5b** + **6b**	Me—C₆H₄—I	**1b**	76
3	**5b** + **6b**	AcHN—C₆H₄—I	**1c**	75
4	**5b** + **6b**	naphthyl-I	**1d**	65
5	**5b** + **6b**	Me, OMe substituted aryl-I	**1e**	73
6	**5c** + disiloxane **6c**	C₆H₅—I	**1f**	71
7	**5c** + **6c**	MeO—C₆H₄—I	**1g**	80
8	**5c** + **6c**	AcHN—C₆H₄—I	**1h**	75
9	**5d** + disiloxane **6d**	MeO, BnO substituted aryl-I **17**	**1i**	84

Synthesis of Dibenzylbutyrolactones and (±)-Matairesinol

Model Synthesis of Dibenzylbutyrolactones

After studying the *cine*-coupling of silanols/disiloxanes **5/ 6** with various iodoarenes, we turned our attention towards the synthesis of lignan skeletons from these coupling prod-ucts **1**. We explored the synthesis of model dibenzylbutyrol-actone lignan skeletons from 1,4-diaryl-1-butene **1a** follow-ing two routes as depicted in Scheme 10.

Diester **1a** was first hydrolyzed to racemic acid **19a**. Ini-tially in the first route, acid **19a** was converted to its methyl-thiomethyl and phenylthiomethyl esters; but neither of them

78:22). The proposed transition states (TS) for ring closures are shown in Figure 3, which resemble the chair form of cyclohexane, and the substituent at the 4-position is disposed pseudo equatorially. As the olefins in **A** and **B** have (*E*) stereochemistry, the facile ring closure results in predominant formation of *trans* 2,3-disubstituted lactones. Although, the olefin geometry will not have any direct effect on the stereochemical outcome as shown in proposed transition states **C** and **D** for (*Z*) olefins, but would impede the cyclization process due to steric hindrance.
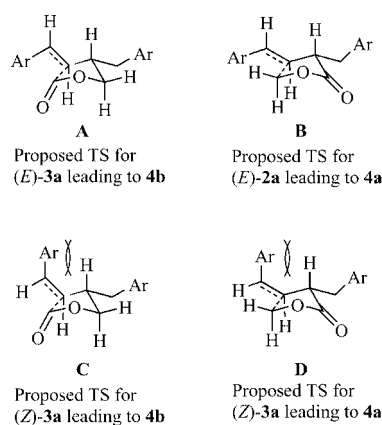
Figure 3. Proposed transition states for radical cyclizations.

Synthesis of (±)-Matairesinol

For the synthesis of matairesinol, diester **1i** was hydrolyzed with KOH to give monoacid **19b**, which was then converted into phenylselenomethyl ester **2b** as shown in

Scheme 10. Synthesis of model dibenzylbutyrolactone lignan skeletons.

underwent a smooth radical cyclization.[30] Later, the acid was transformed to phenylselenomethyl ester[30] **2a**, which to our delight underwent a facile tin hydride mediated radical cyclization ultimately to provide *trans* dibenzylbutyrolactone **4a** as the major product (*trans/cis*, 78:22), as expected to be the dominant isomer on the basis of Beckwith's model[31] for stereoselectivity in 5-*exo* radical cyclizations.

The stereoisomeric lactones, *trans*-**4a** and *cis*-**4a**, were separated by fractional crystallization. The *cis* stereochemistry of the minor isomer was confirmed by recording nOe spectra and about 5% nOe enhancement was observed between H[1] and H[2] (Scheme 10) in the lactone ring. In the second route, acid **19a** was reduced to alcohol **20** and subsequently converted to phenylselenocarbonate[32] **3a**. Tin hydride induced radical cyclization then provided *trans* dibenzylbutyrolactone **4b** with good selectivity (*trans/cis*,

Scheme 11. Synthesis of matairesinol.

Scheme 11. Like the model synthesis, the tributyltin hydride mediated radical cyclization provided bis(benzyl)-protected matairesinol **4c** and its *cis* diastereoisomer (*trans*/*cis*, 85:15) in 78% yield. The individual isomers were separated from the mixture by fractional crystallization. The major isomer *trans*-**4c** on catalytic hydrogenation provided (±)-matairesinol **4d** in nearly quantitative yield. The minor isomer *cis*-**4c** could also be epimerized to the desired major isomer *trans*-**4c** by the reported procedure.[33]

Conclusions

We have developed a highly regio- and stereoselective Heck reaction of iodoarenes with vinylated malonates, generated in situ by fluoride induced protiodesilylation of alkenylsilanol/disiloxanes to give functionalized styryl derivatives and (*E*)-1,4-diaryl-1-butenes in very good yields. A disiloxane embodied with acid-sensitive benzyl-protected aryl group was prepared by a novel dimethylsulfonium methylide mediated double olefination reaction followed by double benzylation. The dibenzylbutyrolactone lignan skeletons have been prepared from 1,4-diaryl-1-butenes by two routes involving stereoselective radical cyclization as the key step. The (*E*) stereochemistry of 1,4-diaryl-1-butenes was very crucial for the facile radical cyclization to give the desired lactones. This strategy has successfully been applied for the synthesis of (±)-matairesinol.

Experimental Section

General Procedure for the Olefination–Alkylation of Ethyl 2-Ethoxycarbonyl-3-dimethyl(phenyl)silyl-2-propenoate (11) Using Trimethylsulfonium Iodide/*n*BuLi – Ethyl 2-(4-Benzloxy-3-methoxybenzyl)-3-dimethyl(phenyl)silyl-2-ethoxycarbonyl-3-butenoate (7d): A solution of *n*butyllithium (1.6 M in hexane, 0.94 mL, 1.5 mmol, 3 equiv.) was added to a stirred suspension of trimethylsulfonium iodide (306 mg, 1.5 mmol, 3 equiv.) in THF (2 mL) at –10 °C under an atmosphere of argon, and the reaction mixture was stirred at the same temperature for 15 min. A solution of 2-silyl alkylidene malonate **11** (153 mg, 0.5 mmol, 1 equiv.) in dry THF (1 mL) was rapidly cannulated to the above reaction mixture. The reaction mixture was slowly brought to room temperature in a span of 45 min. After 15 min at room temperature, the reaction mixture was cooled in an ice-water bath and bromide **12** (231 mg, 0.75 mmol, 1.5 equiv.) was added into the reaction mixture. After 18 h at room temperature, the reaction mixture was quenched with water and extracted with diethyl ether. The combined extract was washed with brine, dried with MgSO₄ and concentrated. The residue was purified by chromatography to give pure vinylated product **7d** (218 mg, 80%). R_f = 0.4 (hexane/EtOAc, 85:15). IR (neat): $\tilde{v}$ = 3066, 2980, 2957, 2903, 1731 (C=O), 1259 (SiMe), 1110 (SiPh) cm⁻¹. ¹H NMR (200 MHz, CDCl₃): δ = 0.27 (s, 6 H, SiMe₂), 1.12 (t, *J* = 7.2 Hz, 6 H, 2×CO₂CH₂C*H₃*), 3.38 (s, 2 H, ArC*H₂*-), 3.83 (s, 3 H, *Me*OAr), 4.03 (q, *J* = 7.2 Hz, 4 H, 2×CO₂C*H₂*CH₃), 5.14 (s, 2 H, PhC*H₂*O-), 5.74 (s, 1 H, C=C*H*ₐH_B), 6.06 (s, 1 H, C=CHₐ*H*_B), 6.62 (dd, *J* = 8, 2 Hz, 1 H, Ar), 6.74 (d, *J* = 8 Hz, 1 H, Ar), 6.76 (d, *J* = 2 Hz, 1 H, Ar), 7.20–7.50 (m, 10 H, 2×Ph) ppm. ¹³C NMR (50 MHz, CDCl₃): δ = –0.56 (2 C), 13.73 (2 C), 42.12, 55.80, 61.16 (2 C), 64.78, 70.88, 113.55, 114.51, 122.81, 127.11 (2 C), 127.29 (2 C), 127.65, 128.34, 128.41 (2 C), 129.62,

131.76, 133.95 (2 C), 137.19, 140.38, 146.91, 148.58, 148.89, 170.47 (2 C) ppm. MS (ESI): *m/z* (%) = 570 (10.90) [M + 24]⁺, 569 (100) [M + 23]⁺, 469 (5.13). C₃₂H₃₈O₆Si (546.7): calcd. C 70.30, H 7.01; found C 70.65, H 7.32.

General Procedure for the Preparation of Silanols/Disiloxanes Using Trifluoromethanesulfonic Acid – 2-[3,3-Diethoxycarbonyl-4-(3-methoxyphenyl)-1-butenyl]dimethylsilanol (5c) and 1,1,3,3-1,3-Bis[(3,3-diethoxycarbonyl)-4-(3-methoxyphenyl)-1-butenyl]tetramethyldisiloxane (6c): Trifluoromethanesulfonic acid (0.25 mL, 2.75 mmol, 5.5 equiv.) was rapidly added to a stirred solution of alkenylsilane **7c** (220 mg, 0.5 mmol, 1 equiv.) in dichloromethane (3.6 mL) at –10 °C (bath). The reaction mixture was stirred under those conditions for 10 min and poured into ice-cold ammonia solution (30% aqueous solution, 3 mL). The organic layer was separated, and the aqueous phase was extracted with chloroform. The combined organic extracts were dried (MgSO₄) and evaporated to give a mixture of disiloxane **6c** and silanol **5c** (**6c**/**5c**, 55:45) (187 mg, 100%). Disiloxane **6c** (116 mg, 63%) and silanol **5c** (28 mg, 15%) were easily separable by column chromatography. Data for Silanol **5c**: R_f = 0.2 (hexane/EtOAc, 85:15). IR (neat): $\tilde{v}$ = 3592, 1729 (C=O), 1257, 1177 cm⁻¹. ¹H NMR (200 MHz, CDCl₃): δ = 0.1 (s, 6 H, SiMe₂), 1.21 (t, *J* = 7.2 Hz, 6 H, 2×CO₂CH₂C*H₃*), 2.20 (br. s, 1 H, OH), 3.40 (s, 2 H, ArC*H₂*-), 3.75 (s, 3 H, ArO*Me*), 4.07–4.23 (m, 4 H, 2×CO₂C*H₂*CH₃), 5.91 (s, 1 H, C=C*H*ₐH_B), 5.95 (s, 1 H, C=CHₐ*H*_B), 6.68–6.75 (m, 3 H, Ar), 7.12 (t, *J* = 8 Hz, 1 H, Ar) ppm. ¹³C NMR (50 MHz, CDCl₃): δ = 0.88 (2 C), 13.51 (2 C), 42.63, 54.66, 61.22 (2 C), 64.43, 111.96, 115.88, 122.49, 128.57, 129.49, 137.34, 149.85, 158.88, 170.68 (2 C) ppm. MS (EI): *m/z* (%) = 363 (0.2) [M – OH]⁺, 317 (4), 289 (89), 261 (16), 185 (20), 159 (30), 121 (100), 75 (91). C₁₉H₂₈O₆Si (380.5): calcd. C 59.97, H 7.42; found C 59.60, H 7.35. Data for Disiloxane **6c**: R_f = 0.37 (hexane/EtOAc, 85:15). IR (neat): $\tilde{v}$ = 2984, 2909, 2838, 1729 (C=O), 1598, 1488, 1257, 1177, 790 cm⁻¹. ¹H NMR (200 MHz, CDCl₃): δ = –0.02 (s, 12 H, 2×SiMe₂), 1.19 (t, *J* = 6 Hz, 12 H, 4×CO₂CH₂C*H₃*), 3.39 (s, 4 H, 2×ArC*H₂*-), 3.74 (s, 6 H, 2×ArO*Me*), 4.06–4.18 (m, 8 H, 4×CO₂C*H₂*CH₃), 5.96 (s, 2 H, 2×C=C*H*ₐH_B), 6.04 (s, 2 H, 2×C=CHₐ*H*_B), 6.66–6.73 (m, 6 H, Ar), 7.10 (t, *J* = 8 Hz, 2 H, Ar) ppm. ¹³C NMR (50 MHz, CDCl₃): δ = 2.04 (4 C), 13.61 (4 C), 42.75 (2 C), 54.67 (2 C), 60.95 (4 C), 64.28 (2 C), 111.86 (2 C), 116.09 (2 C), 122.71 (2 C), 128.50 (2 C), 130.11 (2 C), 137.59 (2 C), 149.75 (2 C), 158.93 (2 C), 170.35 (4 C) ppm. MS: *m/z* (%) = 766 (6) [M + 24]⁺, 765 (15) [M + 23]⁺, 645 (25), 556 (27), 363 (18), 189 (32), 159 (100). HRMS: calcd. for C₃₈H₅₄O₁₁Si₂Na [M + Na] 765.3102; found 765.3077.

General Procedure for the Preparation of Silanols/Disiloxanes Using Trifluoroacetic Acid – 2-[4-(4-benzyloxy-3-methoxyphenyl)-3,3-diethoxycarbonyl-1-butenyl]dimethylsilanol (5d) and 1,1,3,3-1,3-Bis[4-(4-benzyloxy-3-methoxyphenyl)-3,3-diethoxycarbonyl-1-butenyl]tetramethyldisiloxane (6d): Trifluoroacetic acid (1.7 mL, 22.61 mmol, 19 equiv.) was added to the stirred solution of vinylsilane **7d** (650 mg, 1.19 mmol, 1 equiv.) in dichloromethane (4.5 mL) at 0 °C. After 1.5 h at room temperature, the reaction mixture was poured into ice-cooled 30% aqueous ammonia solution and the organic phase was separated. The organic phase was washed with brine, dried with MgSO₄ and evaporated to give a mixture of silanol **5d** and disiloxane **6d** (**5d**/**6d**, 87:13) (571 mg, 100%). The material was purified by chromatography to give pure silanol **5d** (425 mg, 73%) and disiloxane 6d (105 mg, 18%). Data for **5d**: R_f = 0.25 (hexane/EtOAc, 85:15). IR (neat): $\tilde{v}$ = 3650–3200 (br., OH), 1727 (C=O), 1590, 1514, 1260, 1142 cm⁻¹. ¹H NMR (200 MHz, CDCl₃): δ = 0.11 (s, 6 H, SiMe₂), 1.18 (t, *J* = 7 Hz, 6 H, 2×CO₂CH₂C*H₃*), 1.96 (br. s, 1 H, OH), 3.36 (s, 2 H, ArC*H₂*-), 3.83 (s, 3 H, *Me*OAr), 4.02–4.20 (m, 4 H, 2×CO₂C*H₂*CH₃), 5.10 (s, 2 H, PhC*H₂*O-), 5.89

(s, 1 H, C=CH$_A$H$_B$), 5.93 (s, 1 H, C=CH$_A$H$_B$), 6.58 (dd, J = 8, 2 Hz, 1 H, Ar), 6.71 (d, J = 8 Hz, 1 H, Ar), 6.73 (d, J = 2 Hz, 1 H, Ar), 7.26–7.42 (m, 5 H, Ph) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 1.16 (2 C), 13.84 (2 C), 42.57, 55.86, 61.55 (2 C), 64.94, 70.92, 113.66, 114.27, 122.50, 127.18 (2 C), 127.70, 128.45 (2 C), 129.32, 129.62, 137.16, 147.07, 149.02, 150.32, 171.18 (2 C) ppm. MS (ESI): m/z (%) = 510 (4.49) [M + 24]$^+$, 509 (53.20) [M + 23]$^+$, 469 (7.69), 413 (8.97), 411 (14.10), 337 (5.13). C$_{26}$H$_{34}$O$_7$Si (486.6): calcd. C 64.17, H 7.04; found C 63.92, H 6.89. Data for **6d**: R_f = 0.5 (hexane/EtOAc, 85:15). IR (neat): $\tilde{v}$ = 3064, 3015, 2981, 1730 (C=O), 1606, 1590, 1513, 1260, 1037 cm^{-1}. ^{1}H NMR (200 MHz, CDCl$_3$): δ = 0.01 (s, 12 H, 2×SiMe$_2$), 1.17 (t, J = 7.2 Hz, 12 H, 4×CO$_2$CH$_2$CH$_3$), 3.35 (s, 4 H, 2×ArCH$_2$-), 3.82 (s, 6 H, 2×MeOAr), 3.97–4.21 (m, 8 H, 4×CO$_2$CH$_2$CH$_3$), 5.09 (s, 4 H, 2×PhCH$_2$O-), 5.99 (d, J = 1.1 Hz, 2 H, 2×C=CH$_A$H$_B$), 6.02 (d, J = 1.1 Hz, 2 H, 2×C=CH$_A$H$_B$), 6.56 (dd, J = 8, 2 Hz, 2 H, 2×Ar), 6.71 (d, J = 8 Hz, 2 H, 2×Ar), 6.72 (d, J = 2 Hz, 2 H, 2×Ar), 7.24–7.44 (m, 10 H, 2×Ph) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 2.37 (4 C), 13.85 (4 C), 42.57 (2 C), 55.82 (2 C), 61.17 (4 C), 64.66 (2 C), 70.96 (2 C), 113.66 (2 C), 114.44 (2 C), 122.70 (2 C), 127.14 (4 C), 127.66 (2 C), 128.41 (4 C), 129.59 (2 C), 130.12 (2 C), 137.21 (2 C), 146.99 (2 C), 148.95 (2 C), 150.18 (2 C), 170.72 (4 C) ppm. ESI MS: m/z (%) = 979 (4.5) [M + 25]$^+$, 978 (32) [M + 24]$^+$, 977 (100) [M + 23]$^+$, 497 (3.85), 469 (3.21), 365 (21.79). C$_{52}$H$_{66}$O$_{13}$Si$_2$ (955.2): calcd. C 65.38, H 6.96; found C 65.70, H 7.06.

General Procedure for the Palladium-Catalyzed Cross-Coupling of Silanols/Disiloxanes with Iodoarenes in the Presence of TBAF, TBACl and Et$_3$N in DMF – Ethyl (E)-2-Ethoxycarbonyl-2-methyl-4-phenyl-3-butenoate (10a): In a typical experiment, a solution of TBAF (1 M in DMF, 4 mL, 4 mmol, 1.5 equiv.) was added to a mixture of silanol **5a** and disiloxane **6a** (715 mg, 2.66 mmol based on silanol) at 80 °C. After 5 min, a solution of TBACl (1 M in DMF, 2.6 mL, 2.6 mmol, 1 equiv.), iodobenzene (880 mg, 4 mmol, 1.5 equiv.), Et$_3$N (0.28 mL, 2 mmol, 0.75 equiv.) and [Pd(allyl)Cl]$_2$ (48 mg, 0.13 mmol, 0.05 equiv.) were added, and the mixture was heated at 80 °C under a blanket of nitrogen in a Schlenk flask for 40 h. The reaction mixture was cooled, diluted with hexane/EtOAc (8:2) and washed with water. The organic extract was concentrated and purified by column chromatography to give **10a** (550 mg, 75%). R_f = 0.37 (hexane/EtOAc, 95:5). IR (neat): $\tilde{v}$ = 1731 (C=O), 967 (trans C=C) cm^{-1}. ^{1}H NMR (200 MHz, CDCl$_3$): δ = 1.26 (t, J = 7.2 Hz, 6 H, 2×MeCH$_2$OCO), 1.66 [s, 3 H, MeC(CO$_2$Et)$_2$], 4.22 (q, J = 7.2 Hz, 4 H, 2×MeCH$_2$OCO), 6.48 (d, J = 16.4 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.69 (d, J = 16.4 Hz, 1 H, ArCH$_B$=CH$_A$-), 7.23–7.42 (m, 5 H, Ar) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 13.98 (2 C), 20.31, 55.63, 61.64 (2 C), 126.57 (2 C), 127.64, 127.84, 128.52 (2 C), 130.72, 136.50, 171.10 (2 C) ppm. MS (EI): m/z (%) = 277 (3) [M + 1]$^+$, 276 (21) [M]$^+$, 204 (10), 203 (21), 175 (5), 158 (14), 147 (28), 131 (32), 129 (100), 128 (23), 115 (19), 91 (7), 77 (5). C$_{16}$H$_{20}$O$_4$ (276.3): calcd. C 69.54, H 7.30; found C 69.30, H 7.52.

General Procedure for the Hydrolysis of Diethyl Esters – (E)-(2RS)-2-Benzyl-4-(4-methoxyphenyl)-3-butenoic Acid (19a): An aqueous solution of KOH (5 M, 8 mL) was added dropwise to a stirred solution of diester **1a** (1.52 g, 3.98 mmol, 1 equiv.) in EtOH (30 mL) at room temperature. After 4 h, the solvent was evaporated under reduced pressure and the residue was diluted with water. The mixture was once extracted with Et$_2$O and the aqueous phase was cooled, acidified with HCl (4 M) and extracted with ethyl acetate. The organic extract was evaporated and the residue was crystallized (EtOAc/hexanes) to give acid **19a** (985 mg, 88%). M.p. 116–117 °C. IR (CHCl$_3$): $\tilde{v}$ = 3600–3260 (br., OH), 2978, 2938, 2840, 1731 (C=O), 1606, 1509, 1441, 1247, 1030, 977 (trans C=C), 760 cm^{-1}.

^{1}H NMR (200 MHz, CDCl$_3$): δ = 2.98 (dd, J = 7.2, 13.6 Hz, 1 H, PhCH$_A$H$_B$), 3.23 (dd, J = 7.4, 13.6 Hz, 1 H, PhCH$_A$H$_B$), 3.51 (q, J = 7.6 Hz, 1 H, CHCO$_2$H), 3.82 (s, 3 H, MeOAr), 6.11 (dd, J = 8.7, 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.43 (d, J = 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.88 (d, J = 8.6 Hz, 2 H, Ar), 7.19–7.33 (m, 7 H, Ar), 10.68 (br. s, 1 H, COOH) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 38.61, 51.18, 55.20, 113.89 (2 C), 123.76, 126.48, 127.54 (2 C), 128.37 (2 C), 129.04 (2 C), 129.28, 132.64, 138.26, 159.23, 179.97 ppm. MS (EI): m/z (%) = 282 (10) [M]$^+$, 207 (22), 191 (100), 163 (36). C$_{18}$H$_{18}$O$_3$ (282.3): calcd. C 76.57, H 6.43; found C 76.34, H 6.50.

General Procedure for the Preparation of Phenylselenomethyl Ester – Phenylselenomethyl (E)-(2RS)-2-Benzyl-4-(4-methoxyphenyl)-3-butenoate (2a): A mixture of acid **19a** (200 mg, 0.71 mmol, 1 equiv.), N,N-diisopropylethylamine (0.125 mL, 0.71 mmol, 1 equiv.), chloromethylphenyl selenide[30] (150 mg, 0.73 mmol, 1 equiv.), NaI (107 mg, 0.71 mmol) and DME (2 mL) were heated at 80 °C under argon over 18 h. The reaction mixture was diluted with diethyl ether and washed with water. The organic extract was dried with MgSO$_4$ and the solvents evaporated. The residue was purified by chromatography on silica gel to give ester **2a** (278 mg, 87%). R_f = 0.3 (hexane/EtOAc, 95:5). IR (CHCl$_3$): $\tilde{v}$ = 3060, 3029, 2954, 2836, 1737 (C=O), 1606, 1511, 1251, 1134, 1033, 967 (trans C=C), 741 cm^{-1}. ^{1}H NMR (200 MHz, CDCl$_3$): δ = 2.92 (dd, J = 7, 13.6 Hz, 1 H, PhCH$_A$H$_B$), 3.18 (dd, J = 7.8, 13.6 Hz, 1 H, PhCH$_A$H$_B$), 3.48 (q, J = 7.8 Hz, 1 H, CHCO$_2$), 3.81 (s, 3 H, MeOAr), 5.50 (d, J = 10 Hz, 1 H, OCH$_A$H$_B$SePh), 5.57 (d, J = 10 Hz, 1 H, OCH$_A$H$_B$SePh), 6.04 (dd, J = 8.6, 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.38 (d, J = 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.84 (d, J = 8.8 Hz, 2 H, Ar), 7.16–7.28 (m, 10 H, Ar), 7.49 (dd, J = 1.8, 8.8 Hz, 2 H, Ar) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 38.44, 51.02, 54.97, 62.13, 113.73 (2 C), 123.73, 126.29, 127.36 (2 C), 127.52, 128.18 (2 C), 128.92 (4 C), 129.12, 129.29, 132.30, 133.19 (2 C), 138.19, 159.08, 172.47 ppm. MS (ESI): m/z (%; ^{80}Se only) = 475 (6) [M + 23]$^+$, 295 (34), 189 (13.3), 159 (100).

General Procedure for the Radical Cyclization Reaction Using Tributyltin Hydride – (2RS,3RS)-2-Benzyl-3-(4-methoxybenzyl)butyrolactone (4a): A solution of Bu$_3$SnH (0.12 mL, 0.45 mmol, 1.15 equiv.) and AIBN (7 mg, 0.038 mmol, 0.1 equiv.) in dry benzene (5 mL) was added slowly to a stirred solution of ester **2a** (171 mg, 0.38 mmol, 1 equiv.) in benzene (24 mL) under argon at 80 °C within 4 h. The reaction mixture was heated at for another 30 min, cooled and the solvents evaporated. The residue was purified by chromatography on silica gel to give a mixture of trans-**4a** and cis-**4a** (102 mg, 92%) as a colourless solid. On fractional crystallization from hexane/EtOAc, trans-**4a** (75 mg, 67%) and cis-**4a** (20 mg, 18%) were obtained. Data for trans-**4a**: M.p. 77 °C. R_f = 0.2 (hexane/EtOAc, 90:10). IR (CHCl$_3$): $\tilde{v}$ = 3020, 2933, 2838, 1766 (C=O), 1611, 1513, 1249, 1216, 756 cm^{-1}. ^{1}H NMR (500 MHz, CDCl$_3$): δ = 2.46–2.52 (m, 2 H, CHCH$_2$O-, ArCH$_A$H$_B$), 2.57–2.63 (m, 2 H, COCH, ArCH$_A$H$_B$), 2.95 (dd, J = 7.5, 14 Hz, 1 H, PhCH$_A$H$_B$), 3.08 (dd, J = 5, 14 Hz, 1 H, PhCH$_A$H$_B$), 3.78 (s, 3 H, MeOAr), 3.84 (t, J = 8.5 Hz, 1 H, OCH$_A$H$_B$), 4.07 (t, J = 8 Hz, 1 H, OCH$_A$-H$_B$), 6.80 (d, J = 8.5 Hz, 2 H, Ar), 6.91 (d, J = 8.8 Hz, 2 H, Ar), 7.18 (d, J = 7.5 Hz, 2 H, Ar), 7.24 (t, J = 7.5 Hz, 1 H, Ar), 7.30 (t, J = 7.5 Hz, 2 H, Ar) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 34.95, 37.46, 41.36, 46.24, 55.18, 71.07, 114.00 (2 C), 126.79, 128.61 (2 C), 129.23 (2 C), 129.49 (2 C), 129.84, 137.69, 158.28, 178.50 ppm. C$_{19}$H$_{20}$O$_3$ (296.4): calcd. C 77.00, H 6.80; found C 77.13, H 7.04. Data for cis-**4a**: M.p. 57 °C. IR (CHCl$_3$): $\tilde{v}$ = 3061, 3027, 2935, 2836, 1769 (C=O), 1611, 1513, 1249, 1179, 1035, 752 cm^{-1}. ^{1}H NMR (500 MHz, CDCl$_3$): δ = 2.33 (t, J = 14 Hz, 1 H, ArCH$_A$H$_B$), 2.60–2.65 (m, 1 H, CHCH$_2$O-), 2.85 (dd, J = 11,

15 Hz, 1 H, PhCH$_A$H$_B$), 2.93 (dd, J = 3.5, 15 Hz, 1 H, ArCH$_A$H$_B$), 3.09–3.14 (m, 1 H, COCH), 3.33 (dd, J = 4.5, 15 Hz, 1 H, PhCH$_A$H$_B$), 3.78 (s, 3 H, *Me*OAr), 4.00 (dd, J = 5, 9.5 Hz, 1 H, OCH$_A$H$_B$), 4.04 (d, J = 9.5 Hz, 1 H, OCH$_A$H$_B$), 6.81 (d, J = 8.5 Hz, 2 H, Ar), 6.95 (d, J = 8.8 Hz, 2 H, Ar), 7.25–7.31 (m, 3 H, Ar), 7.36 (t, J = 7 Hz, 2 H, Ar) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 30.76, 31.94, 39.95, 45.17, 55.20, 69.36, 114.06 (2 C), 126.63, 128.33 (2 C), 128.73 (2 C), 129.84 (2 C), 130.30, 138.58, 158.27, 177.93 ppm. C$_{19}$H$_{20}$O$_3$ (296.4): calcd. C 77.00, H 6.80; found 77.35, H 6.95.

(*E*)-(2*RS*)-2-Benzyl-4-(4-methoxyphenyl)-3-butenol (20): A solution of acid **19a** (634 mg, 2.25 mmol, 1 equiv.) in THF (25 mL) was added to a stirred suspension of LAH (350 mg, 10 mmol, 4.4 equiv.) in THF (25 mL). The reaction mixture was heated at reflux for 4 h, cooled in an ice-bath and excess LAH was destroyed by adding moist ether into it. The complex was decomposed by the dropwise addition of a saturated aqueous Na$_2$SO$_4$ solution (3 mL). The reaction mixture was filtered through Celite and the filtrate was evaporated. The residue was crystallized from EtOAc/hexane to give alcohol **20** (576 mg, 96%). M.p. 65 °C. R_f = 0.3 (hexane/EtOAc, 80:20). IR (CHCl$_3$): ṽ = 3600–3100 (br., OH), 3027, 2932, 2836, 1607, 1510, 1247, 1175, 1034, 968 (*trans* C=C), 755, 701 cm^{-1}. ^{1}H NMR (200 MHz, CDCl$_3$): δ = 2.03 (br. s, 1 H, OH), 2.61–2.95 (m, 3 H, PhCH$_2$CH-), 3.53–3.73 (m, 2 H, -CH$_2$OH), 3.82 (s, 3 H, *Me*OAr), 5.98 (dd, J = 7.8, 16 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.40 (d, J = 16 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.88 (d, J = 8.6 Hz, 2 H, Ar), 7.21–7.33 (m, 7 H, Ar, Ph) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 37.78, 47.29, 55.12, 65.04, 113.79 (2 C), 125.88, 127.17 (2 C), 128.15 (2 C), 128.35, 129.09 (2 C), 129.80, 131.46, 139.61, 158.84 ppm. MS (ESI): *m/z* (%) = 291 (6) [M + 23]$^+$, 251 (7), 159 (34), 143 (100) ppm. HRMS (ESI): calcd. for C$_{18}$H$_{20}$O$_2$Na [M + Na] 291.1361; found 291.1370.

(*E*)-(2*RS*)-2-Benzyl-4-(4-methoxyphenyl)-1-(phenylselenocarbonyl-oxy)-3-butene (3a): A solution of triphosgene (110 mg, 0.37 mmol, 0.66 equiv.) in dichloromethane (1 mL) was added to a stirred solution of alcohol **20** (147 mg, 0.55 mmol, 1 equiv.) and pyridine (0.09 mL, 1.1 mmol, 2 equiv.) in dichloromethane (2.5 mL) at –15 °C under an argon atmosphere. The reaction mixture was allowed to attain 10 °C, left for about 2 min and again cool to 0 °C. Triethylamine (0.155 mL, 1.1 mmol, 2 equiv.) was added into the reaction mixture followed by the addition of PhSeH (0.12 mL, 1.1 mmol, 2 equiv.). After 30 min, the reaction mixture was stirred at room temperature for 15 min. The reaction mixture was diluted with diethyl ether and washed with water, dried and the solvents evaporated. The residue was purified by chromatography to give **3a** (223 mg, 91%). R_f = 0.5 (hexane/EtOAc, 10:90). ^{1}H NMR (200 MHz, CDCl$_3$): δ = 2.70–2.90 (m, 3 H, PhCH$_2$CH-), 3.81 (s, 3 H, *Me*OAr), 4.21–4.32 (m, 2 H, CH$_2$OCOSe), 5.85 (dd, J = 7.6, 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 5.38 (d, J = 15.8 Hz, 1 H, ArCH$_B$=CH$_A$-), 6.85 (d, J = 8.6 Hz, 2 H, Ar), 7.11–7.39 (m, 10 H, Ar, 2×Ph), 7.61 (dd, J = 2.2, 7.8 Hz, 2 H, COSePh) ppm. ^{13}C NMR (50 MHz, CDCl$_3$): δ = 37.76, 43.73, 55.08, 69.94, 113.78 (2 C), 125.92, 126.11, 126.80, 127.25 (2 C), 128.22 (2 C), 128.98, 129.10 (4 C), 129.77, 131.28, 135.78 (2 C), 138.71, 158.94, 166.60 ppm. MS (ESI): *m/z* (% ^{80}Se only) = 475 (1) [M + 23]$^+$, 263 (13), 253 (48), 251 (100), 159 (25), 147 (65).

(2*RS*,3*RS*)-2,3-Bis(4-hydroxy-3-methoxybenzyl)butyrolactone (4d): Palladium on charcoal (10% on Pd, 5 mg) was added to a solution of bis(benzyl) ether **4c** (30 mg, 0.056 mmol, 1 equiv.) in EtOH (4 mL), and the mixture stirred under H$_2$ for 24 h. The reaction mixture was filtered through a pad of Celite, washed with EtOAc and evaporated under reduced pressure. The residue was purified

by column chromatography to give (±)-matairesinol **4d**[13a] (19 mg, 95%). R_f = 0.1 (hexane/EtOAc, 70:30). IR (CHCl$_3$): ṽ = 3540 (OH), 3019, 2938, 2849, 1765 (C=O), 1612, 1515, 1270, 1238, 1216, 1153, 1122, 1034, 756 cm^{-1}. ^{1}H NMR (500 MHz, CDCl$_3$): δ = 2.42–2.58 (m, 3 H, CH$_A$H$_B$Ar, -CHCH$_2$O-, -CHCOO-), 2.61 (dd, J = 6.5, 13.5 Hz, 1 H, CH$_A$H$_B$Ar), 2.87 (dd, J = 14, 7 Hz, 1 H, CH$_A$H$_B$Ar), 2.94 (dd, J = 14.5, 5.5 Hz, 1 H, CH$_A$H$_B$Ar), 3.80 (s, 3 H, ArO*Me*), 3.81 (s, 3 H, ArO*Me*), 3.88 (dd, J = 7.5, 9 Hz, 1 H, -OCH$_A$H$_B$-), 4.14 (dd, J = 9, 7.5 Hz, 1 H, -OCH$_A$H$_B$-), 5.51 (s, 1 H, OH), 5.53 (s, 1 H, OH), 6.4 (d, J = 2 Hz, 1 H, Ar), 6.50 (dd, J = 8, 1.5 Hz, 1 H, Ar), 6.59 (dd, J = 8, 1.5 Hz, 1 H, Ar), 6.60 (s, 1 H, Ar), 6.79 (d, J = 8 Hz, 1 H, Ar), 6.81 (d, J = 8 Hz, 1 H, Ar) ppm. ^{13}C NMR (125 MHz): δ = 34.54, 38.29, 40.95, 46.53, 55.75, 55.80, 71.30, 110.89, 111.43, 114.02, 114.36, 121.29, 122.04, 129.50, 129.73, 144.36, 144.50, 146.55, 146.67, 178.76 ppm.

Supporting Information (see footnote on the first page of this article): Complete experimental details for all preparative procedures, full characterization of all starting materials and products along with copies of ^{1}H and ^{13}C NMR spectra.

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