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Boronic acid/Brønsted acid co-catalyst systems for the synthesis of 2*H*-chromenes from phenols and α,β-unsaturated carbonyls†

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Protocols for the synthesis of substituted 2*H*-chromenes from α,β-unsaturated carbonyls and phenols are described. Optimal combinations of arylboronic acids and Brønsted acids have been identified, such that both can be employed in catalytic quantities to accelerate these condensations. The method has been used to synthesize a variety of substituted 2*H*-chromenes, as well as photochromic naphthopyrans. The use of pentafluorophenylboronic acid and diphenylphosphinic acid enabled an expansion of the electrophile scope to include α,β-unsaturated ketones. Hall's 'phase-switching' of boronic acids has been exploited to achieve the separation of the two co-catalysts from unpurified reaction mixtures by a simple liquid–liquid extraction.

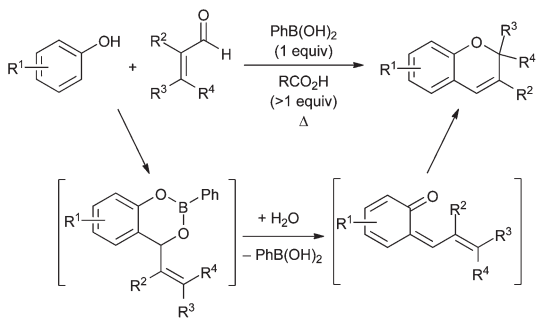
Introduction

The 2*H*-chromene ring system is a core structure of numerous biologically active natural products,[1] and its annelated congeners (naphthopyrans and related structures) display useful photochromic properties.[2] Several methods exist for the synthesis of 2*H*-chromenes, enabling access to a variety of substitution patterns.[3] Transition metal-catalyzed transformations that have been exploited for 2*H*-chromene synthesis include alkyne hydroarylation,[4] allylic substitution[5] and olefin metathesis.[6] Approaches based on Brønsted or Lewis acid-catalyzed condensations[7–9] or cyclizations[10] have also been reported.

Boronic acid-promoted condensations of phenols with α,β-unsaturated carbonyl compounds provide access to 2*H*-chromenes from readily available starting materials (Scheme 1). This mode of reactivity was initially reported by scientists at Merck,[11] and was further developed into a general method for 2*H*-chromene synthesis by Snieckus and co-workers.[12] The likely reaction pathway involves formation of a benzodioxaborinine intermediate by Nagata alkylation,[13] followed by fragmentation to an *ortho*-quinone methide and electrocyclic ring closure. Over the years, boronic acid-mediated condensations of this type have been applied to the synthesis of several classes of benzopyran-based natural products.[14–16]

The protocol for boronic acid-promoted 2*H*-chromene synthesis has changed relatively little since Dufresne's initial report more than two decades ago. This described the use of 1.6 equivalents of phenylboronic acid ($PhB(OH)_2$) and 30 mol% of propionic acid relative to phenol, with removal of water by azeotropic reflux in toluene using a Dean–Stark trap.[11] Snieckus and co-workers reported similar conditions, employing 1 equivalent of $PhB(OH)_2$ and an excess (>85 equiv.) of acetic acid, also in toluene with a Dean–Stark apparatus.[12] A survey of Brønsted acids (including carboxylic acids, sulfonic acids and H_2SO_4) was carried out in 2007, revealing that propionic acid (110 equiv.) provided best results for the coupling of umbelliferone and 3-methyl-2-butenal (1 equiv. of $PhB(OH)_2$ in toluene at reflux). Each of these studies points towards the combination of stoichiometric phenylboronic acid and a carboxylic acid promoter.

Although the thermolysis of the benzodioxaborinine intermediate provides a pathway for catalyst turnover, examples of



Scheme 1 Phenylboronic acid-mediated condensations of phenols and α,β-unsaturated aldehydes. A proposed pathway is shown below the reaction equation.

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protocols that employ substoichiometric quantities of arylboronic acid are scarce. Wilson and co-workers showed that 25 mol% of $PhB(OH)_2$ was able to promote the condensation of phloroglucinol with 3-methyl-2-butenal, yielding a mixture of bis- and tris-annulated products (39% and 55% yields, respectively, for a total of >9 turnovers).[17] As part of the synthesis of a series of pyranocarbazole alkaloids, Knölker's group found that condensations of citral with a hydroxycarbazole could be achieved in 75% yield using 20 mol% of $PhB(OH)_2$ in toluene at reflux.[15] Another relevant study by McCubbin showed that pentafluorophenylboronic acid (10 mol%) was able to catalyse condensations of 2-naphthol with propargylic alcohols, generating substituted naphthopyran products.[18] These same conditions were used to effect Friedel–Crafts propargylations of other electron-rich aromatics, and it is not clear whether there is a direct mechanistic connection to the above-mentioned phenol–enal annulations. In any case, it appeared to us that evaluating a range of organoboron acid and Brønsted acid catalysts might be an opportunity to improve the efficiency or expand the scope of such condensations, especially given the impressive progress that has been achieved in the development of 'designer' boronic acids for use in catalysis in recent years.[19,20]

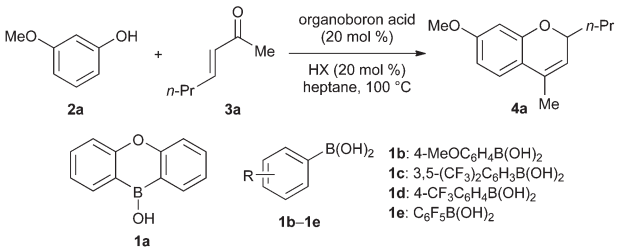
Here, we describe a systematic evaluation of organoboron acid/Brønsted acid combinations for the synthesis of 2*H*-chromenes from phenols and α,β-unsaturated carbonyl compounds. By variation of the two promoters, we have developed efficient and operationally simple protocols in which both are employed in catalytic quantities. These conditions have been applied to a range of reaction partners, including α,β-unsaturated ketones as well as aldehydes.

Results and discussion

3-Methoxyphenol (**2a**) and enone **3a** were chosen as the substrates for evaluation of organoboron acid and Brønsted acid co-catalysts (Table 1). Previous reports of boronic acid-promoted 2*H*-chromene synthesis describe couplings of α,β-unsaturated aldehydes, but not ketones, and so we anticipated that screening against this substrate combination might be useful for identifying particularly active catalysts.

We began by testing diarylborinic acids R_2BOH: these are more Lewis acidic than the corresponding boronic acids $RB(OH)_2$, and are useful catalysts for several types of transformations, including carbon–carbon[21] and carbon–heteroatom bond-forming reactions,[22] dehydrations[23] and oxidations.[24] However, both Ph_2BOH and oxaboraanthracene-derived borinic acid **1a** showed only modest activity: yields of **4a** were low (≤5%) in the absence of a Brønsted acid (entries 1 and 2), and were not significantly different from that obtained with $PhB(OH)_2$ when benzoic acid was employed as a co-catalyst (entries 3–5). On the other hand, an improvement in yield was achieved using more Lewis acidic arylboronic acids **1c–1e** (entries 7–9). Several Brønsted acids, including carboxylic, phosphinic and sulfonic acids, were then surveyed (entries 10–16). Diphenylphosphinic acid provided superior results to propionic and benzoic acid, whereas the use of the stronger acid camphorsulfonic acid (CSA) resulted in decomposition. Although further mechanistic study is needed to make a definitive conclusion on this point, we speculate that increasing the acidity of both the boronic acid and Brønsted acid components (relative to the original $PhB(OH)_2$/carboxylic acid system) accelerates the addition of the phenol to the rather poorly electrophilic enone. It should be noted that the yields reported in Table 1 are for reactions carried out under an inert argon atmosphere. Inferior results were obtained when air was not excluded. However, azeotropic removal of water using a Dean-Stark apparatus was not required under this protocol.

Table 1 Catalyst optimization for the synthesis of 2*H*-chromene **4a**

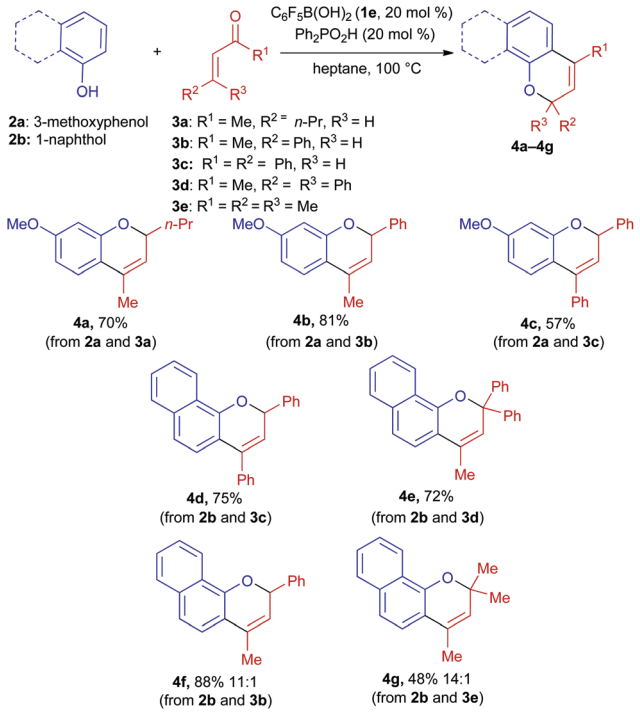


Entry	Organoboron acid	Brønsted acid HX	Yield[a]
1	Ph_2BOH	—	<5%
2	**1a**	—	5%
3	Ph_2BOH	$PhCO_2H$	15%
4	**1a**	$PhCO_2H$	30%
5	$PhB(OH)_2$	$PhCO_2H$	20%
6	**1b**	$PhCO_2H$	30%
7	**1c**	$PhCO_2H$	40%
8	**1d**	$PhCO_2H$	45%
9	**1e**	$PhCO_2H$	45%
10	$PhB(OH)_2$	$CH_3CH_2CO_2H$	10%
11	$PhB(OH)_2$	Ph_2PO_2H	60%
12	**1c**	$CH_3CH_2CO_2H$	60%
13	**1c**	Ph_2PO_2H	70%
14	**1c**	CSA	<5%
15	**1e**	$CH_3CH_2CO_2H$	15%
16	**1e**	Ph_2PO_2H	70%

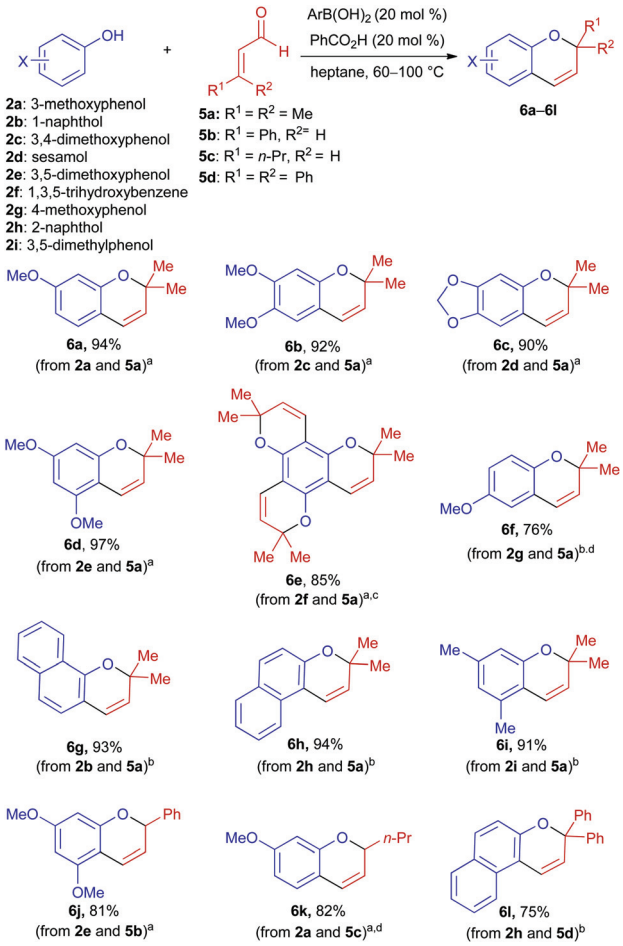
[a] Determined by ^1H NMR spectroscopy of the crude reaction mixture using 1,3,5-trimethoxybenzene as an internal standard. Reactions were carried out under inert atmosphere.

Having identified the combination of pentafluorophenylboronic acid and diphenylphosphinic acid (20 mol% each) as being optimal, we investigated the scope of this process (Scheme 2). Enones **3a–3e** were successfully coupled with 3-methoxyphenol and 1-naphthol, yielding 2,4-disubstituted and 2,2,4-trisubstituted 2*H*-chromene products. These were obtained in high levels of purity after column chromatography on silica gel, with the exception of products **4f** and **4g**, which were isolated along with small amounts (<10%) of the corresponding 4-methylenechromane regioisomers.

Condensations of α,β-unsaturated aldehydes with phenols were also investigated under boronic acid/Brønsted acid co-catalysis (Scheme 3). Unlike the aforementioned reactions with enones, syntheses of 2*H*-chromenes from α,β-unsaturated alde-



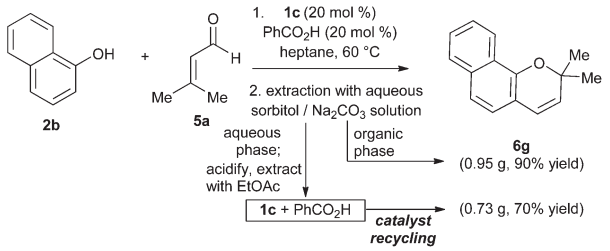
Scheme 2 Condensations of α,β-unsaturated ketones with phenol derivatives. Reaction conditions: phenol (0.2 mmol), enone (0.4 mmol), **1e** (20 mol%), Ph_2PO_2H (20 mol%) in heptane (1 mL) at 100 °C for 3 h under argon. Isolated yields after purification by chromatography on silica gel are listed. Products **4f** and **4g** were obtained as mixtures of endocyclic and exocyclic olefin isomers.



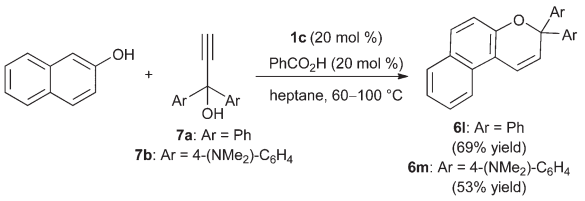
Scheme 3 Condensations of α,β-unsaturated aldehydes with phenol derivatives. Reaction conditions: phenol (0.5 mmol), aldehyde (1.0 mmol), $ArB(OH)_2$ (5–20 mol%), $PhCO_2H$ (20 mol%), in heptane (2.5 mL) at 60–100 °C for 17 h. For details, see the Experimental section. Isolated yields after purification by chromatography on silica gel are listed. [a] $PhB(OH)_2$ was used as the catalyst. [b] **1c** was used as the catalyst. [c] The reaction was carried out using 6.0 equiv. of **5a**. [d] Ph_2PO_2H (10 mol%) was used as the Brønsted acid co-catalyst.

hydes did not require an argon atmosphere, and benzoic acid (rather than Ph_2PO_2H) was found to be the most suitable Brønsted acid catalyst. Variation in the identity of the optimal boronic acid was also observed. The parent $PhB(OH)_2$ was able to promote condensations of activated phenols, and provided superior results in cases where electron-deficient **1c** promoted decomposition of the phenol (**2a**) or aldehyde (**5b**) component. On the other hand, **1c** displayed higher activity than Ph_2BOH for condensations of less nucleophilic phenols (**2b** and **2g–2i**). When unsubstituted phenol was subjected to these conditions, little to no product was observed.

To establish the preparative utility of this method, we undertook the synthesis of naphthopyran **6g** on gram scale (5 mmol). For this larger-scale experiment, we took advantage of the 'phase-switching' protocol developed by Hall and co-workers.[25] This technique uses simple liquid–liquid extractions to separate boronic acids from other organic compounds, based on the pH-switchable solubility of boronic acids in aqueous sorbitol solution (increased solubility at high pH due to formation of a tetracoordinate boronate ester). In the present case, working up the reaction mixture by extraction with basic aqueous sorbitol solution resulted in a straightforward separation of the product (organic phase) from the arylboronic acid and carboxylic acid components (aqueous phase). The product was purified by elution through a short plug of silica gel, while the catalyst mixture was recovered after acidification and extraction of the aqueous sorbitol solution (Scheme 4). The recovered catalyst mixture was re-used without further purification in a second gram scale synthesis, affording **6g** in 70% yield.



Scheme 4 Separation of co-catalysts from naphthopyran product by phase-switching.



Scheme 5 Synthesis of naphthopyrans from propargylic alcohols.

Hall and co-workers have shown that electron-deficient boronic acids catalyze the Meyer–Schuster rearrangement of propargylic alcohols to α,β-unsaturated compounds.[26] We envisioned that an *in situ* rearrangement of this type could enable the synthesis of 2*H*-chromene derivatives from propargylic alcohols under our optimized reaction conditions. To test this idea, we investigated condensations of 2-naphthol with readily available 1,1-diarylpropyn-1-ol derivatives as a way to access *gem*-diaryl-substituted naphthopyran products (Scheme 5). The latter have been studied extensively for applications in ophthalmic lenses due to their useful photochromic properties.[2] Using 20 mol% each of **1c** and benzoic acid, naphthopyran **6l** was generated from 2-naphthol and propargylic alcohol **7a**. The yield of this process was comparable to that obtained from enal **5d** (Scheme 3), and the isomerization of **7a** to **5d** was evident upon monitoring the condensation reaction by thin layer chromatography. In a similar way, the photochromic and solvatochromic naphthopyran **6m** was synthesized from **7b**.[27] As mentioned in the introduction, McCubbin and co-workers have also developed condensations of 2-naphthol with propargylic alcohols, using pentafluorophenylboronic acid and 4 Å molecular sieves in dichloromethane at room temperature. Propargylic alcohols having a (trimethylsilyl) alkynyl or phenylalkynyl group, rather than a terminal alkynyl group, were employed. The proposed mechanism involved Friedel–Crafts allenylation followed by cyclization through addition of the phenol group across the terminal carbon–carbon double bond. Subjecting compound **7a** and 2-naphthol to these conditions resulted in appreciable consumption of **7a** (approximately 55% conversion), but only a 10% yield of naphthopyran **6l** (conversion and yield were determined by ^{1}H NMR with an internal standard). Thus, these superficially similar protocols appear to differ in scope, and may proceed by different mechanisms.

Conclusions

Through variation of the arylboronic acid and Brønsted acid components, we have identified combinations that show optimal catalytic activity for 2*H*-chromene synthesis *via* condensations of phenols and α,β-unsaturated carbonyls. The use of an electron-deficient boronic acid ($C_6F_5B(OH)_2$ or 3,5-$(CF_3)_2$-$C_6H_3B(OH)_2$), in concert with diphenylphosphinic acid, is particularly effective for condensations of less reactive substrates such as α,β-unsaturated ketones or non-activated phenols. Hall's 'phase-switching' protocol has been used to achieve a convenient separation of both catalyst components from unpurified reaction mixtures by a simple liquid–liquid extraction.

Experimental

General methods

Reactions were carried out without effort to exclude air or moisture, unless otherwise indicated. Stainless steel needles and syringes were used to transfer air- and moisture-sensitive liquids. Flash chromatography was carried out using neutral silica gel (60 Å, 230–400 mesh, Silicycle). Analytical thin layer chromatography was carried out using aluminum-backed silica gel 60 F_{254} plates (EMD), and compounds were visualized through the use of UV light or basic $KMnO_4$ stain. HPLC grade THF was dried and purified using a solvent purification system equipped with columns of activated alumina, under nitrogen (Innovative Technology, Inc.). Anhydrous heptane was purchased from Sigma Aldrich. Distilled water was obtained from an in-house supply. All other solvents and reagents were purchased from Sigma Aldrich or Alfa Aesar and used without further purification. Screw cap test tubes were purchased from Pyrex® (13 mm × 100 mm, mfr. no. = Corning, 9825-13). Nuclear magnetic resonance (NMR) solvents were purchased from Cambridge Isotope Laboratories or from Sigma Aldrich. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ or C_6D_6 using either a Bruker Avance III 400 MHz, Varian Mercury 400 MHz or Agilent 500 MHz spectrometer. ^{1}H NMR are reported in parts per million (ppm) relative to tetramethylsilane and referenced to residual protium in the solvent. Spectral features are tabulated in the following order: chemical shift (δ, ppm); multiplicity (s-singlet, d-doublet, t-triplet, q-quartet, m-complex multiplet); number of protons; coupling constant (s) (J, Hz). High-resolution mass spectra (HRMS) were obtained on a JEOL AccuTOF JMS-T1000LC mass spectrometer equipped with a DART (direct analysis in real time) ion source, and are not corrected for the mass of the electron. Infrared (IR) spectra were obtained on a Perkin-Elmer Spectrum 100 instrument equipped with a single-bounce diamond/ZnSe ATR accessory as solids or thin films, as indicated. Spectral features are tabulated as follows: wavenumber (cm^{-1}); intensity (s-strong, m-medium, w-weak).

General procedure A: condensations of phenols and naphthols with α,β-unsaturated ketones. An oven-dried 25 mL Schlenk tube equipped with a teflon-coated magnetic stir bar was evacuated and purged with argon. The phenol (0.2 mmol), pentafluorophenylboronic acid (8.5 mg, 0.04 mmol, 20 mol%), diphenylphoshinic acid (8.7 mg, 0.04 mmol, 20 mol%), α,β-unsaturated ketone (0.4 mmol) and heptane (1 mL) were added to the tube under argon. The tube was evacuated and backfilled three times with argon after addition of the solid reagents and prior to the addition of the liquid reagents. The tube was capped, sealed and stirred at 100 °C for three hours. The tube was then cooled to room temperature and the

mixture was concentrated *in vacuo*. The resulting crude material was purified by flash chromatography on silica gel.

General procedure B: condensations of phenols and naphthols with α,β-unsaturated aldehydes. To a screw cap test tube equipped with a teflon-coated magnetic stir bar were added phenol (0.5 mmol), arylboronic acid (5–20 mol%), Brønsted acid (20 mol%), α,β-unsaturated aldehyde (1.0 mmol) and heptane (2.5 mL). The tube was capped in ambient atmosphere and stirred at 60–100 °C. The catalyst loading and reaction temperature for each substrate combination are provided below. After 17 hours, the mixture was concentrated *in vacuo* and the resulting crude material was purified by flash chromatography on silica gel.

7-Methoxy-4-methyl-2-propyl-2*H*-chromene (4a). Synthesized according to general procedure A, from 3-methoxyphenol (24.7 mg, 0.20 mmol) and 3-hepten-2-one (47.6 mg, 0.42 mmol). Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes (47.6 mg, 70%). **^{1}H NMR (500 MHz, C_6D_6):** δ 6.95 (d, J = 8.4 Hz, 1H), 6.65 (d, J = 2.6 Hz, 1H), 6.49 (dd, J = 8.4, 2.6 Hz, 1H), 5.10 (dq, J = 3.0, 1.4 Hz, 1H), 4.72 (dddq, J = 7.9, 4.9, 3.3, 1.7 Hz, 1H), 3.28 (s, 3H), 1.80 (dd, J = 1.6, 1.6 Hz, 3H), 1.77–1.69 (m, 1H), 1.59–1.32 (m, 4H), 0.84 (dd, J = 7.3, 7.2 Hz, 3H). **^{13}C NMR (126 MHz, C_6D_6):** δ 161.4, 155.9, 129.7, 124.6, 120.1, 117.5, 107.1, 102.2, 75.4, 54.8, 38.1, 18.6, 18.6, 18.1, 14.2, 14.2. **IR (neat, cm^{-1}):** 2957(m), 2932 (m), 2872 (w), 2836 (w), 1652 (w), 1612 (s), 1570 (m), 1504 (s), 1443 (m), 1379 (m), 1311 (m), 1275 (m), 1194 (m), 1159 (s), 1145 (s), 1132 (s), 1067 (m), 1031 (s), 809 (m). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{14}H_{19}O_2$ [(M + H)$^+$]: 219.1385. Found: 219.1383.

7-Methoxy-4-methyl-2-propyl-2*H*-chromene (4b). Synthesized according to general procedure A, from 3-methoxyphenol (24.8 mg, 0.2 mmol) and benzylideneacetone (58.9 mg, 0.4 mmol). Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes (40.7 mg, 81%).**^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.46–7.41 (m, 2H), 7.39–7.34 (m, 2H), 7.34–7.29 (m, 1H), 7.10 (d, J = 8.5 Hz, 1H), 6.47 (dd, J = 8.4, 2.6 Hz, 1H), 6.42 (d, J = 2.6 Hz, 1H), 5.84 (dq, J = 3.5, 1.8 Hz, 1H), 5.48 (dq, J = 3.3, 1.7 Hz, 1H), 3.76 (s, 3H), 2.06 (dd, J = 1.7, 1.7 Hz, 3H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 160.9, 154.7, 141.5, 129.7, 128.7, 128.3, 127.1, 124.4, 119.1, 116.7, 106.9, 101.8, 77.6, 55.5, 18.2. **IR (neat, cm^{-1}):** 3061 (w), 3031 (w), 2999 (w), 2917 (w), 2835 (w), 1648 (w), 1612 (s), 1504 (s), 1442 (m), 1310 (m), 1274 (s), 1193 (s), 1193 (s), 1159 (s), 1141 (s), 1126 (s), 1066 (s), 1028 (s), 810 (m), 745 (m), 696 (s). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{17}H_{17}O_2$ [(M + H)$^+$]: 253.1229. Found: 253.1229.

7-Methoxy-2,4-diphenyl-2*H*-chromene (4c). Synthesized according to general procedure A, from 3-methoxyphenol (24.8 mg, 0.20 mmol) and *trans*-chalcone (83.4 mg, 0.40 mmol). Isolated as a yellow oil after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes (39.1 mg, 57%). **^{1}H NMR (400 MHz, C_6D_6):** δ 7.48–7.42 (m, 2H), 7.34–7.29 (m, 2H), 7.20–7.12 (m, 5H), 7.11–7.05 (m, 2H), 6.68 (d, J = 2.5 Hz, 1H), 6.39 (dd, J = 8.6, 2.6 Hz, 1H), 5.79 (d, J = 3.7 Hz, 1H), 5.53 (d, J = 3.7 Hz, 1H), 3.20 (s, 3H). **^{13}C NMR (126 MHz, C_6D_6):** δ 161.7, 156.0, 141.4, 139.0, 137.1, 129.1, 128.8, 128.7, 128.5, 127.6, 127.2, 121.0, 116.4, 107.7, 102.6, 77.6, 54.8, 30.3. **IR (neat, cm^{-1}):** 3059 (w), 3030 (w), 3000 (w), 2926 (w), 2851 (w), 2835 (w), 1609 (m), 1567 (m), 1501 (m), 1443 (m), 1351 (m), 1308 (m), 1268 (m), 1247 (m), 1193 (m), 1155 (s), 1111 (m), 1031 (m), 979 (m), 760 (m), 696 (s). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{22}H_{19}O_2$ [(M + H)$^+$]: 315.1385. Found: 315.1390.

2,4-Diphenyl-2*H*-naphtho[1,2-*b*]pyran (4d). Synthesized according to general procedure A, from 1-naphthol (29.1 mg, 0.20 mmol) and *trans*-chalcone (83.6 mg, 0.40 mmol). Isolated as a pale yellow solid after flash chromatography on silica gel, eluting with 2–3% diethyl ether/hexanes (50.6 mg, 75%). **^{1}H NMR (500 MHz, C_6D_6):** δ 8.49–8.43 (m, 1H), 7.56–7.53 (m, 1H), 7.47–7.44 (m, 2H), 7.33–7.29 (m, 3H), 7.27–7.17 (m, 5H), 7.14–7.10 (m, 2H), 7.08–7.04 (m, 1H), 5.88 (d, J = 3.7 Hz, 1H), 5.65 (d, J = 3.7 Hz, 1H). **^{13}C NMR (126 MHz, C_6D_6):** δ 150.2, 141.4, 138.9, 137.8, 135.2, 129.2, 128.9, 128.7, 128.5, 128.1, 128.0, 127.3, 127.0, 126.0, 125.5, 123.8, 122.9, 122.3, 120.7, 117.6, 77.6. **IR (neat, cm^{-1}):** 3057 (w), 2922 (w), 2851 (w), 1638 (w), 1615 (w), 1599 (w), 1562 (w), 1494 (w), 1454 (w), 1385 (m), 1345 (m), 1298 (m), 1257 (m), 1209 (m) 1096 (m), 953 (m), 808 (s), 748 (s), 695 (s). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{25}H_{19}O_1$ [(M + H)$^+$]: 335.1436. Found: 335.1438.

4-Methyl-2,2-diphenyl-2*H*-naphtho[1,2-*b*]pyran (4e). Synthesized according to general procedure A, from 1-naphthol (28.7 mg, 0.20 mmol) and 4,4-diphenylbut-3-en-2-one (89.1 mg, 0.40 mmol). Isolated as a pale yellow solid after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes (50.1 mg, 72%). **^{1}H NMR (500 MHz, C_6D_6):** δ 8.56–8.51 (m, 1H), 7.62–7.57 (m, 4H), 7.57–7.53 (m, 1H), 7.28 (ddd, J = 8.3, 6.8, 1.3 Hz, 1H), 7.25–7.17 (m, 2H), 7.13 (d, J = 8.5 Hz, 2H), 7.10–7.05 (m, 4H), 7.02–6.95 (m, 2H), 5.83 (q, J = 1.5 Hz, 1H), 1.88 (d, J = 1.5 Hz, 3H). **^{13}C NMR (126 MHz, C_6D_6):** δ 148.3, 146.1, 135.1, 130.0, 128.4, 128.0, 127.7, 127.4, 126.6, 126.0, 125.4, 124.8, 122.8, 121.8, 120.7, 117.8, 83.6, 18.4. **IR (neat, cm^{-1}):** 3049 (w), 2968 (w), 2918 (w), 2854 (w), 1653 (w), 1618 (w), 1563 (w), 1491 (w), 1465 (w), 1445 (m), 1372 (m), 1264 (m), 1206 (m), 1074 (m), 972 (m), 819 (m), 748 (s), 686 (s), 684 (m). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{26}H_{21}O_1$ [(M + H)$^+$]: 349.1592. Found: 349.1600.

4-Methyl-2-phenyl-2*H*-naphtho[1,2-*b*]pyran (4f). Synthesized according to general procedure A, from 1-naphthol (28.8, 0.20 mmol) and benzylideneacetone (58.5 mg, 0.40 mmol). Isolated as a light green oil after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes. The title compound was isolated as an inseparable mixture of regioisomers (11 : 1, ^{1}H NMR) (47.8 mg, 88%). **^{1}H NMR (500 MHz, C_6D_6):** δ 8.45–8.41 (m, 1H), 7.63–7.58 (m, 1H), 7.43–7.39 (m, 2H), 7.31 (d, J = 8.5 Hz, 1H), 7.26–7.17 (m, 4H), 7.15–7.07 (m, 3H), 7.08–7.03 (m, 1H), 5.86 (dq, J = 3.6, 1.8 Hz, 1H), 5.32 (dq, J = 3.2, 1.5 Hz, 1H), 1.83 (dd, J = 1.7, 1.7 Hz, 3H). **^{13}C NMR (126 MHz, C_6D_6):** δ 149.4, 142.2, 135.1, 130.3, 128.8, 128.2, 127.9, 127.0, 126.7, 125.9, 125.2, 122.9, 121.8, 120.6, 120.6, 117.9, 77.8, 18.3. **IR (neat, cm^{-1}):** 3059 (w), 3030 (w), 2970 (w), 2915 (w), 2854 (w), 1653 (w), 1620 (w), 1564 (m), 1465 (w), 1453

(w), 1389 (m), 1377 (m), 1259 (m), 1205 (m), 1092 (m), 1074 (m), 947 (m), 811 (s), 739 (s), 695 (s), 678 (m). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{20}H_{17}O_1$ [$(M + H)^+$]: 273.1279. Found: 273.1276. Selected NMR data for the minor regioisomer: **^{1}H NMR (500 MHz, C_6D_6):** δ 5.51 (d, J = 2.1 Hz, 1H), 4.96 (dd, J = 11.5, 2.7 Hz, 1H), 4.76 (ddd, J = 2.1, 0.8, 0.7 Hz, 1H), 2.71 (dddd, J = 14.8, 11.5, 2.1, 2.1 Hz, 1H), 2.52 (ddd, J = 14.8, 2.7, 1.0 Hz, 1H).

2,2,4-Trimethyl-2*H*-naphtho[1,2-*b*]pyran (4g). Synthesized according to general procedure A, from 1-naphthol (28.8 mg, 0.20 mmol) and mesityl oxide (39.3 mg, 0.40 mmol). Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 2% diethyl ether/hexanes. The title compound was isolated as an inseparable mixture of regioisomers (14 : 1, ^{1}H NMR) (21.4 mg, 48%). **^{1}H NMR (500 MHz, C_6D_6):** δ 8.51–8.49 (m, 1H), 7.66–7.63 (m, 1H), 7.34–7.29 (m, 2H), 7.26 (ddd, J = 8.1, 6.8, 1.4 Hz, 1H), 7.23 (d, J = 8.5 Hz, 1H), 5.12 (q, J = 1.5 Hz, 1H), 1.84 (d, J = 1.5 Hz, 3H), 1.35 (s, 6H). **^{13}C NMR (126 MHz, C_6D_6):** δ 148.9, 135.0, 128.6, 127.9, 126.5, 126.0, 125.8, 125.6, 122.9, 121.8, 120.0, 117.4, 76.6, 28.0, 18.3. **IR (neat, cm^{-1}):** 3056 (w), 2973 (w), 2923 (w), 2855 (w), 1657 (w), 1619 (w), 1565 (w), 1508 (w), 1459 (w), 1377 (s), 1358 (m), 1279 (m), 1208 (m), 1158 (m), 1146 (m), 1077 (s), 951 (m), 924 (m), 815 (s), 799 (s), 744 (s), 685 (m). **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{16}H_{17}O_1$ [$(M + H)^+$]: 225.1279. Found: 225.1279. Selected NMR data for the minor regioisomer: **^{1}H NMR (500 MHz, C_6D_6):** δ 5.53 (dt, J = 2.3, 1.3, 1.3 Hz, 1H), 4.79 (dt, J = 2.5, 1.5, 1.5 Hz, 1H), 2.24 (dd, J = 1.4, 1.4 Hz, 2H), 1.20 (s, 6H).

7-Methoxy-2,2-dimethyl-2*H*-chromene (6a). Synthesized according to general procedure B, from 3-methoxyphenol (61.6 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 80 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (88.4 mg, 94%). Spectral data were in agreement with previous reports.[12] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 6.88 (dd, J = 8.2, 0.3 Hz, 1H), 6.40 (dd, J = 8.2, 2.5 Hz, 1H), 6.38–6.37 (m, 1H), 6.27 (ddd, J = 9.8, 0.7, 0.3 Hz, 1H), 5.47 (dd, J = 9.8, 0.3 Hz, 1H), 3.77 (s, 3H), 1.42 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$):** δ 160.8, 154.3, 128.0, 127.0, 122.0, 114.8, 106.8, 102.1, 76.5, 55.4, 28.2.

6,7-Dimethoxy-2,2-dimethyl-2*H*-chromene (6b). Synthesized according to general procedure B, from 3,4-dimethoxyphenol (79.2 mg, 0.51 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with CH_2Cl_2 (104.4 mg, 92%). Spectral data were in agreement with previous reports.[12] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 6.53 (s, 1H), 6.41 (s, 1H), 6.24 (d, J = 9.7 Hz, 1H), 5.48 (d, J = 9.7 Hz, 1H), 3.83 (s, 3H), 3.82 (s, 3H), 1.41 (s, 6H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 149.8, 147.4, 143.2, 128.4, 122.1, 113.2, 109.9, 101.2, 76.1, 56.7, 56.1, 27.8.

2,2-Dimethyl-6,7-methylenedioxy-2*H*-chromene (6c). Synthesized according to general procedure A, from 3,4-(methylenedioxy)phenol (68.7 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (91.3 mg, 90% yield). Spectral data were in agreement with previous reports.[12] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 6.47 (s, 1H), 6.38 (s, 1H), 6.19 (d, J = 9.7 Hz, 1H), 5.87 (s, 2H), 5.47 (d, J = 9.7 Hz, 1H), 1.39 (s, 6H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 148.4, 147.7, 141.5, 128.3, 122.4, 114.4, 105.8, 101.0, 99.2, 76.2, 27.6.

5,7-Dimethoxy-2,2-dimethyl-2*H*-chromene (6d). Synthesized according to general procedure B, from 3,5-dimethoxyphenol (78.6 mg, 0.51 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using phenylboronic acid (5 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 1–2% EtOAc/pentane (109.4 mg, 97%). Spectral data were in agreement with previous reports.[28] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 6.58 (dd, J = 9.9, 0.7 Hz, 1H), 6.03 (dd, J = 2.3, 0.7 Hz, 1H), 6.01 (d, J = 2.3 Hz, 1H), 5.42 (d, J = 9.9 Hz, 1H), 3.79 (s, 3H), 3.76 (s, 3H), 1.41 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$):** δ 161.1, 156.3, 154.8, 126.0, 116.8, 104.3, 94.1, 91.6, 76.4, 55.7, 55.5, 27.9.

2,2,6,6,10,10-Hexamethyl-2*H*,6*H*,10*H*-dipyrano[6,5-*f*,6′,5′-*h*]chromene (6e). Synthesized according to general procedure B, from 1,3,5-trihydroxylbenzene (60.8 mg, 0.48 mmol) and 3-methyl-2-butenal (300 μL, 3.0 mmol) using phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow solid after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (133.3 mg, 85%). Spectral data were in agreement with previous reports.[17] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 6.59 (d, J = 9.9 Hz, 3H), 5.42 (d, J = 9.9 Hz, 3H), 1.41 (s, 18H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 149.3, 126.0, 117.0, 103.6, 76.6, 28.1. **HRMS (DART-TOF$^+$, *m*/*z*):** Calculated for $C_{21}H_{25}O_3$ [$(M + H)^+$]: 325.1793. Found: 325.1804.

6-Methoxy-2,2-dimethyl-2*H*-chromene (6f). Synthesized according to general procedure B, from 4-methoxyphenol (60.2 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and diphenylphosphinic acid (10 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (70.5 mg, 76%). Spectral data were in agreement with previous reports.[12] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 6.71 (d, J = 8.7 Hz, 1H), 6.66 (dd, J = 8.7, 2.9 Hz, 1H), 6.55 (d, J = 2.8 Hz, 1H), 6.28 (d, J = 9.8 Hz, 1H), 5.64 (d, J = 9.8 Hz, 1H), 3.75 (s, 3H), 1.41 (s, 6H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 153.9, 146.9, 131.9, 122.5, 122.0, 116.9, 114.3, 111.6, 75.9, 55.9, 27.8.

2,2-Dimethyl-2*H*-naphtho[1,2-*b*]pyran (6g). Synthesized according to general procedure B, from 1-naphthol (72.9 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 60 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (98.6 mg, 93%). Spectral data were in agreement with previous reports.[9] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.24–8.18 (m, 1H), 7.76–7.70 (m, 1H), 7.47–7.39 (m, 2H), 7.34

(d, J = 8.3 Hz, 1H), 7.15 (d, J = 8.3 Hz, 1H), 6.45 (d, J = 9.7 Hz, 1H), 5.64 (d, J = 9.7 Hz, 1H), 1.53 (s, 6H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 148.4, 134.6, 129.4, 127.7, 126.2, 125.3, 125.2, 124.6, 122.9, 122.1, 119.9, 115.5, 76.9, 28.1.

Gram scale synthesis of 2,2-dimethyl-2*H*-naphtho[1,2-*b*]pyran (6g). An oven-dried 100 mL round bottomed flask equipped with a teflon-coated magnetic stir bar was charged with 1-naphthol (720.1 mg, 5 mmol), 3-methyl-2-butenal (0.97 mL, 10 mmol), bis(trifluoromethyl)phenylboronic acid (257.9 mg, 20 mol%), benzoic acid (121.8 mg, 20 mol%) and heptane (25 mL). The reaction mixture was stirred at 60 °C for 17 hours. The mixture was then cooled to room temperature, diluted with ethyl acetate (50 mL) and then transferred to a separatory funnel to which a 75 mL of a sorbitol : Na_2CO_3 (1 M : 1 M) solution. The two layers were hand shaken for 10 minutes, separated and the organic layer was washed with H_2O, and then saturated aq. NaCl. The organic phase was then dried with $MgSO_4$, filtered and concentrated *in vacuo* to afford a brown oil. This crude oil was then loaded onto a 1.5 × 1.5″ silica gel column, eluted with 2.5% EtOAc/hexanes (300 mL) and concentrated *in vacuo* to give the title compound as a yellow-orange oil (947.5 mg, 90%). *Catalyst Recovery*: The sorbitol layer was acidified with 4 M HCl (pH 2) and the catalyst mixture extracted three times with EtOAc, washed with H_2O and then dried over $MgSO_4$. The organic solution was then filtered and concentrated to afford a ~1 : 1 mixture of boronic: benzoic acid as a light brown solid (356.5 mg, 94%). When this recovered mixture was used in the same reaction described above, the titled compound was isolated in 70% yield (728.2 mg). Workup procedure adapted from ref. 25.

2,2-Dimethyl-2*H*-naphtho[2,1-*b*]pyran (6h). Synthesized according to general procedure B, from 2-naphthol (71.7 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 80 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (97.9 mg, 94%). Spectral data were in agreement with previous reports.[9] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.96–7.93 (m, 1H), 7.75–7.73 (m, 1H), 7.65 (d, J = 8.8 Hz, 1H), 7.47 (ddd, J = 8.4, 6.8, 1.3 Hz, 1H), 7.33 (ddd, J = 8.1, 6.8, 1.1 Hz, 1H), 7.06 (dd, J = 8.8, 0.7 Hz, 1H), 7.03 (d, J = 9.9 Hz, 1H), 5.72 (dd, J = 9.9, 0.3 Hz, 1H), 1.49 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$):** δ 151.1, 130.0, 129.5, 129.4, 129.3, 128.6, 126.6, 123.5, 121.4, 118.6, 118.4, 113.9, 76.2, 27.7.

2,2,5,7-Tetramethyl-2*H*-chromene (6i). Synthesized according to general procedure A, from 3,5-dimethylphenol (61.5 mg, 0.5 mmol) and 3-methyl-2-butenal (100 μL, 1.0 mmol) using 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (86.1 mg, 91%). Spectral data were in agreement with previous reports.[12] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 6.52–6.51 (m, 1H), 6.49–6.46 (m, 2H), 5.58 (d, J = 10.0 Hz, 1H), 2.25 (s, 3H), 2.23 (s, 3H), 1.41 (s, 6H). **^{13}C NMR (125 MHz, $CDCl_3$):** δ 153.0, 138.8, 133.8, 129.6, 123.4, 119.4, 117.3, 115.0, 75.4, 27.9, 21.5, 18.5.

5,7-Dimethoxy-flav-3-ene (6j). Synthesized according to general procedure B, from 3,5-dimethoxyphenol (76.5 mg, 0.5 mmol) and *trans*-cinnamaldehyde (130 μL, 1.0 mmol) using phenylboronic acid (5 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a viscous yellow oil after flash chromatography on silica gel, eluting with 1–2% EtOAc/pentane (108.6 mg, 81%). Spectral data were in agreement with previous reports.[29] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.49–7.44 (m, 2H), 7.40–7.29 (m, 3H), 6.81 (ddd, J = 10.0, 1.9, 0.6 Hz, 1H), 6.06 (d, J = 2.2 Hz, 1H), 6.03 (d, J = 2.3 Hz, 1H), 5.83 (dd, J = 3.4, 1.9 Hz, 1H), 5.62 (dd, J = 9.9, 3.5 Hz, 1H), 3.81 (s, 3H), 3.75 (s, 3H). **HRMS (DART-TOF$^+$, m/z):** Calculated for $C_{17}H_{17}O_3$ [$(M + H)^+$]: 269.1174. Found: 269.1178.

7-Methoxy-2-propyl-2*H*-chromene (6k). Synthesized according to general procedure B, from 3-methoxyphenol (62.2 mg, 0.5 mmol) and *trans*-2-hexen-1-al (120 μL, 1.0 mmol) using phenylboronic acid (20 mol%) and benzoic acid (20 mol%) at 100 °C. Isolated as a pale yellow oil after flash chromatography on silica gel, eluting with 0.5–1% EtOAc/pentane (83.5 mg, 82%). Spectral data were in agreement with previous reports.[30] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 6.86 (d, J = 8.2 Hz, 1H), 6.40 (dd, J = 8.2, 2.5 Hz, 1H), 6.37 (d, J = 2.5 Hz, 1H), 6.34 (dd, J = 9.9, 1.4 Hz, 1H), 5.54 (dd, J = 9.8, 3.3 Hz, 1H), 4.83 (dddd, J = 6.8, 5.0, 3.4, 1.7 Hz, 1H), 3.77 (s, 3H), 1.83–1.74 (m, 1H), 1.68–1.40 (m, 3H), 0.96 (t, J = 7.3 Hz, 3H). **^{13}C NMR (100 MHz, $CDCl_3$):** δ 160.7, 155.0, 127.2, 123.6, 123.2, 115.5, 106.8, 102.0, 75.2, 55.4, 37.7, 18.2, 14.1. **HRMS (DART-TOF$^+$, m/z):** Calculated for $C_{13}H_{17}O_2$ [$(M + H)^+$]: 205.1234. Found: 205.1228.

3,3-Diphenyl-[3*H*]-naphtho-[2,1-*b*]pyran (6l). To a 2-dram vial equipped with a teflon-coated magnetic stir bar was added 2-naphthol (28.8 mg, 0.2 mmol), β-phenylcinnamaldehyde (83.3 mg, 0.4 mmol), 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and benzoic acid (20 mol%) and heptane (1 mL). The reaction mixture was stirred at 80 °C for 17 hours, after which the mixture was cooled to room temperature and then concentrated *in vacuo*. The resulting crude material was purified by silica gel chromatography (1–2% EtOAc/hexanes) to afford the title compound in as a white solid (75%, 50 mg). When 1,1-diphenylprop-2-yn-1-ol was utilized in replacement of β-phenylcinnamaldehyde under otherwise identical conditions, the title compound was isolated as a white solid (46 mg, 69%). Spectral data were in agreement with previous reports.[8] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.96 (d, J = 8.5 Hz, 1H), 7.73–7.69 (m, 1H), 7.66 (d, J = 8.9 Hz, 1H), 7.52–7.42 (m, 5H), 7.35–7.28 (m, 6H), 7.27–7.23 (m, 2H), 7.20 (dd, J = 8.8, 0.7 Hz, 1H), 6.27 (d, J = 10.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 150.7, 145.0, 130.0, 130.0, 129.5, 128.2, 127.7, 127.2, 126.7, 123.7, 121.5, 119.7, 118.5, 114.1, 82.7.

3,3-Bis[4-(*N*,*N*-dimethylamino)phenyl]-3-naphtho[2,1-*b*]pyran (6m). To a 2-dram vial equipped with a teflon-coated magnetic stir bar was added 2-naphthol (21.0 mg, 0.146 mmol), 1,1-bis(4-(dimethylamino)phenyl)prop-2-yn-1-ol (83.8 mg, 0.29 mmol), 3,5-bis(trifluoromethyl)phenylboronic acid (20 mol%) and benzoic acid (20 mol%) and heptane (0.73 mL). The reaction mixture was stirred at 80 °C for 17 hours, after which the mixture was cooled to room tempera-

ture and then concentrated *in vacuo*. The resulting crude material was purified by silica gel chromatography (20% EtOAc/hexanes) to afford the title compound in as an off white solid (53%, 61.4 mg), R_f = 0.4 (30% EtOAc/hexanes). Spectral data were in agreement with previous reports.[27] **^{1}H NMR (500 MHz, $CDCl_3$):** δ 7.97–7.92 (m, 1H), 7.71–7.67 (m, 1H), 7.62 (d, J = 8.8 Hz, 1H), 7.46–7.40 (m, 1H), 7.34 (d, J = 8.5 Hz, 4H), 7.30–7.26 (m, 1H), 7.25 (d, J = 10.0 Hz, 1H), 7.16 (dd, J = 8.8, 0.7 Hz, 1H), 6.67 (s, 4H), 6.21 (d, J = 9.9 Hz, 1H), 2.92 (s, 12H).

4,4-Diphenylbut-3-en-2-one (3d). Prepared according to a modified literature procedure.[31] Zinc dust (<10 μm, 600 mg, 6.5, 1.3 eq.) was added to a flask containing 4 mL of 2 M HCl and stirred vigorously until the surface of the zinc became lustrous. The aqueous solution was decanted and the zinc powder washed by successive decantation with H_2O (4 × 10 mL). The powder was then washed successively with MeOH (2 mL), acetone (4 mL) and dry THF (2 mL) and quickly transferred to an oven dried round bottomed flask. The powder was dried under vacuum for 20 minutes, after which the flask was filled with argon. A solution of benzophenone (908 mg, 5 mmol, 1 eq.) and propargyl bromide (80 wt% in toluene, 0.9 mL, 7.8 mmol, 1.6 eq.) in dry THF was prepared in an oven dried round bottomed flask that was evacuated and backfilled with argon. The solution was then added to the activated zinc powder at 0 °C with vigorous stirring at room temperature. After three hours, the reaction mixture was poured into ice water and a 20 w/v% solution of aq. acetic acid was added to the reaction mixture until acidic to pH paper. The mixture was extracted twice with diethyl ether and the combined organic layers washed successively with water, and saturated aq. $NaHCO_3$, and then dried over Na_2SO_4. Filtration and evaporation of the solvent afforded crude 1,1-diphenyl-but-3-yn-1-ol, which was subjected to a Rupe rearrangement without further purification. To a solution of the crude alcohol in concentrated acetic acid (4 mL) was added concentrated H_2SO_4 (50 μL). The reaction mixture was stirred vigorously at 70 °C for 40 minutes, and then poured into ice water and extracted twice with CH_2Cl_2. The combined organic layers were washed with H_2O, saturated aq. $NaHCO_3$, and then dried over Na_2SO_4. The crude mixture was concentrated *in vacuo* and then purified by silica gel chromatography (10–15% EtOAc/hexanes) to afford the title compound as an orange oil (422 mg, 38%). Spectral data were in agreement with previous reports.[32] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.44–7.40 (m, 3H), 7.37–7.28 (m, 5H), 7.24–7.20 (m, 2H), 6.58 (s, 1H), 1.88 (s, 3H).

1,1-Diphenylprop-2-yn-1-ol (7a). Prepared according to a modified literature procedure.[33] To a solution of trimethylsilylacetylene (1.4 mL, 10 mmol, 2 eq.) in THF (16 mL) at −10 °C was added a solution of *n*BuLi (2.5 M in hexanes, 4 mL, 10 mmol, 2.0 eq.) dropwise under an atmosphere of argon. The resulting solution was stirred at −10 °C for 30 minutes after which time benzophenone (911 mg, 5 mmol, 1 eq.) was added. The solution was then warmed to room temperature and stirred for 4 hours, after which time KOH (1.4 g, 25 mmol, 5 eq.) in methanol was added at 0 °C and stirred for 20 minutes. The mixture was then poured into a solution of saturated aq. NH_4Cl and extracted three times with EtOAc. The combined organic layers were washed sequentially with H_2O and saturated aq. NaCl, and then dried over Na_2SO_4. The drying agent was then removed by filtration and the solution was concentrated *in vacuo*. The title compound was obtained by silica gel chromatography (10% EtOAc/hexanes, R_f = 0.3) as a white solid (90 mg, 87%). Spectral data were in agreement with previous reports.[34] **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.65–7.58 (m, 4H), 7.36–7.27 (m, 6H), 2.88 (s, 1H), 2.76 (s, 1H).

1,1-Bis[4-(*N*,*N*-dimethylamino)phenyl]prop-2-yn-1-ol (7b). Prepared according to a modified literature procedure.[33] To a solution of trimethylsilylacetylene (0.7 mL, 5 mmol, 2 eq.) in THF (8 mL) at −10 °C was added a solution of *n*BuLi (2.5 M in hexanes, 2 mL, 5 mmol, 2.0 eq.) dropwise under an atmosphere of argon. The resulting solution was stirred at −10 °C for 30 minutes after which time benzophenone (677.5 mg, 2.5 mmol, 1 eq.) was added. The solution was then warmed to room temperature and stirred for 4 hours, after which time KOH (1.4 g, 25 mmol, 5 eq.) in methanol was added at 0 °C and stirred for 20 minutes. The mixture was then poured into a solution of saturated aq. NH_4Cl and extracted three times with EtOAc. The combined organic layers were washed sequentially with H_2O and saturated aq. NaCl, and then dried over Na_2SO_4. The drying agent was then removed by filtration and the solution was concentrated *in vacuo*. The crude mixture was subjected to silica gel chromatography (30% EtOAc/hexanes, R_f = 0.5) to afford a mixture of the titled compound and the respective α,β-unsaturated aldehyde (337.2 mg). Half of the mixture was recrystallized from EtOAc/hexanes to afford the titled compound as a light green solid (85.4 mg). Spectral data were in agreement with previous reports.[35] **^{1}H NMR (400 MHz, C_6D_6):** δ 7.78–7.71 (m, 4H), 6.61–6.53 (m, 4H), 2.47 (s, 12H).

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