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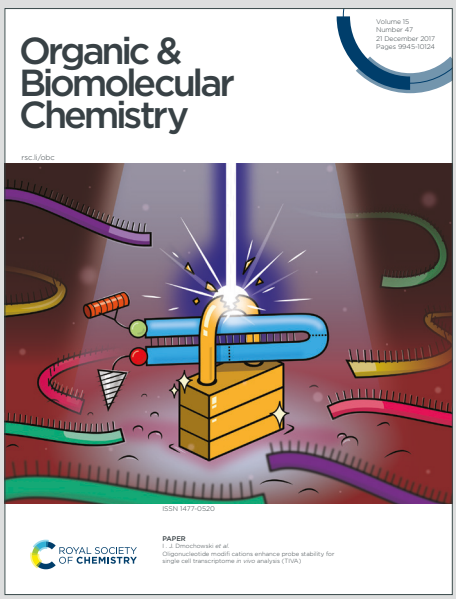

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ARTICLE

Chemoselective Acid-Catalyzed [4+2]-Cycloaddition Reactions of *ortho*-Quinone Methides and Styrenes/Stilbenes/Cinnamates

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ortho-Quinone methides (*o*-QMs) generated from the corresponding benzyl acetate precursors chemoselectively underwent the formal [4+2]-cycloadditions with the olefin of styrene, stilbene, or cinnamate derivatives by using different transition metal salts or Brønsted acids. Such selectivity was obtained when these olefins either separately acted as the dienophiles or were simultaneously present on the same dienophiles. Complete selectivity was also achieved between the stilbene olefin and acetylene to furnish the key chroman intermediate for the subsequent ring-closing metathesis (RCM), affording the corresponding tetracyclic 5*H*-dihydronaphtho[1,2-*c*]chromene.

Introduction

ortho-Quinone methides (*o*-QMs) have served as important intermediates in organic synthesis, bioorganic chemistry, and biosynthesis of natural products.[1,2] Their utilization during the total synthesis of complex natural products has been well documented.[3] Among their chemical reactivity, the formal [4+2]-cycloaddition reactions with electron-rich dienophiles, where *o*-QMs were regarded as the electron-deficient dienes, could furnish the corresponding chromans arising from the inverse electron-demand Diels-Alder-type process. As shown in Fig. 1, various chroman-containing natural products, namely rubicordifolin (**1**),[4] rubioncolin (**2**),[5] berkelic acid (**3**),[6] cytosporolide (**4**),[7] psidial A (**5**),[8] and psiguadial C (**6**)[9] were readily prepared via total synthesis employing this chemistry.

As shown in Scheme 1, over the past few years, our research group has actively investigated the reactions of *o*-QMs generated from the benzyl acetate precursor **7** with (*E*)-styrene **8a**, (*E*)-chalcone **8b**, or (*E*)-cinnamate **8c** under the mediation/catalysis of *p*-toluenesulfonic acid immobilized on silica (PTS-Si) and some transition metal salts such as $PtCl_4$ to generate the corresponding 3/4-substituted 2-arylchroman **9a**, **9b**, or **9c**, respectively, in good to excellent yields (up to 99%) and *trans* stereocontrol at C2–C3 (>99:1) as well as predominantly *cis* stereochemistry at C2–C4 (up to >99:1).[10] We now envisioned that such formal [4+2]-cycloaddition reactions of *o*-QMs could be extended to stilbenes **10** to provide the corresponding 2,3-diaryl-4-substiutted chromans **11**. More importantly, we anticipated that, by using different transition metals/Brønsted acids, these olefin-containing

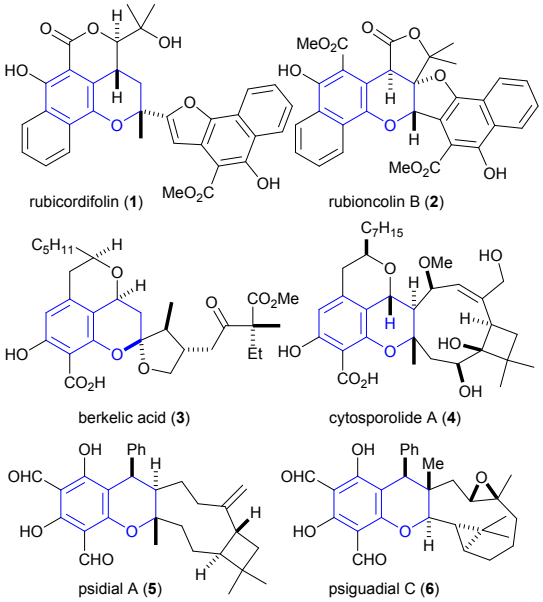

Fig. 1 Representative chroman-containing natural products **1**-**6** accessible via the formal [4+2]-cycloaddition reactions of *o*-QMs.

dienophiles may undergo chemoselective [4+2]-cycloaddition reactions in a controlled and desirable manner. Herein, we wish to report catalyst- and substrate-controlled chemoselectivity when these formal [4+2]-cycloaddition reactions were performed competitively on the mixture of these dienophiles to afford **9a**, **9c**, or **11**. Alternatively, these reactions would be performed on single molecules of dienophiles simultaneously containing two different types of these olefins to afford the cycloadducts **12**. On the basis of chemoselectivity between alkyne and stilbene, a key chroman intermediate bearing two intact TMS acetylene groups would be prepared which could afford the corresponding tetracyclic 5*H*-dihydronaphtho[1,2-*c*]chromene **13** upon subsequent steps including the Ru(II)-catalyzed ring-closing metathesis (RCM).

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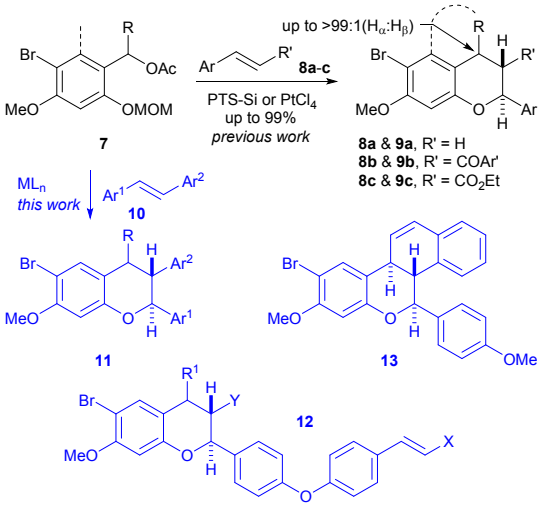
†Electronic Supplementary Information (ESI) available: Detailed experimental for the preparation of compounds **28**-**30** and copies of ^1H and ^{13}C NMR spectra. See DOI: 10.1039/x0xx00000x



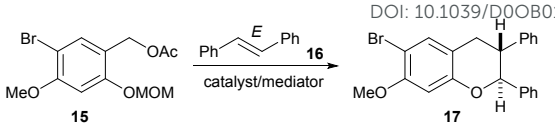
Scheme 1 [4+2]-Cycloaddition reactions of *o*-QMs and olefins under acid catalysis.

Results and Discussion

Because the reaction conditions for the [4+2]-cycloaddition reactions of *o*-QMs and stilbenes have not been optimized, benzyl acetate **15** and the commercially available (*E*)-stilbene **16** were used as models while various transition metal salts or Brønsted acids were employed as catalyst/mediator. As summarized in Table 1, neither the use of stoichiometric amount of PTS-Si[10a,b] nor catalytic amount of $PtCl_4$[10c] gave the corresponding chroman **17** (entries 1–2); similar results were also found when different salts of Cu(I) and Cu(II) were used as catalyst (entries 3–4). In contrast, catalytic amount of the chloride salts of Fe(II) and Fe(III) gave **17** in low yields (up to 31%; entries 5–6)[11] while slightly better yield of 40% was obtained from $InCl_3$ (entry 7).[12] Interestingly, while $MgCl_2$ did not give any product, $Mg(ClO_4)_2$[13] could furnish **17** in 37% yield (entries 8–9). Silver trifluoroacetate did not provide the product (entry 10) but various transition metal triflates except $Yb(OTf)_3$ furnished **17** in moderate to good yields (up to 58%; entries 11–15).[14] Apparently, the reaction conditions (amount of catalyst, temperature, and reaction time) contributed towards the yields when $In(OTf)_3$ was employed. Therefore, the optimized condition for the reaction between **15** and **16** was the use of 5-10 mol% of $In(OTf)_3$ at 0–15 °C for 1 h.[15]

Previously, we reported that the dienophiles bearing an electron-donating methoxy group at the 4-position of the aromatic ring of styrenes or cinnamates gave the cycloadducts in better yields than those with proton or electron-withdrawing group at the same position.[10] Thus, in order to assess the difference in the reactivity of styrenes, stilbenes, and cinnamates in the [4+2]-cycloaddition reactions, we decided to employ styrene **18**, stilbene **19**, and cinnamate **20** as the dienophiles while using benzyl acetate **15** and **21** as the *o*-QM precursors. Three transition metals/Brønsted acids, namely PTS-Si, $PtCl_4$, and $In(OTf)_3$, were utilized as the catalyst/mediator to furnish the corresponding cycloadducts **22**-**27** in moderate to excellent yields (up to 99%). The results were summarized in Fig. 2.

Table 1 Optimization for the [4+2]-cycloaddition reactions of **15** and **16**[a]



Entry	Mediator (mol%)	Yield[b] (%)
1[c]	PTS-Si (110)	0
2	$PtCl_4$ (10)	0
3	CuTC (10) or CuI (10)	0
4	$CuBr_2$ (10) or $Cu(OTf)_2$ (10)	0
5	$FeCl_2$ (10-100)	< 20
6	$FeCl_3$ (10)	31
7	$InCl_3$ (10)	40
8	$MgCl_2$ (10)	0
9	$Mg(ClO_4)_2$ (10)	37
10	$Ag(TFA)_2$ (5)	0
11	$Bi(OTf)_3$ (10)	31
12[d]	$Sc(OTf)_3$ (5-10)	47
13	$Yb(OTf)_3$ (10)	0
14	$In(OTf)_3$ (10)	44
15[e]	$In(OTf)_3$ (5)	58
16[f]	$In(OTf)_3$ (1)	48

[a]Unless noted otherwise, the reactions were carried out in CH_2Cl_2 as solvent and performed at 0 °C to room temperature until the benzyl acetate was completely consumed as indicated by tlc. [b]Isolated yields. [c]Toluene was employed as solvent. [d]Use of 20 mol% gave the product in lower yield (33%). [e]The reaction was performed at 0–15 °C for 1 h. [f]The reaction was carried out at 0–15 °C for 3 h; performing the reaction at 0 °C to room temperature for 18 h led to decomposition of **15** without any detectable amount of the product **17**.

For the electron-rich styrene **18**, catalytic amount of both $PtCl_4$ and $In(OTf)_3$ led to their complete decomposition, presumably the polymerization, prior to catalyzing the formation of the corresponding *o*-QM from **15**. Therefore, for electron-rich styrenes, only PTS-Si was effective, affording the product **22** in excellent yield (99%). The results were somewhat different when the reactions were evaluated using *o*-QM generated from the benzyl acetate **21**. While PTS-Si was still the most effective mediator and furnished the cycloadduct **25** in 57% yield (4:1 mixture of the C4 epimers favoring C2-C4 in a *cis* relationship), both $PtCl_4$ and $In(OTf)_3$ could also provide **25** in 19% (4:1 mixture) and 40% (1.5:1 mixture) yields, respectively. In case of the stilbene **19**, both PTS-Si and $In(OTf)_3$ could provide the product **23** in excellent yields of 94% and 90%, respectively, while $PtCl_4$ in moderate 43% yield. Similar results were also obtained when stilbene **19** reacted with the *o*-QM from the benzyl acetate **21**. The reactions afforded the corresponding cycloadduct **26** in moderate to good yields of 84%, 37%, and 75% from PTS-Si, $PtCl_4$, and $In(OTf)_3$, respectively, with excellent diastereocontrol at C2-C4 of >10:1 favoring the *cis* relationship in all cases. When the cinnamate **20** was employed, all three catalysts/mediators could furnish the chromans **24** and **27** from the corresponding benzyl acetates **15** and **21**, respectively, in moderate to good yields (58–80%). In case of **15**, $PtCl_4$ gave the best yield of 76% while PTS-Si gave the best yield of 80% for **21**. Chroman **27** was obtained with moderate diastereoselectivity between C2-C4 of 3:1 favoring the *cis* relationship in all cases.

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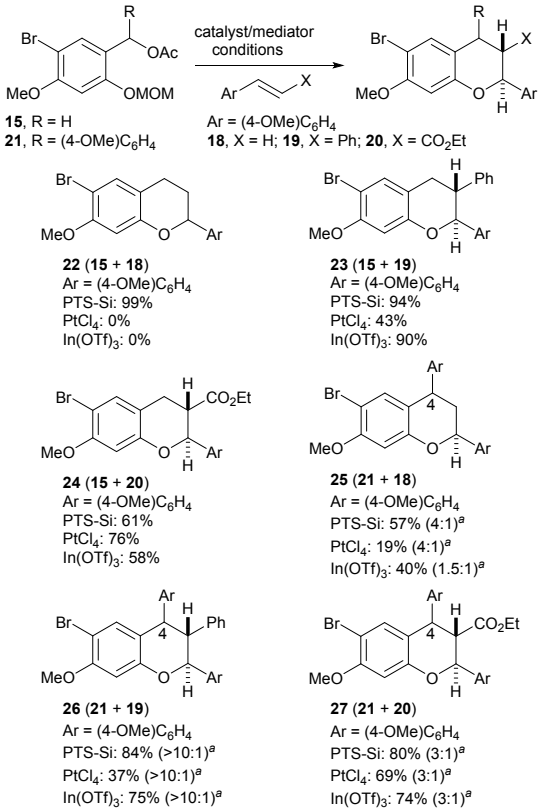
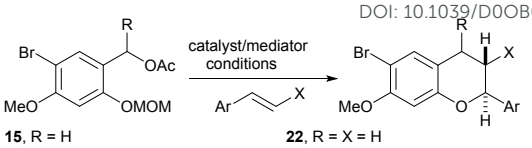


Fig. 2 [4+2]-Cycloaddition reactions of **15** and **21** with dienophiles **18**–**20** using PTS-Si, $PtCl_4$, or $In(OTf)_3$ as catalyst/mediator. [a] H_α:H_β at C4.

Having established the reaction conditions for each dienophile, we turned our attention to assess the outcome of the reactions when two or all three dienophiles were simultaneously present in the reactions (Table 2). This would shed some light on the relative kinetics of each dienophile under the catalysis/mediation of PTS-Si, $PtCl_4$, or $In(OTf)_3$.

Some generalizations could be made based on the results shown in Table 2. In most cases (except entries 4, 13, and 14), complete orthogonality for the [4+2]-cycloaddition reactions, which excluded the cinnamate **20** as a dienophile, were observed; the corresponding cycloadducts **24** and **27** were not obtained and **20** could be recovered virtually quantitatively. In addition, *o*-QM from the benzyl acetate **21** generally favored the [4+2]-cycloaddition reactions with styrene **18** to furnish the chroman **25** (entries 10–13 and 17–19). When comparing benzyl acetates **15** and **21** as the *o*-QM precursors, the presence of a PMB group in **21** apparently affected and facilitated the [4+2]-cycloaddition with each reacting dienophile to furnish the corresponding cycloadducts in better yields (entry 1 *vs* 10, entry 3 *vs* 12, entry 7 *vs* 16, and entry 8 *vs* 17). Because $PtCl_4$ caused extensive decomposition of the styrene **18** when reacting with *o*-QM from **15** as shown in Figure 2, we decided not to employ $PtCl_4$ as a catalyst when styrene **18** was used as a dienophile (entries 1–4 and 8–9). In general, when PTS-Si was employed, low yields (20-26%) of the chroman **22** were obtained from the reactions of **15** with the styrene **18** in the presence of either the stilbene **19** and/or cinnamate **20** (entries 1, 3, and 8). In these cases, both

Table 2 Competitive [4+2]-cycloaddition reactions[a]



15, R = H
21, R = (4-OMe)C_6H_4
Ar = (4-OMe)C_6H_4
18, X = H
19, X = Ph
20, X = CO_2Et

22, R = X = H
23, R = H; X = Ph
24, R = H; X = CO_2Et
25, R = (4-OMe)C_6H_4; X = H
26, R = (4-OMe)C_6H_4; X = Ph
27, R = (4-OMe)C_6H_4; X = CO_2Et

Entry	Benzyl Acetate	Dienophile	Mediator (mol%)	Yield[b] (%)
1	**15**	**18**+**19**	PTS-Si (110)	**22** (20) : **23** (25)
2	**15**	**18**+**19**	$In(OTf)_3$ (10)	**22** (0) : **23** (80)
3	**15**	**18**+**20**	PTS-Si (110)	**22** (26) : **24** (0)
4	**15**	**18**+**20**	$In(OTf)_3$ (10)	**22** (0) : **24** (26)
5[c]	**15**	**19**+**20**	PTS-Si (110)	**23** (62) : **24** (0)
6[c]	**15**	**19**+**20**	$PtCl_4$ (10)	**23** (54) : **24** (0)
7[c]	**15**	**19**+**20**	$In(OTf)_3$ (10)	**23** (61) : **24** (0)
8	**15**	**18**+**19**+**20**	PTS-Si (110)	**22** (23) : **23** (8) : **24** (0)
9	**15**	**18**+**19**+**20**	$In(OTf)_3$ (10)	**22** (0) : **23** (54) : **24** (0)
10	**21**	**18**+**19**	PTS-Si (110)	**25** (68) : **26** (0)
11	**21**	**18**+**19**	$In(OTf)_3$ (10)	**25** (28) : **26** (0)
12	**21**	**18**+**20**	PTS-Si (110)	**25** (60) : **27** (0)
13	**21**	**18**+**20**	$PtCl_4$ (10)	**25** (57) : **27** (31)
14	**21**	**19**+**20**	PTS-Si (110)	**26** (51) : **27** (29)[d]
15	**21**	**19**+**20**	$PtCl_4$ (10)	**26** (58) : **27** (0)
16	**21**	**19**+**20**	$In(OTf)_3$ (10)	**26** (89) : **27** (0)
17	**21**	**18**+**19**+**20**	PTS-Si (110)	**25** (60) : **26** (0) : **27** (0)
18	**21**	**18**+**19**+**20**	$PtCl_4$ (10)	**25** (25) : **26** (28) : **27** (0)
19	**21**	**18**+**19**+**20**	$In(OTf)_3$ (10)	**25** (50) : **26** (0) : **27** (0)

[a]Unless noted otherwise, all reactions were performed using CH_2Cl_2 as solvent until the benzyl acetate **15** or **21** was completely consumed as indicated by tlc; 2 equivalents of **18**, **19**, and/or **20** were added. [b]Isolated yield. [c]**20** was recovered virtually quantitatively (>97%) while approximately 27% yield of **19** was recovered. [d]Obtained as a 2:1 mixture of two C4 epimers favoring *cis*.

chromans **22** and **23** were obtained virtually as 1:1 mixture. Interestingly, when catalytic amount of $In(OTf)_3$ was used, in the presence of both **18** and **19**, the *o*-QM from **15** selectively reacted with **19** to furnish **23** in 80% yield (entry 2). In addition, in the presence of **18** and **20**, only chroman **24** from the reaction between the *o*-QM and the cinnamate **20** was obtained in low yield of 26% (entry 4). In both cases, as monitored by tlc, substantial decomposition of **18** was evident and preceded the cycloaddition reactions. In cases where both stilbene **19** and cinnamate **20** were simultaneously present, using PTS-Si, $PtCl_4$, or $In(OTf)_3$ only furnished the chroman **23** in moderate 54–62% yields (entries 5–7). Similar results were also obtained when the benzyl acetate **21** was employed as substrate (entries 14–16); $In(OTf)_3$ gave the best yield of chroman **26** (89%) while $PtCl_4$ in moderate 58% yield. When the three dienophiles were present, the selectivity depended on the *o*-QM substrate (**15** *vs* **21**) and the catalyst/mediator. With PTS-Si as a mediator, both **15** and **21** preferably gave the cycloadduct **22** and **25** arising from the reactions with the styrene **18** in 23% and 60% yields, respectively (entries 8 and 17). However, when $In(OTf)_3$ was employed, different types of the chroman product were obtained from **15** and **21**. Compound **15** reacted selectively with stilbene **19** to furnish **23**

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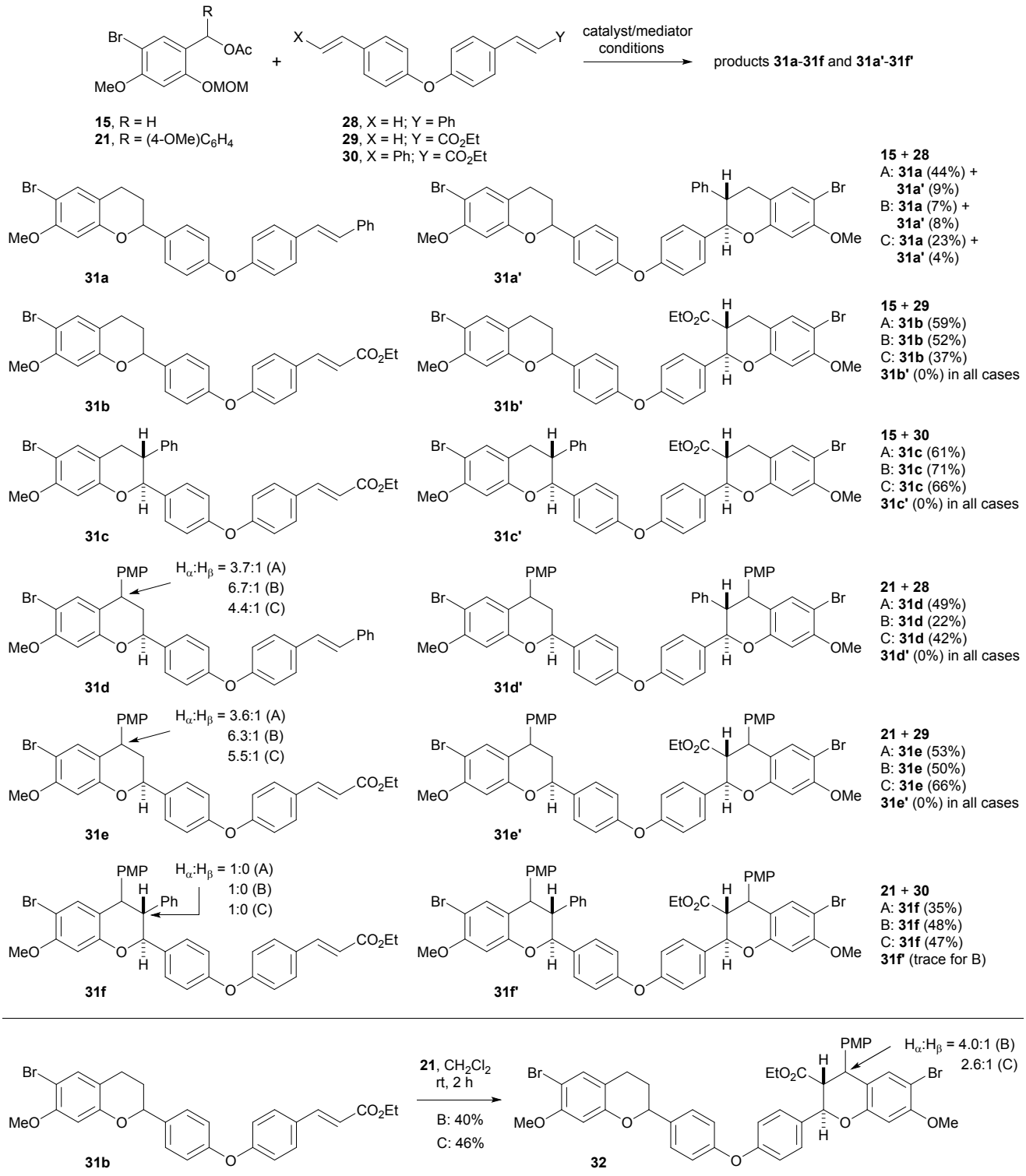

Scheme 2 Chemoselective [4+2]-cycloaddition reactions of benzyl acetates **15** and **21** with dienophiles **28**–**30** containing two different olefins. A = PTS-Si; B = $PtCl_4$; C = $In(OTf)_3$.

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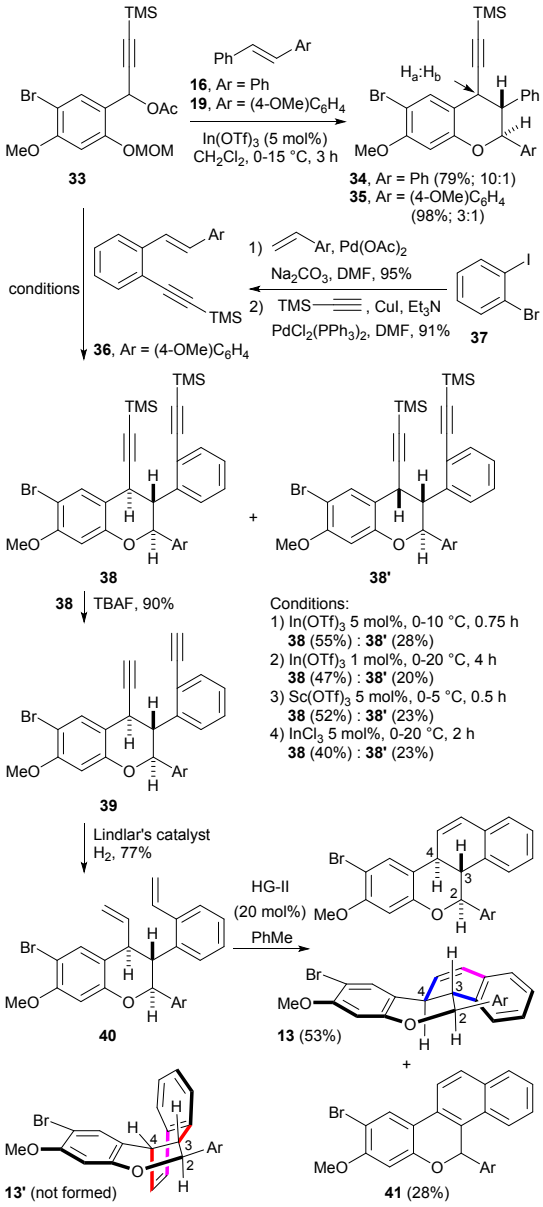
in 54% yield (entry 9) while **21** reacted with styrene **18** to provide **25** in 50% yield (entry 19).

With the above results, we then investigated the reactions between the benzyl acetate **15** or **21** with compounds **28**–**30**[16] each of which contains two different olefin functionalities acting as dienophiles on the same molecule: **28** containing styrene and stilbene moieties, **29** containing styrene and cinnamate moieties, and **30** containing stilbene and cinnamate moieties. We anticipated that cycloaddition reactions should proceed with high selectivity among these olefins acting as dienophiles. The results were depicted in Scheme 2. In most cases, excellent selectivity among different olefins was observed; the only exceptions were the cases where *o*-QM from **15** reacted with **28**, yielding both **31a** and **31a'** arising from the reactions of *o*-QM on both styrene and stilbene moieties regardless of the catalyst/mediator. Compound **31a** was obtained as the major product when using PTS-Si (44% yield) or $In(OTf)_3$ (23% yield). In each case, **31a'** was obtained only in low yields (4–9%). $PtCl_4$, on the other hand, gave both **31a** (7% yield) and **31a'** (8% yield) without any selectivity. Apparently, there were a number of inseparable and uncharacterizable products from the decomposition of **28** under the reaction conditions or from different side reactions, leading to low mass balance, especially for $PtCl_4$. To our delight, in other cases, whether *o*-QM from **15** or **21** was employed as substrate to react with **28**–**30**, the corresponding products **31b**–**31f** were obtained from the mono-cycloaddition reaction on one of the two dienophiles with only trace amount, if any, of the undesired **31b'**–**31f'**. Similar to the results obtained above (Table 2), virtually no reactions took place on the cinnamate moiety of compounds **29** and **30** in all cases regardless of the catalysts/mediators.[17] Interestingly, when compound **28** reacted with benzyl acetate **21**, excellent selectivity was also obtained on the styrene even when $PtCl_4$ was employed; however, the yields of the product **31d** remained moderate (less than 49%). In case of compound **29**, the resulting cycloadducts **31b** and **31e** were furnished equally effectively from both **15** (37–59% yields) and **21** (50–66% yields) with PTS-Si and $In(OTf)_3$ as the best catalyst/mediator, respectively. For compound **30**, consistently higher yields (61–71%) of **31c** from the benzyl acetate **15** were obtained when compared with those (35–48%) of **31f** from the benzyl acetate **21**; the range of yields for both *o*-QM precursors appeared to be independent of the catalyst/mediator. Regarding the C2-C4 stereoselectivity for the cycloadducts **31d–f**, **31d** and **31e** were obtained as mixtures of C4-epimers favoring 2,4-*cis* relationship in the ratios of 3.6:1–6.7:1; $PtCl_4$ consistently gave the best C2-C4 diastereoselectivity among the mediators. Surprisingly, **31f** was obtained as a single diastereomer regardless of the mediators. We further demonstrated that the sequential [4+2]-cycloaddition reaction could be realized by employing **31b**, the cycloadduct from the benzyl acetate **15** and compound **29**, as a starting material for the subsequent [4+2]-cycloaddition reaction using the benzyl acetate **21**. Both $PtCl_4$ and $In(OTf)_3$ could affect such cycloaddition reaction, furnishing the desired product **32** in moderate yields of 40% and 46% and C2-C4 diastereoselectivity of 4:1 and 2.6:1, respectively.

Interestingly, as shown in Scheme 3, alkyne could be tolerated during the catalysis of $In(OTf)_3$ between the *o*-QM precursor **33** bearing a TMS acetylene and stilbene **16** or **19**. The corresponding chromans **34** and **35** were obtained in 79% and 98% yields, each as a 10:1 and a 3:1 mixture of C4-epimers, respectively. The presence of an alkyne on the dienophile was also evaluated; the stilbene-alkyne **36** bearing another TMS acetylene moiety *ortho* to the stilbene was prepared for this purpose via sequential Heck and Sonogashira cross-coupling reactions of 2-bromoiodobenzene **37** in 95%



Scheme 3 Synthesis of the tetracyclic 5*H*-dihydronaphtho[1,2-*c*]chromene **13**.

and 91% yields, respectively.[18] $In(OTf)_3$-catalyzed [4+2]-cycloaddition required some additional optimization; 5 mol% of $In(OTf)_3$ furnished the chroman **38** in 55% yield with the C2-C4 in the *cis* relationship along with **38'**, its C4-epimer, in 28% yield. Subsequent treatment of **38** with tetrabutylammonium fluoride (TBAF) smoothly cleaved both TMS groups and gave **39** in 90% yield which was then subjected to hydrogenation using Lindlar's catalyst. The diene **40** was obtained in 77% yield; Hoveyda-Grubbs II (HG-II)-catalyzed ring closing metathesis (RCM) of **40** proceeded rather sluggishly, requiring heating at 70 °C and 80 °C for 24 h each. The desired tetracyclic 5*H*-dihydronaphtho[1,2-*c*]chromene **13** was finally obtained in 53% yield along with the aromatized 5*H*-naphtho[1,2-c]chromene **41** in 28% yield. Other reaction conditions (other catalysts, higher temperatures with shorter reaction times, or lower temperatures with longer reaction times) gave no improvement of yields or selectivity between **13** and **41**.

It should be noted that **38'** could not undergo such reaction sequence smoothly, especially the final RCM to furnish **13'**. Apparently, the difference in stereochemistry at C4 of **38'** affected its reactivity which led to undesired side reactions and low yields of the products from TBAF desilylation as well as Lindlar's hydrogenation. More importantly, the resulting diene was unreactive during the RCM and could be recovered virtually quantitatively under various conditions. This could be accounted for by considering and comparing the conformations of **13**, which was obtained from **38**, and **13'**, which would otherwise be the product from **38'**. The geometry required for the ring fusion between the cyclohexene and the aromatic ring of the dihydronaphthalene unit would necessitate the two adjacent bonds on the aromatic ring (blue and pink for **13** *vs* red and pink for **13'**) to assume coplanarity; clearly, the conformation in **13** would be more optimal. In part, this also results from the more favorable pseudoequatorial-pseudoequatorial ring fusion (blue bonds; H_3-H_4 in the *trans* relationship) in **13** than the pseudoequatorial-pseudoaxial ring fusion (red bonds; H_3-H_4 in the *cis* relationship) in **13'**.

Conclusions

In summary, we have demonstrated that under different transition metal salt/Brønsted acid-catalyzed formal [4+2]-cycloaddition reaction conditions, three classes of structurally related olefins conjugated with aromatic rings containing electron-donating methoxy group, namely styrenes, stilbenes, and cinnamates, could chemoselectively react with *ortho*-quinone methides (*o*-QMs) generated under the same reaction conditions from the corresponding benzyl acetates to furnish the corresponding cycloadducts in moderate to excellent yields. Such chemoselectivity could also be obtained when two or more possible dienophiles were present simultaneously in the reaction or two different olefins were present on the same molecule of the dienophile. In addition, complete chemoselectivity was also observed between the stilbene moiety and the TMS acetylene groups present on both *o*-QM and the aromatic ring of the stilbene. Subsequent functional group manipulations of the chroman **38** containing two TMS acetylene groups then led to the synthesis of tetracyclic 5*H*-dihydronaphtho[1,2-*c*]chromene in 20% overall yield in 4 steps starting from the [4+2]-cycloaddition reaction.

Experimental section

General Information

Unless otherwise noted, reactions were run in oven-dried round-bottomed flasks. Tetrahydrofuran (THF) was distilled from sodium benzophenone ketyl or purified by the solvent purification system while dichloromethane (CH_2Cl_2) was also purified by the solvent purification system prior to use. All other compounds were used as received from the suppliers; PTS-Si (*p*-TsOH immobilized on silica) employed in these experiments possessed the surface area of 500 m^2/g as indicated by the supplier. The crude reaction mixtures were concentrated under reduced pressure by removing organic solvents on rotary evaporator. Column chromatography was performed using silica gel 60 (particle size 0.06-0.2 mm; 70-230 mesh ASTM). Analytical thin-layer chromatography (TLC) was performed with silica gel 60 F_{254} aluminum sheets. Chemical shifts for ^1H nuclear magnetic resonance (NMR) spectra were reported in parts per million (ppm,□□) downfield from tetramethylsilane. Splitting patterns are described as singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), broad (br), doublet of doublet (dd), doublet of triplet (dt), and doublet of doublet of doublet (ddd). All ^{13}C NMR data were obtained with the use of broadband decoupling ($^{13}C\{^1H\}$) and reported as proton-decoupled data. Resonances for infrared (IR) spectra were reported in wavenumbers (cm^{-1}). Low resolution (LRMS) mass spectra were obtained either using electron ionization (EI) or time-of-flight (TOF) while high resolution (HRMS) mass spectra were obtained using time-of-flight (TOF) via the atmospheric-pressure chemical ionization (APCI) or electrospray ionization (ESI). Melting points were uncorrected.

General procedure for the formal [4+2]-cycloaddition reaction

To a stirred solution of benzyl acetate (1.0 equiv) in toluene (for PTS-Si as mediator) or CH_2Cl_2 (for other transition metals as Lewis acids) (15 mL/mmol) was added the corresponding alkene (2 equiv) at room temperature. The resulting mixture was stirred at 0 °C for 10 min and then PTS-Si (1.1 equiv) or transition-metals (10 mol%) was added. The stirring was continued (for time and temperature as indicated for each substrate). At that time, in case of PTS-Si, it was filtered off before the resulting mixture was concentrated under reduced pressure. In other cases, the reaction mixture was concentrated under reduced pressure directly to give a crude product mixture which was further purified by PTLC (10% EtOAc/hexane) to furnish the desired product.

6-Bromo-7-methoxy-2,3-diphenylchroman (17).

Following the General Procedure, benzyl acetate **15** (0.020 g, 0.06 mmol), (*E*)-1,2-diphenylethene **16** (0.023 g, 0.13 mmol), and $In(OTf)_3$ (0.002 g, 0.003 mmol) were employed to give **17**

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as a white sticky gum (0.014 g, 0.037 mmol, 58%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.91–3.05 (m, 1H), 3.11–3.29 (m, 2H), 3.83 (s, 3H), 5.05 (d, *J* = 9.2 Hz, 1H), 6.54 (s, 1H), 6.97–7.02 (m, 2H), 7.08–7.23 (m, 8H), 7.28 (s, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 32.2, 45.4, 56.2, 83.0, 101.0, 102.1, 115.6, 126.8, 127.1, 127.98, 128.03, 128.1, 128.4, 132.8, 139.3, 140.8, 154.9, 155.1; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{20}H_{20}{}^{79}BrO_2$, 395.0641; found, 395.0633; calcd for $C_{20}H_{20}{}^{81}BrO_2$, 397.0623; found, 397.0621.

6-Bromo-7-methoxy-2-(4-methoxyphenyl)-3-phenylchro-man (23).

Following the General Procedure, benzyl acetate **15** (0.020 g, 0.06 mmol), (*E*)-1-methoxy-4-styrylbenzene **19** (0.0263 g, 0.12 mmol), and PTS-Si (0.0851 g, 0.07 mmol) were employed to give **23** as a white solid (0.024 g, 0.057 mmol, 94%); Mp 130−132 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.93–3.02 (m, 1H), 3.11–3.28 (m, 2H), 3.73 (s, 3H), 3.83 (s, 3H), 5.02 (d, *J* = 9.4 Hz, 1H), 6.54 (s, 1H), 6.73 (d, *J* = 8.7 Hz, 2H), 7.01 (d, *J* = 6.6 Hz, 2H), 7.09 (d, *J* = 8.7 Hz, 2H), 7.12–7.22 (m, 3H), 7.28 (s, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 32.6, 45.3, 55.1, 56.2, 82.6, 100.9, 102.0, 113.5, 115.6, 126.7, 128.0, 128.3, 128.5, 131.4, 132.7, 141.0, 154.9, 155.0, 159.2; TOF-HRMS (*m/z*): [M$^{\cdot+}$], calcd for $C_{23}H_{21}O_3{}^{79}Br$, 424.0674; found, 424.0666; calcd for $C_{23}H_{21}O_3{}^{81}Br$, 426.0654; found, 426.0647.

Ethyl-6-bromo-7-methoxy-2-(4-methoxyphenyl)chroman-3-carboxylate (24).

Following the General Procedure, benzyl acetate **15** (0.050 g, 0.16 mmol), ethyl (*E*)-3-(4-methoxyphenyl)acrylate **20** (0.065 g, 0.31 mmol), and PTS-Si (0.213 g, 0.17 mmol) were employed to give **24** as colorless oil (0.040 g, 0.096 mmol, 61%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.99 (t, *J* = 7.1 Hz, 3H), 2.92 (dd, *J* = 15.2, 4.7 Hz, 1H), 3.02 (m, 1H), 3.19 (dd, *J* = 14.8, 10.9 Hz, 1H), 3.81 (s, 5H), 3.95 (qd, *J* = 7.1, 1.2 Hz, 2H), 5.00 (d, *J* = 9.1 Hz, 1H), 6.48 (s, 1H), 6.90 (d, *J* = 8.7 Hz, 2H), 7.26 (s, 1H), 7.32 (d, *J* = 8.7 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 13.9, 28.0, 45.4, 55.3, 56.2, 60.7, 79.0, 101.0, 102.5, 113.5, 113.9, 128.4, 130.3, 132.8, 154.5, 155.1, 159.9, 172.2; TOF-HRMS (*m/z*): [M$^{\cdot+}$], calcd for $C_{20}H_{21}O_5{}^{79}Br$, 420.0572; found, 420.0570; calcd for $C_{20}H_{21}O_5{}^{81}Br$, 422.0552; found, 422.0548.

6-Bromo-7-methoxy-2,4-bis(4-methoxyphenyl)chroman (25).

Following the General Procedure, benzyl acetate **21** (0.025 g, 0.06 mmol), 1-methoxy-4-vinylbenzene **18** (10 μL, 0.12 mmol), and PTS-Si (0.081 g, 0.066 mmol) were employed to give **25** a yellow oil (0.016 g, 0.034 mmol, 57%) as a 4:1 mixture of C4-epimers; ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.13 (ddd, *J* = 2.1, 3.2, 13.8 Hz, 1H, minor), 2.19 (ddd, *J* = 11.2, 11.8, 13.7 Hz, 1H, major), 2.31 (ddd, *J* = 2.1, 6.0, 13.7 Hz, 1H, major), 2.38 (ddd, *J* = 5.5, 10.6, 13.8 Hz, 1H, minor), 3.77 (s, 3H, minor), 3.78 (s, 3H, minor), 3.79 (s, 3H, major), 3.80 (s, 3H, major), 3.81 (s, 3H, major), 3.85 (s, 3H, minor), 4.10 (dd, *J* = 3.2, 5.5 Hz, 1H, minor), 4.18 (dd, *J* = 6.0, 11.8 Hz, 1H, major), 4.94 (dd, *J* = 2.1, 10.6 Hz, 1H, minor), 5.11 (dd, *J* = 2.1, 11.2 Hz, 1H, major), 6.50 (s, 1H, major), 6.56 (s, 1H, minor), 6.84 (d, *J* = 8.6 Hz, 2H, minor), 6.858 (d, *J* = 8.7 Hz, 2H, major), 6.864 (d, *J* = 8.6 Hz, 2H, minor), 6.90 (s, 1H, major), 6.91 (d, *J* = 8.7 Hz, 2H, major), 7.02 (d, *J* = 8.6 Hz, 2H, minor), 7.11 (d, *J* = 8.7 Hz, 2H, major), 7.13 (s, 1H, minor), 7.23 (d, *J* = 8.6 Hz, 2H, minor), 7.37 (d, *J* = 8.7 Hz, 2H, major); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 38.0 (minor), 38.6 (minor), 40.1 (major), 41.9 (major), 55.2 (major), 55.3 (major), 56.1 (major), 73.2 (minor), 78.3 (major), 100.86 (minor), 100.94 (major), 102.2 (major), 102.3 (minor), 113.82 (minor), 113.84 (minor), 113.9 (major), 114.1 (major), 116.8 (minor), 119.6 (major), 127.4 (minor), 127.5 (major), 129.3 (major), 129.4 (minor), 132.7 (major), 132.9 (minor), 133.2 (major), 134.1 (minor), 135.8 (major), 137.7 (minor), 155.0 (major), 155.3 (minor), 155.5 (minor), 155.7 (major), 158.2 (minor), 158.5 (major), 159.3 (minor), 159.5 (major); TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{24}H_{24}O_4{}^{79}Br$, 455.0852; found, 455.2249; calcd for $C_{24}H_{24}O_4{}^{81}Br$, 457.0832; found, 457.0857.

6-Bromo-7-methoxy-2,4-bis(4-methoxyphenyl)-3-phenyl-chroman (26).

Following the General Procedure, benzyl acetate **21** (0.025 g, 0.06 mmol), (*E*)-1-methoxy-4-styrylbenzene **19** (0.025 g, 0.12 mmol), and PTS-Si (0.081 g, 0.066 mmol) were employed to give **26** as a white solid (0.027 g, 0.050 mmol, 84%) of a >10:1 mixture of C4-epimers; Mp 193.3–195.0 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.24 (dd, *J* = 11.1, 10.5 Hz, 1H), 3.69 (s, 3H), 3.71 (s, 3H), 3.82 (s, 3H), 4.33 (d, *J* = 11.1 Hz, 1H), 5.18 (d, *J* = 10.5 Hz, 1H), 6.54 (s, 1H), 6.67 (d, *J* = 8.6 Hz, 2H), 6.70 (d, *J* = 8.6 Hz, 2H), 6.73–6.79 (m, 2H), 6.82 (d, *J* = 8.6 Hz, 2H), 6.92 (s, 1H), 6.96–7.06 (m, 3H), 7.11 (d, *J* = 8.6 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 49.0, 54.4, 55.0, 55.1, 56.2, 82.7, 100.8, 102.5, 113.5, 113.7, 120.3, 126.4, 128.1, 128.5, 129.8, 131.1, 133.7, 134.4, 139.4, 155.0, 155.4, 158.1, 159.2; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{30}H_{28}O_4{}^{79}Br$, 531.1165; found, 531.1159; calcd for $C_{30}H_{28}O_4{}^{81}Br$, 533.1146; found, 533.1136.

Ethyl-6-bromo-7-methoxy-2,4-bis(4-methoxyphenyl)-chroman-3-carboxylate (27).

Following the General Procedure, benzyl acetate **21** (0.025 g, 0.06 mmol), ethyl (*E*)-3-(4-methoxyphenyl)acrylate **20** (0.025 g, 0.06 mmol), and PTS-Si (0.081 g, 0.066 mmol) were employed to give **27** as a white sticky gum (0.026 g, 0.048 mmol, 80%) as a 3:1 mixture of C4-epimers; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.72 (t, *J* = 7.1 Hz, 3H, major), 0.91 (t, *J* = 7.1 Hz, 3H, minor), 3.10 (dd, *J* = 11.4, 10.2 Hz, 1H, major), 3.43 (dd, *J* = 11.0, 5.8 Hz, 1H, minor), 3.63–3.75 (m, 2H), 3.778 (s, 3H, minor), 3.783 (s, 3H, minor), 3.795 (s, 3H, major), 3.800 (s, 3H, major), 3.81 (s, 3H, major), 3.83 (s, 3H, minor), 4.44 (d, *J* = 5.8 Hz, 1H, minor), 4.45 (d, *J* = 11.4 Hz, 1H, major), 5.10 (d, *J* = 10.2 Hz, 1H, major), 5.19 (d, *J* = 11.0 Hz, 1H, minor), 6.50 (s, 1H, major), 6.53 (s, 1H, minor), 6.82 (d, *J* = 8.7 Hz, 2H, minor), 6.84 (d, *J* = 8.7 Hz, 2H, major), 6.86 (d, *J* = 8.7 Hz, 2H, minor), 6.895 (d, *J* = 8.7 Hz, 2H, major), 6.899 (s, 1H, major), 6.99 (d, *J* = 8.7 Hz, 2H, minor), 7.08 (d, *J* = 8.7 Hz, 2H, major), 7.14 (d, *J* = 8.7 Hz, 2H, minor), 7.31 (d, *J* = 8.7 Hz, 2H, minor), 7.36 (d, *J* = 8.7 Hz, 2H, major); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 13.7, 42.7 (minor), 45.5 (major), 50.4 (minor), 54.8 (major), 55.18 (major), 55.21 (minor), 55.3 (major), 56.2 (major), 60.27 (minor), 60.35 (major), 73.7 (minor), 79.8 (major), 100.5 (major), 100.7 (minor), 102.9 (major), 113.6 (minor), 113.7 (minor), 113.9 (major), 114.1 (major), 116.5 (minor), 118.5 (major), 128.6 (major), 129.1 (minor), 129.7 (major), 129.8 (major), 130.3, (minor), 131.0 (minor), 132.9 (major), 133.2 (major), 133.5 (minor), 133.7 (minor), 154.5 (minor), 154.8 (major), 155.2

(major), 155.5 (minor), 158.77 (minor), 158.81 (major), 159.7 (minor), 160.0 (major), 169.9 (minor), 171.3 (major); TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{27}H_{28}{}^{79}BrO_6$, 527.1064; found, 527.1057; calcd for $C_{27}H_{28}{}^{81}BrO_6$, 529.1044; found, 529.1033.

(*E*)-1-Styryl-4-(4-vinylphenoxy)benzene (28).[16]

Mp 158−159 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.21 (dd, *J* = 10.9, 0.6 Hz, 1H), 5.68 (dd, *J* = 17.6, 0.6 Hz, 1H), 6.70 (dd, *J* = 17.6, 10.9 Hz, 1H), 6.98–7.02 (m, 4H), 7.06 (d, *J* = 6.9 Hz, 2H), 7.23–7.29 (m, 1H), 7.33–7.43 (m, 4H), 7.48–7.52 (m, 4H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 112.9, 118.9, 119.0, 126.4, 127.5, 127.6, 127.8, 127.9, 128.7, 132.7, 133.0, 136.0, 137.4, 156.7, 156.8; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{22}H_{19}O$, 299.1430; found, 299.1429.

Ethyl (*E*)-3-(4-(4-vinylphenoxy)phenyl)acrylate (29).[16]

Mp 58−59 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.34 (t, *J* = 7.1 Hz, 3H), 4.26 (q, *J* = 7.1 Hz, 2H), 5.23 (dd, *J* = 10.9, 0.6 Hz, 1H), 5.69 (dd, *J* = 17.6, 0.6 Hz, 1H), 6.34 (d, *J* = 16.0 Hz, 1H), 6.71 (dd, *J* = 17.7, 11.0 Hz, 1H), 6.99–7.02 (m, 4H), 7.41 (d, *J* = 8.6 Hz, 2H), 7.49 (d, *J* = 8.7 Hz, 2H), 7.65 (d, *J* = 16.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 14.3, 60.4, 113.4, 117.0, 118.4, 119.6, 127.7, 129.3, 129.7, 133.7, 135.9, 143.8, 155.8, 159.3, 167.1; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{19}H_{19}O_3$, 295.1329; found, 295.1331.

Ethyl (*E*)-3-(4-(4-((*E*)-styryl)phenoxy)phenyl)acrylate (30).[16]

Mp 148−149 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.34 (t, *J* = 7.1 Hz, 3H), 4.27 (q, *J* = 7.1 Hz, 2H), 6.35 (d, *J* = 16.0 Hz, 1H), 6.97–7.09 (m, 6H), 7.24–7.29 (m, 1H), 7.37 (t, *J* = 7.5 Hz, 2H), 7.49–7.53 (m, 6H), 7.67 (d, *J* = 16.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 14.3, 60.4, 117.0, 118.5, 119.8, 126.4, 127.6, 127.7, 128.0, 128.3, 128.7, 129.4, 129.7, 133.4, 137.2, 143.8, 155.7, 159.3, 167.1; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{25}H_{23}O_3$, 371.1642; found, 371.1642.

(*E*)-6-Bromo-7-methoxy-2-(4-(4-styrylphenoxy)phenyl)-chroman (31a).

Following the General Procedure, benzyl acetate **15** (0.031 g, 0.09 mmol), compound **28** (0.056 g, 0.19 mmol), and PTS-Si (0.128 g, 0.103 mmol) were employed to give **31a** as a white foam (0.021 g, 0.04 mmol, 44%) along with **31a'** as a white foam (0.0033 g, 0.005 mmol, 5%).

31a: ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.00–2.24 (m, 2H), 2.70–2.78 (m, 1H), 2.87–2.98 (m, 1H), 3.83 (s, 2H), 5.02 (dd, *J* = 10.1, 2.2 Hz, 1H), 6.50 (s, 1H), 7.00 (s, 1H), 7.03–7.05 (m, 5H), 7.23–7.28 (m, 2H), 7.34–7.41 (m, 4H), 7.48–7.52 (m, 4H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 24.2, 29.6, 56.2, 77.7, 101.1, 102.0, 115.1, 118.9, 119.1, 126.4, 127.5, 127.6, 127.8, 127.9, 128.7, 132.7, 133.1, 136.1, 137.3, 154.9, 155.1, 156.7, 156.9; TOF-HRMS (*m/z*): [M$^{\cdot+}$], calcd for $C_{30}H_{25}O_3{}^{79}Br$, 512.0987; found, 512.0977; calcd for $C_{30}H_{25}O_3{}^{81}Br$, 514.0967; found, 514.0950.

(31a'): ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.98 – 2.21 (m, 2H), 2.68 – 2.77 (m, 1H), 2.86 –3.04 (m, 2H), 3.16 –3.26 (m, 1H), 3.21 (d, *J* = 8.5 Hz, 1H), 3.83 (s, 3H), 3.85 (s, 3H), 4.99 (dd, *J* = 10.1, 2.1 Hz, 1H), 5.04 (d, *J* = 8.3 Hz, 1H), 6.48 (s, 1H), 6.55 (s, 1H), 6.85 (d, *J* = 8.6 Hz, 2H), 6.92 (d, *J* = 8.5 Hz, 2H), 7.01 (d, *J* = 6.9 Hz, 2H), 7.13 (d, *J* = 8.7 Hz, 4H), 7.17–7.22 (m, 3H), 7.24 (s, 1H), 7.29 (s, 1H), 7.34 (d, *J* = 8.5 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 24.2, 29.6, 32.3, 45.7, 56.2, 56.3, 77.7, 82.6, 100.9, 101.1, 102.0, 102.2, 115.1, 115.5, 118.7, 118.8, 126.9, 127.5, 128.1, 128.5, 128.6, 132.8, 133.1, 134.4, 135.9, 140.7, 154.8, 154.9, 155.1, 155.1, 156.6, 157.0; TOF-HRMS (*m/z*): [M$^{\cdot+}$], calcd for $C_{38}H_{32}O_5{}^{79}Br_2$, 726.0616; found, 726.0602 and calcd for $C_{38}H_{32}O_5{}^{79}Br{}^{81}Br$, 728.0598; found, 728.0577; calcd for $C_{38}H_{32}O_5{}^{81}Br_2$, 730.0585; found, 730.0558.

Ethyl (*E*)-3-(4-(4-(6-bromo-7-methoxychroman-2-yl)phenoxy)phenyl)acrylate (31b).

Following the General Procedure, benzyl acetate **15** (0.052 g, 0.16 mmol), compound **29** (0.093 g, 0.31 mmol), and PTS-Si (0.213 g, 0.17 mmol) were employed to give **31b** as a white foam (0.049 g, 0.09 mmol, 59%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.34 (t, *J* = 7.1 Hz, 3H), 1.99–2.13 (m, 1H), 2.16–2.24 (m, 1H), 2.69–2.77 (m, 1H), 2.86–2.98 (m, 1H), 3.83 (s, 3H), 4.26 (q, *J* = 7.1 Hz, 2H), 5.02 (dd, *J* = 10.1, 2.3 Hz, 1H), 6.35 (d, *J* = 16.0 Hz, 1H), 6.49 (s, 1H), 6.99 (d, *J* = 8.7 Hz, 2H), 7.07 (d, *J* = 8.6 Hz, 2H), 7.24 (s, 1H), 7.41 (d, *J* = 8.6 Hz, 2H), 7.49 (d, *J* = 8.7 Hz, 2H), 7.66 (d, *J* = 16.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 14.3, 24.1, 29.6, 56.2, 60.4, 77.6, 101.1, 102.0, 115.1, 117.0, 118.5, 119.6, 127.7, 129.4, 129.7, 133.0, 136.9, 143.7, 154.9, 155.0, 155.9, 159.2, 167.0; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{27}H_{26}O_5{}^{79}Br$, 509.0958; found, 509.0943; calcd for $C_{27}H_{26}O_5{}^{81}Br$, 511.0938; found, 511.0921.

Ethyl (*E*)-3-(4-(4-(6-bromo-7-methoxy-3-phenylchroman-2-yl)phenoxy)phenyl)acrylate (31c).

Following the General Procedure, benzyl acetate **15** (0.071 g, 0.22 mmol), compound **30** (0.163 g, 0.44 mmol), and $PtCl_4$ (7.40 mg, 0.02 mmol) were employed to give **31c** as a white foam (0.092 g, 0.16 mmol, 71%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.33 (t, *J* = 7.1 Hz, 3H), 2.94–3.04 (m, 1H), 3.14–3.27 (m, 2H), 3.84 (s, 3H), 4.26 (q, *J* = 7.1 Hz, 2H), 5.04 (d, *J* = 9.1 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.55 (s, 1H), 6.87 (d, *J* = 8.6 Hz, 4H), 7.00 (d, *J* = 6.5 Hz, 2H), 7.12–7.24 (m, 5H), 7.29 (s, 1H), 7.45 (d, *J* = 8.7 Hz, 2H), 7.64 (d, *J* = 16.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 14.3, 32.2, 45.7, 56.2, 60.4, 82.5, 100.9, 102.3, 115.5, 117.0, 118.2, 119.4, 126.9, 128.0, 128.5, 128.7, 129.2, 129.6, 132.8, 135.2, 140.6, 143.7, 154.7, 155.0, 155.6, 159.3, 167.1; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{33}H_{30}O_5{}^{79}Br$, 585.1271; found, 585.1275; calcd for $C_{33}H_{30}O_5{}^{81}Br$, 587.1253; found, 587.1253.

6-Bromo-7-methoxy-4-(4-methoxybenzyl)-2-(4-(4-((*E*)-styryl)phenoxy)phenyl)chroman (31d).

Following the General Procedure, benzyl acetate **21** (0.050 g, 0.12 mmol), compound **28** (0.071 g, 0.24 mmol), and PTS-Si (0.16 g, 0.13 mmol) were employed to give **31d** as a white foam (0.036 g, 0.06 mmol, 49%) of a 3.7:1 mixture of C4-epimers, favoring the *cis* C2-C4; ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.15–2.27 (m, 2H, major, minor), 2.34 (dd, *J* = 5.8, 1.9 Hz, 1H, major), 2.38 (dd, *J* = 5.9, 2.0 Hz, 1H, minor), 3.81 (s, 3H, minor), 3.82 (s, 3H, major), 3.85 (s, 3H, major), 3.88 (s, 3H, minor), 4.14 (dd, *J* = 5.1, 3.3 Hz, 1H, minor), 4.22 (dd, *J* = 11.9, 6.0 Hz, 1H, major), 4.99 (dd, *J* = 10.6, 2.3 Hz, 1H, minor), 5.17 (dd, *J* = 11.2, 1.6 Hz, 1H, major), 6.53 (s, 1H, major), 6.58 (s, 1H, minor), 6.85-6.92 (m, 8H, major, minor), 6.97–7.03 (m, 6H, major, minor), 7.04–7.05 (m, 4H, major, minor), 7.07 (s, 2H, major, minor), 7.10–7.16 (m, 6H, major, minor), 7.23–7.29 (m, 2H, major, minor), 7.36 (t, *J* = 7.5 Hz, 4H, major, minor), 7.43–7.52 (m, 10H, major, minor); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 38.2

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(minor), 38.7 (minor), 40.3 (major), 41.9 (major), 55.3 (major), 56.2 (major), 73.2 (minor), 78.2 (major), 100.9 (minor), 101.0 (major), 102.4 (major), 102.5 (minor), 113.9 (minor), 114.2 (major), 116.8 (minor), 118.4 (minor), 118.9 (minor), 119.0 (minor), 119.0 (major), 119.6 (major), 126.4 (major), 127.5 (minor), 127.7 (major), 127.8 (minor), 127.8 (major), 127.9 (minor), 128.2 (minor), 128.7 (major), 128.8 (minor), 129.3 (major), 129.4 (minor), 130.3 (minor), 132.7 (major), 133.3 (major), 134.2 (minor), 135.7 (major), 135.7 (major), 135.8 (minor), 137.3 (major), 137.7 (minor), 155.1 (major), 155.4 (minor), 155.5 (major), 156.7 (major), 156.8 (minor), 157.0 (major), 158.2 (minor), 158.5 (major); TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{37}H_{31}O_4{}^{79}BrNa$, 641.1298; found, 641.1290; calcd for $C_{37}H_{31}O_4{}^{81}BrNa$, 643.1280; found, 643.1284.

Ethyl (*E*)-3-(4-(4-(6-bromo-7-methoxy-4-(4-methoxybenzyl)chroman-2-yl)phenoxy)phenyl)acrylate (31e).

Following the General Procedure, benzyl acetate **21** (0.071 g, 0.16 mmol), compound **29** (0.098 g, 0.33 mmol), and $In(OTf)_3$ (9.2 mg, 0.016 mmol) were employed to give **31e** as a white foam (0.069 g, 0.11 mmol, 66%) of a 5.5:1 mixture of C4-epimers, favoring the *cis* C2-C4; ^1H NMR (300 MHz, $CDCl_3$): δ 1.19 (t, *J* = 7.1 Hz, 3H, minor), 1.34 (t, *J* = 7.1 Hz, 3H, major), 2.13–2.26 (m, 2H, major, minor), 2.34 (dd, *J* = 5.8, 1.8 Hz, 1H, major), 2.39 (dd, *J* = 5.8, 1.7 Hz, 1H, minor), 3.81 (s, 3H, minor), 3.82 (s, 3H, major), 3.85 (s, 3H, major), 3.88 (s, 3H, minor), 4.05–4.15 (m, 3H, minor), 4.19–4.25 (m, 1H, minor), 4.26 (q, *J* = 7.1 Hz, 2H, major), 6.35 (d, *J* = 16.0 Hz, 1H, major), 6.52 (s, 1H, major), 6.58 (s, 1H, minor), 6.87 (d, *J* = 8.6 Hz, 4H, major, minor), 6.92 (s, 2H, major, minor), 6.96–7.00 (m, 2H, minor), 6.98 (d, *J* = 8.7 Hz, 2H, major), 7.03–7.15 (m, 6H, major, minor), 7.45–7.50 (m, 6H, major, minor), 7.65 (d, *J* = 16.0 Hz, 2H, major, minor); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 14.3, 40.4, 41.9, 55.3, 56.2, 60.4, 78.2, 101.0, 102.5, 114.2, 117.1, 118.5, 119.5, 119.7, 127.8, 129.3, 129.4, 129.7, 133.3, 135.7, 136.5, 143.7, 155.2, 155.5, 156.1, 158.6, 159.2, 167.1; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{34}H_{32}O_6{}^{79}Br$, 615.1377; found, 615.1385; calcd for $C_{34}H_{32}O_6{}^{81}Br$, 617.1359; found, 617.1359.

Ethyl (*E*)-3-(4-(4-(6-bromo-7-methoxy-4-(4-methoxybenzyl)-3-phenylchroman-2-yl)phenoxy)phenyl)-acrylate (31f).

Following the General Procedure, benzyl acetate **21** (0.071 g, 0.17 mmol), compound **30** (0.122 g, 0.33 mmol), and $PtCl_4$ (5.54 mg, 0.017 mmol) were employed to give **31f** as a white foam (0.055 g, 0.080 mmol, 48%); ^1H NMR (300 MHz, $CDCl_3$): δ 1.33 (t, *J* = 7.1 Hz, 3H), 3.22 (t, *J* = 10.8 Hz, 1H), 3.73 (s, 3H), 3.86 (s, 3H), 4.25 (q, *J* = 7.1 Hz, 2H), 4.39 (d, *J* = 11.1 Hz, 1H), 5.22 (d, *J* = 10.5 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.58 (s, 1H), 6.68 (d, *J* = 8.7 Hz, 2H), 6.78–6.80 (m, 2H), 6.84 (m, 6H), 6.95 (d, *J* = 0.8 Hz, 1H), 7.02–7.06 (m, 3H), 7.18 (d, *J* = 8.6 Hz, 2H), 7.44 (d, *J* = 8.7 Hz, 2H), 7.63 (d, *J* = 16.0 Hz, 1H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 14.3, 48.6, 54.8, 55.1, 56.3, 60.4, 82.6, 100.7, 102.8, 113.7, 116.9, 118.2, 119.4, 120.3, 126.6, 128.2, 128.5, 128.9, 129.2, 129.6, 129.8, 133.8, 134.2, 134.9, 139.0, 143.7, 155.1, 155.2, 155.6, 158.2, 159.3, 167.1; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{40}H_{36}O_6{}^{79}Br$, 691.1690; found, 691.1695; calcd for $C_{40}H_{36}O_6{}^{81}Br$, 693.1674; found, 693.1678.

Ethyl 6-bromo-2-(4-(4-(6-bromo-7-methoxy-3-phenylchroman-2-yl)phenoxy)phenyl)-7-methoxy-4-(4-methoxybenzyl)chroman-3-carboxylate (32).

Following the General Procedure, benzyl acetate **21** (0.021 g, 0.049 mmol), compound **31b** (0.050 g, 0.098 mmol), and $PtCl_4$ (1.7 mg, 0.005 mmol) were employed to give **32** as a white foam (0.0164 g, 0.02 mmol, 40%) of a 4:1 mixture of C4-epimers, favoring the *cis* C2-C4; ^1H NMR (300 MHz, $CDCl_3$): δ 0.77 (t, *J* = 7.1 Hz, 3H, major), 0.94 (t, *J* = 7.1 Hz, 3H, minor), 1.98–2.13 (m, 2H, major, minor), 2.15–2.23 (m, 2H, major, minor), 2.69–2.77 (m, 2H, major, minor), 2.86–2.98 (m, 2H, major, minor), 3.06–3.15 (m, 2H, major, minor), 3.67–3.76 (m, 4H, major, minor), 3.79 (s, 3H, minor), 3.80 (s, 3H, major), 3.81 (s, 3H, minor), 3.83 (s, 3H, major), 3.84 (s, 3H, major), 3.85 (s, 3H, minor), 4.47 (d, *J* = 11.2 Hz, 1H, major), 4.49 (d, *J* = 19.2 Hz, 1H, minor), 5.01 (dd, *J* = 10.0, 2.0 Hz, 2H, major, minor), 5.15 (d, *J* = 10.2 Hz, 1H, major), 5.23 (d, *J* = 11.0 Hz, 1H, minor), 6.49 (s, 2H, major, minor), 6.52 (s, 1H, major), 6.55 (s, 1H, minor), 6.81–6.86 (m, 2H, major, minor), 6.89–6.94 (m, 2H, major, minor), 6.95–7.05 (m, 6H, major, minor), 7.07–7.15 (m, 3H, major, minor), 7.24 (s, 2H), 7.35–7.44 (m, 5H, major, minor); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 13.8 (major), 24.2 (major), 29.6 (major), 45.5 (major), 45.6 (minor), 55.0 (major), 55.2 (major), 55.3 (minor), 56.2 (major), 60.5 (major), 77.7 (major), 79.7 (major), 79.8 (minor), 100.7 (major), 100.8 (minor), 101.1 (major), 102.0 (major), 103.1 (major), 113.7 (minor), 113.9 (minor), 114.2 (major), 115.0 (minor), 115.1 (major), 118.5 (major), 118.8 (major), 119.0 (major), 119.1 (minor), 119.1 (minor), 127.6 (major), 128.6 (minor), 128.9 (major), 129.5 (minor), 129.8 (major), 130.1 (minor), 130.3 (minor), 132.7 (major), 132.7 (major), 133.1 (major), 133.3 (major), 133.8 (minor), 136.1 (minor), 136.3 (major), 154.7 (major), 154.9 (major), 155.1 (major), 155.2 (major), 155.3 (minor), 156.4 (minor), 156.7 (major), 157.6 (major), 158.9 (major), 169.8 (minor), 171.3 (major); TOF-HRMS (*m/z*): [M + Na^+], calcd for $C_{42}H_{38}O_8{}^{79}Br_2Na$, 851.0826; found, 851.0812; calcd for $C_{42}H_{38}O_8{}^{79}Br{}^{81}BrNa$, 853.0809; found, 853.0789; calcd for $C_{42}H_{38}O_8{}^{81}Br_2Na$, 855.0798; found, 855.0777.

((6-Bromo-7-methoxy-2-methyl-2,3-diphenylchroman-4-yl)ethynyl)trimethylsilane (34).

Following the General Procedure, benzyl acetate **33** (0.026 g, 0.063 mmol), (*E*)-1,2-diphenylethene **16** (0.023 g, 0.125 mmol), and $In(OTf)_3$ (0.002 g, 0.003 mmol) were employed to give **34** as a white sticky gum (0.025 g, 0.050 mmol, 79%) of a 10:1 mixture of C4-epimers, favoring the *cis* C2-C4; ^1H NMR (300 MHz, $CDCl_3$): δ 0.01 (s, 9H), 3.22 (t, *J* = 10.8 Hz, 1H), 3.84 (s, 3H), 4.22 (d, *J* = 10.8 Hz, 1H), 5.12 (d, *J* = 10.8 Hz, 1H), 6.51 (s, 1H), 6.97–7.02 (m, 2H), 7.11–7.22 (m, 8H), 7.71 (s, 1H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ -0.2, 36.8, 51.4, 56.3, 82.6, 88.2, 100.7, 102.7, 105.2, 115.3, 127.0, 127.3, 128.16, 128.22, 128.5, 132.9, 138.6, 138.7, 154.0, 155.8; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{28}H_{28}O_2{}^{79}BrSi$, 491.1036; found, 491.0856; calcd for $C_{28}H_{28}O_2{}^{81}BrSi$, 493.1017; found, 493.1012.

((6-Bromo-7-methoxy-2-(4-methoxyphenyl)-3-phenylchroman-4-yl)ethynyl)trimethylsilane (35).

Following the General Procedure, benzyl acetate **33** (0.026 g, 0.063 mmol), stilbene **19** (0.026 g, 0.125 mmol), and $In(OTf)_3$

(0.002 g, 0.003 mmol) were employed to give **35** as a yellow solid (0.032 g, 0.062 mmol, 98%) of a 3:1 mixture of C4-epimers, favoring the *cis* C2-C4; ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.02 (s, 9H, major), 0.11 (s, 9H, minor), 3.21 (dd, *J* = 11.2, 10.5 Hz, 1H, major), 3.49 (dd, *J* = 8.7, 4.8 Hz, 1H, minor), 3.71 (s, 3H, major), 3.73 (s, 3H, minor), 3.82 (s, 3H, major), 3.83 (s, 3H, minor), 3.92 (d, *J* = 4.8 Hz, 1H, minor), 4.18 (d, *J* = 11.2 Hz, 1H, major), 5.08 (d, *J* = 10.5 Hz, 1H, major), 5.63 (d, *J* = 8.7 Hz, 1H, minor), 6.48 (s, 1H, major), 6.51 (s, 1H, minor), 6.71 (d, *J* = 8.7 Hz, 2H, major), 6.78 (d, *J* = 8.6 Hz, 2H, minor), 6.98–7.03 (m, 2H, major), 7.08 (d, *J* = 8.7 Hz, 2H, major), 7.11–7.15 (m, 2H, minor), 7.15–7.20 (m, 1H, major), 7.20–7.25 (m, 1H, major), 7.28–7.31 (m, 1H, minor), 7.41 (s, 1H, minor), 7.70 (s, 1H, major); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ -0.2 (major), 34.7 (minor), 37.1 (major), 47.1 (minor), 51.2 (major), 55.11 (major), 55.14 (minor), 56.2 (minor), 56.3 (major), 78.6 (minor), 82.1 (major), 88.1 (major), 90.8 (minor), 100.7 (major), 100.8 (minor), 102.3 (minor), 102.5 (major), 105.1 (minor), 105.3 (major), 113.6 (major), 113.8 (minor), 115.3 9major), 115.5 (minor), 126.9 (major), 127.0 (minor), 127.8 (minor), 128.2 (major), 128.5 (major), 128.6 (major), 129.4 (minor), 130.7 (major), 131.2 (minor), 132.8 (major), 132.9 (minor), 138.3 (minor), 139.0 (major), 153.7 (minor), 154.1 (major), 155.7 (major), 155.9 (minor), 159.3 (major); TOF-HRMS (*m/z*): [M + Na$^+$], calcd for $C_{28}H_{29}O_3{}^{79}BrSiNa$, 543.0962; found, 543.0959; calcd for $C_{28}H_{29}O_3{}^{81}BrSiNa$, 545.0946; found, 545.0940.

(*E*)-((2-(4-Methoxystyryl)phenyl)ethynyl)trimethylsilane (36).

Heck Reaction: To a stirred mixture of 2-bromoiodobenzene **37** (0.85 mL, 5.00 mmol), 1-methoxy-4-vinylbenzene **18** (0.78 mL, 5.85 mmol) and $Pd(OAc)_2$ (0.084 g, 0.38 mmol) in anhydrous MeCN (25 mL) was added Et_3N (0.81 mL, 5.85 mmol). The reaction was stirred at 90 °C under argon for 20 h. The mixture was cooled down to room temperature and concentrated under reduced pressure to give a crude product, which was further purified by column chromatography on silica (4% CH_2Cl_2/hexane) to give the stilbene derivative as a colorless solid (1.38 g, 4.75 mmol, 95%); Mp 63.8–65.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.80 (s, 3H), 6.89 (d, *J* = 8.7 Hz, 2H), 6.97 (d, *J* = 16.2 Hz, 1H), 7.06 (t, *J* = 7.7 Hz, 1H), 7.26 (t, *J* = 7.7 Hz, 1H), 7.32 (d, *J* = 16.2 Hz, 1H), 7.47 (d, *J* = 8.7 Hz, 2H), 7.55 (d, *J* = 7.7 Hz, 1H), 7.61 (d, *J* = 7.7 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 55.3, 114.1, 123.9, 125.2, 126.4, 127.5, 128.1, 128.3, 129.8, 130.9, 133.0, 137.3, 159.6; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{15}H_{14}O^{79}BrSi$, 289.0223; found, 289.0221; calcd for $C_{15}H_{14}O^{81}BrSi$, 291.0203; found, 291.0198.

Sonogashira: To a stirred mixture of the stilbene derivative obtained from the Heck reaction (0.413 g, 1.43 mmol), $PdCl_2(PPh_3)_2$ (0.060 g, 0.086 mmol and CuI (0.016 g, 0.086 mmol) in Et_3N (0.72 mL) was added trimethylsilylacetylene (0.36 mL, 2.55 mmol). The reaction was stirred at 80 °C under argon for 24 h. The mixture was cooled down to room temperature and concentrated under reduced pressure to give a crude product, which was further purified by column chromatography on silica (0–10% CH_2Cl_2/hexane) to give the stilbene-alkyne **36** as a yellow solid (0.40 g, 1.30 mmol, 91%); Mp 58.2–60.9 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.30 (s, 9H), 3.84 (s, 3H), 6.91 (d, *J* = 8.8 Hz, 2H), 7.13 (d, *J* = 16.3 Hz, 1H), 7.16 (dd, *J* = 7.8, 7.5 Hz, 1H), 7.30 (dd, *J* = 7.8, 7.5 Hz, 1H), 7.47 (d, *J* = 7.8 Hz, 1H), 7.48 (d, *J* = 8.8 Hz, 2H), 7.54 (d, *J* = 16.3 Hz, 1H), 7.65 (d, *J* = 7.5 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 0.05, 55.3, 99.4, 103.7, 114.2, 121.7, 124.7, 126.6, 127.9, 128.7, 129.7, 130.2, 132.8, 139.4, 159.5; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{20}H_{23}OSi$, 307.1513; found, 307.1516.

((6-Bromo-7-methoxy-2-(4-methoxyphenyl)-3-(2-((trimethylsilyl)ethynyl)phenyl)chroman-4-yl)ethynyl)trimethylsilane (38).

Following the General Procedure, benzyl acetate **33** (0.026 g, 0.063 mmol), stilbene alkyne **36** (0.038 g, 0.125 mmol), and $In(OTf)_3$ (0.002 g, 0.003 mmol) were reacted at 0–10 °C for 45 min to give **38** as brown sticky gum (0.021 g, 0.035 mmol, 55%) along with its C4-epimer **38'** as yellow sticky gum (0.011 g, 0.018 mmol, 28%); ^{1}H NMR (400 MHz, DMSO-*d*$_6$, 100 °C): δ 0.02 (s, 9H), 0.22 (s, 9H), 3.70 (s, 3H), 3.85 (s, 3H), 3.95 (br t, 10.7 Hz, 1H), 4.49 (br d, *J* = 10.7 Hz, 1H), 5.44 (br d, *J* = 10.7 Hz, 1H), 6.66 (s, 1H), 6.73 (d, *J* = 8.7 Hz, 2H), 7.12 (td, *J* = 7.6, 1.2 Hz, 1H), 7.18 (d, *J* = 8.7 Hz, 1H), 7.26 (dd, *J* = 7.6, 1.2 Hz, 1H), 7.30 (td, *J* = 7.6, 1.2 Hz, 1H), 7.40 (d, *J* = 7.6 Hz, 1H), 7.57 (d, *J* = 1.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, DMSO-*d*$_6$, 100 °C): δ -0.8, 35.5 (br), 47.4 (br), 54.6, 56.0, 80.4 (br), 86.7, 97.7 (br), 101.1, 101.2, 104.0, 105.3, 112.9, 115.4, 122.8 (br), 126.0, 127.4 (br), 128.2, 128.3, 129.9, 131.3, 131.4, 141.0, 153.7, 155.1, 158.7; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{33}H_{38}O_3{}^{79}BrSi$, 617.1537; found, 617.1525; and calcd for $C_{33}H_{38}$ $O_3{}^{81}BrSi$, 619.1523; found, 619.1522.

38': ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.06 (s, 9H), 0.20 (s, 9H), 3.74 (s, 3H), 3.84 (s, 3H), 4.08 (d, *J* = 5.0 Hz, 1H), 4.30 (dd, *J* = 8.6, 5.0 Hz, 1H), 5.64 (d, *J* = 8.6 Hz, 1H), 6.50 (s, 1H), 6.80 (d, *J* = 8.7 Hz, 2H), 7.04–7.16 (m, 3H), 7.29 (d, *J* = 8.7 Hz, 2H), 7.37–7.43 (m, 3H), 7.45 (s, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ -0.13, -0.08, 32.6, 43.4, 55.2, 56.2, 78.3, 99.7, 100.8, 102.3, 103.4, 105.3, 113.9, 115.5, 123.1, 126.4, 127.7, 128.7, 129.0, 130.9, 132.2, 132.9, 140.5, 153.7, 155.8, 159.5; TOF-HRMS (*m/z*): [M + H$^+$], calcd for $C_{33}H_{38}O_3{}^{79}BrSi$, 617.1537; found, 617.1538; and calcd for $C_{33}H_{38}$ $O_3{}^{81}BrSi$, 619.1523; found, 619.1522.

6-Bromo-4-ethynyl-3-(2-ethynylphenyl)-7-methoxy-2-(4-methoxyphenyl)chroman (39).

To a solution of the chroman **38** (0.037 g, 0.06 mmol) in anhydrous THF (0.5 mL) was added TBAF (0.18 mL, 0.18 mmol, 1.0 M in THF) at 0 °C under argon and the reaction mixture was continued at this temperature for 1 h. The reaction mixture was quenched with water (0.5 mL) and the resulting mixture was extracted with EtOAc (3 x 1 mL). The combined organic phases were washed with water (3 x 1 mL) and brine (1 mL), dried over Na_2SO_4, filtered, and concentrated under reduced pressure to give a crude product which was further purified by column chromatography on silica (15% EtOAc/hexane) to give the chroman alkyne **39** as a yellow oil (0.026 g, 0.054 mmol, 90%); ^{1}H NMR (400 MHz, DMSO-*d*$_6$, 100 °C): δ 2.78 (d, *J* = 2.4 Hz, 1H), 3.69 (s, 3H), 3.83 (s, 3H), 3.94 (br t, *J* = 10.8 Hz, 1H), 4.03 (s, 1H), 4.52 (br d, *J* = 10.8 Hz, 1H), 5.43 (br d, *J* = 10.8 Hz, 1H), 6.66 (s, 3H), 6.74 (d, *J* = 8.6 Hz, 2H), 7.14 (t, *J* = 7.8 Hz, 1H), 7.18 (d, *J* = 8.6 Hz, 2H), 7.31 (t, *J* = 7.8 Hz, 1H), 3.32 (d, *J* = 7.8 Hz, 1H), 7.42 (d, *J* = 7.8 Hz, 1H), 7.61 (s, 1H); ^{13}C{^{1}H} NMR (100

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MHz, DMSO-d_6, 100 °C): δ 34.4 (br), 47.0 (br), 54.6, 56.0, 72.7, 80.6 (br), 81.8, 82.5, 83.3, 101.1, 101.3, 112.9, 115.3, 122.1 (br), 126.1, 127.5 (br), 128.3, 129.7, 131.3, 131.9, 140.8, 153.8, 155.2, 158.7; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{27}H_{22}O_3{}^{79}Br$, 473.0747; found, 473.0738; and calcd for $C_{27}H_{22}O_3{}^{81}Br$, 475.0730; found, 475.0709.

6-Bromo-7-methoxy-2-(4-methoxyphenyl)-4-vinyl-3-(2-vinylphenyl)chroman (40).

A suspension of the chroman alkyne **39** (0.025 g, 0.053 mmol) and Pd on $CaCO_3$ (0.066 g, 0.033 mmol) in CH_2Cl_2 (3 mL) was stirred at room temperature under H_2 atmosphere (500 psi). After being stirred for 18 h, the palladium catalyst was removed by filtration through Celite® and the filtrate was concentrated under reduced pressure to give the crude product, which was further purified by PTLC (20% EtOAc/hexane, developed twice) to give the diene chroman **40** as a pale yellow sticky gum (0.020 g, 0.041 mmol, 77%); ^{1}H NMR (400 MHz, DMSO-d_6, 100 °C): δ 3.55 (dd, *J* = 11.0, 10.2 Hz, 1H), 3.68 (s, 3H), 3.82 (s, 3H), 3.90 (dd, *J* = 11.0, 9.1 Hz, 1H), 4.83 (dd, *J* = 17.0, 1.8 Hz, 1H), 4.95 (dd, *J* = 10.0, 1.8 Hz, 1H), 5.17 (dd, *J* = 11.0, 1.6 Hz, 1H), 5.29 (dd, *J* = 17.2, 1.6 Hz, 1H), 5.31 (d, *J* = 10.2 Hz, 1H), 5.57 (ddd, *J* = 17.0, 10.0, 9.1 Hz, 1H), 6.66 (s, 1H), 6.70 (d, *J* = 8.7 Hz, 2H), 6.86 (dd, *J* = 17.2, 11.0 Hz, 1H), 7.06 (t, *J* = 7.8 Hz, 1H), 7.10 (d, *J* = 8.7 Hz, 2H), 7.18 (d, *J* = 7.8 Hz, 1H), 7.22 (t, *J* = 7.8 Hz, 1H), 7.25 (d, *J* = 0.9 Hz, 1H), 7.37 (d, *J* = 7.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, DMSO-d_6, 100 °C): δ 44.3 (br), 47.5, 54.6, 56.0, 81.1, 101.1, 101.3, 112.8, 115.7, 117.3, 118.0, 125.4, 125.7, 127.0, 127.1 (br), 128.1, 130.5, 131.6, 134.7, 137.0, 137.3, 137.6, 154.5, 154.7, 158.5; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{27}H_{26}O_3{}^{79}Br$, 477.1060; found, 477.1061; and calcd for $C_{27}H_{26}O_3{}^{81}Br$, 479.1043; found, 479.1069.

9-Bromo-8-methoxy-5-(4-methoxyphenyl)-4b,10b-dihydro-5*H*-naphtho[1,2-*c*]chromene (13).

Hoveyda-Grubbs' II catalyst (0.002 g, 0.002 mmol) was added to a solution of the corresponding diene **40** (0.015 mg, 0.024 mmol) in toluene (2.4 mL). Then, the mixture was heated at 70 °C for 24 h. The second portion of Hoveyda-Grubbs' II catalyst (0.002 g, 0.002 mmol) was added to the reaction mixture and heated at 80 °C for 24 h. The reaction mixture was evaporated under reduced pressure. The residue was purified by PTLC (10% EtOAc/hexane, developed 6 times) to give the desired chroman **13** as a colorless oil (0.008 g, 0.013 mmol) along with the naphthochromene byproduct **41** as a colorless oil (0.004 g, 0.008 mmol); ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.53 (dd, *J* = 14.7, 10.3 Hz, 1H), 3.65 (br d, *J* = 14.7 Hz, 1H), 3.80 (s, 3H), 3.85 (s, 3H), 5.34 (d, *J* = 10.3 Hz, 1H), 6.46 (s, 1H), 6.48 (dd, *J* = 9.6, 1.9 Hz, 1H), 6.69–6.75 (m, 2H), 6.87–6.95 (m, 1H), 6.98 (d, *J* = 8.6 Hz, 2H), 7.13–7.17 (m, 2H), 7.45 (d, *J* = 8.6 Hz, 2H), 7.54 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 36.2, 41.3, 55.3, 56.2, 80.5, 101.2, 102.5, 114.7, 116.8, 125.7, 126.3, 126.7, 126.9, 129.26, 129.34, 130.1, 131.5, 132.0, 134.8, 135.0, 154.5, 155.2, 160.2; TOF-HRMS (*m/z*): [M + Na^+], calcd for $C_{25}H_{21}O_3{}^{79}BrNa$, 471.0566; found, 471.0565; and calcd for $C_{25}H_{21}O_3{}^{81}BrNa$, 473.0549; found, 473.0570.

41: ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.70 (s, 3H), 3.84 (s, 3H), 6.50 (s, 1H), 6.73 (d, *J* = 8.7 Hz, 2H), 7.00 (s, 1H), 7.12 (d, *J* = 8.7 Hz, 2H), 7.41–7.48 (m, 2H), 7.64–7.71 (m, 1H), 7.85 (d, *J* = 8.7 Hz, 1H), 7.85–7.89 (m, 1H), 7.934 (d, *J* = 8.7 Hz, 1H), 7.935 (s, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 55.1, 56.3, 75.8, 102.3, 103.7, 113.8, 117.2, 120.0, 122.9, 125.6, 126.0, 126.2, 127.1, 127.5, 128.8, 129.1, 129.5, 129.7, 130.9, 132.7, 152.7, 156.8, 159.6; TOF-HRMS (*m/z*): [M + H^+], calcd for $C_{25}H_{19}O_3{}^{79}Br$, 446.0518; found, 446.0513; and calcd for $C_{25}H_{19}O_3{}^{81}Br$, 448.0497; found, 448.0490.

Conflicts of interest

There are no conflicts to declare.

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16 See the Electronic Supplementary Information (ESI) for the detailed preparation of compounds **28**-**30**. For the C–O bond formation of **vi**, see: M. P. Drapeau, T. Ollevier and M. Taillefer, *Chem. Eur. J.*, 2014, **20**, 5231.

17 When the benzyl acetate **21** reacted with compound **30**, **31f** was the sole product when using PTS-Si. Trace amount of **31f'** was obtained when $PtCl_4$ was employed. Interestingly, trace amount of the product arising from the reaction on the cinnamate moiety of compound **30** could be detected when $In(OTf)_3$ was employed. However, in both cases, insufficient amount of these by-products was obtained, rendering their complete spectroscopic characterization not possible.

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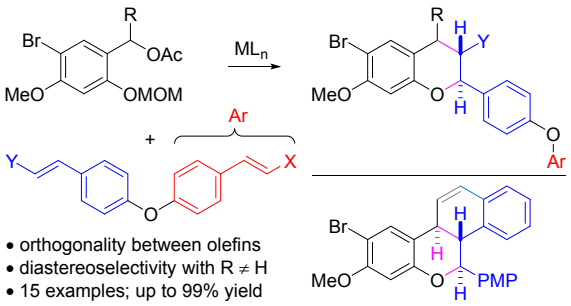

Chemoselective [4+2]-cycloaddition reactions between *o*-QMs and different olefins—styrenes, stilbenes, and cinnamates—yielded distinct cycloadducts in moderate to good yields.