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One-pot sequential four-component coupling via Cp*RuCl-catalyzed cyclotrimerization and Suzuki–Miyaura coupling

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Abstract—The catalytic intermolecular cyclotrimerization of alkynylboronates, propargyl alcohols, and terminal alkynes was accomplished by means of the ruthenium catalysis and the temporary tethering approach with the C–B–O linkage to give rise to highly substituted arylboronates with excellent selectivity. The resultant arylboronates were further converted to highly substituted biaryls via the Suzuki–Miyaura coupling with various aryl iodides using $Pd_2(dba)_3/PCy_3$ as a catalyst precursor in aqueous toluene. As a consequence, the four-component coupling approach to highly substituted biaryls was successfully established by combining these two operations into a sequential one-pot process.

1. Introduction

Transition-metal-catalyzed multi-component coupling cyclizations are powerful methods for assembling complex cyclic frameworks from inexpensive acyclic starting materials.[1] In particular, a sequential catalytic process that effects multiple reactions in a single-pot is highly desirable, because it would reduce wastes produced from the separation of intermediates.[2] Toward this end, each catalytic reaction should be refined as to be mutually compatible, and thus, a judicious choice of the catalyst combination as well as a substrate design play critical roles in the one-pot sequential catalytic process. In this context, we recently reported the one-pot sequential [2+2+2] cyclotrimerization/Suzuki–Miyaura coupling process, in which the catalytic cyclotrimerization of three different unsymmetrical alkynes was achieved regioselectively by means of a boron temporary tether, and the subsequent Suzuki–Miyaura coupling of the resultant cyclic arylboronates with aryl iodides successfully gave rise to the desired biaryls in reasonable yields.[3] Herein, we report the full detail of the study on the one-pot sequential four-component coupling synthesis of biaryls.

2. Results and discussion

2.1. Exploratory study on the Cp*RuCl-catalyzed cyclotrimerization of three unsymmetrical alkynes by means of boron temporary tether

The transition-metal-catalyzed [2+2+2] alkyne cyclotrimerization has received continuous attention as a straightforward route to substituted benzenes.[4] Because of its atom-economical[5] and convergent nature, the cyclotrimerization approach to substituted benzene rings is considerably advantageous over conventional strategies requiring the sequential substitutions of a benzene ring by way of electrophilic aromatic substitutions or orthometalation techniques.[6] Although the selective cyclotrimerization of three different alkynes was accomplished using stoichiometric transition metal reagents,[7–9] the development of a catalytic protocol is highly desirable in terms of the atom-economy. In this context, intramolecular approach utilizing diynes or triynes have been explored as a promising tool to afford polycyclic arenes selectively.[10] However, additional synthetic operations are required, if the resultant polycyclic framework is not desirable. An unnecessary ring moiety needs to be cleaved and transformed into required side chains. Moreover, the preparation of polyalkyne substrates equipped with a cleavable tether as well as substituents or functional groups at appropriate positions can be troublesome.

One effective strategy to address these issues is the

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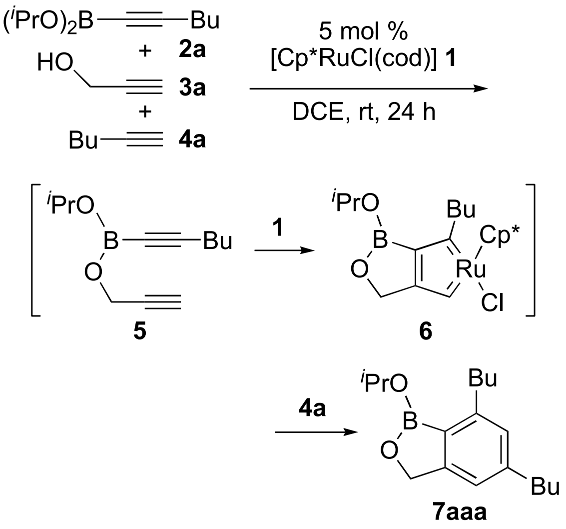
temporary connecting of monoalkynes with a disposable tether group.[11] To realize the selective cyclotrimerization of three different alkynes through a temporary tether, Cp*RuCl(cod) **1** (Cp* = η^5-C_5Me_5, cod = 1,5-cyclooctadiene) is the desired catalyst precursor, because the previous density functional calculations revealed that the oxidative cyclization on the Cp*RuCl fragment yielding a key ruthenacycle intermediate is the rate-determining step, and, therefore, the ruthenium catalysis favors 1,6-diynes rather than monoalkynes.[12] In addition, the cycloaddition of unsymmetrical diyne with terminal monoalkynes proceeds with excellent regioselectivity at room temperature under the ruthenium catalysis.[12a] As a temporary tether, a C–B–O linkage is the better choice rather than widely prevalent C–Si–O or O–Si–O linkages,[13] because relatively long Si–C and Si–O bonds might cause deleterious effect on the formation of the ruthenacycle intermediate. Surprisingly, such boron tethers have remained less explored in transition-metal catalysis, while the boron temporary tethers were successfully applied to Diels–Alder reactions.[14] Various unsaturated organoboranes have been employed for transition-metal-catalyzed reactions,[15] but, to the best of our knowledge, the temporary boron tether approach has been confined to the ruthenium-catalyzed enyne metathesis using alkynyl- or allylboronates reported by Schreiber and Micalizio.[16]

With these in mind, we carried out the exploratory study on the cyclotrimerization of 1-hexynylboronate **2a**, propargyl alcohol **3a**, and 1-hexyne **4a** (Scheme 1). Propargyl alcohol **3a** (1.1 equiv) was added dropwise over 15 min to a solution of 5 mol% **1**, 1-hexynylboronate **2a**, and 1-hexyne **4a** (4 equiv) in 1,2-dichloroethane (DCE) at room temperature, and the solution was stirred for 24 h. In the ^{1}H NMR spectrum of the crude product mixture, the absorptions of aromatic and benzylic methylene protons were observed together with those of two *n*-butyl chains, indicative of the cyclotrimerization of the three alkyne components taking place via the expected diyne and ruthenacycle intermediates **5** and **6**. Unfortunately, the resultant arylboronate **7aaa** could not be purified at this stage, due to the facile exchange of the boronate ligands. Accordingly, we further attempted the Suzuki–Miyaura coupling[17] of the crude **7aaa** without purification.



Scheme 1.

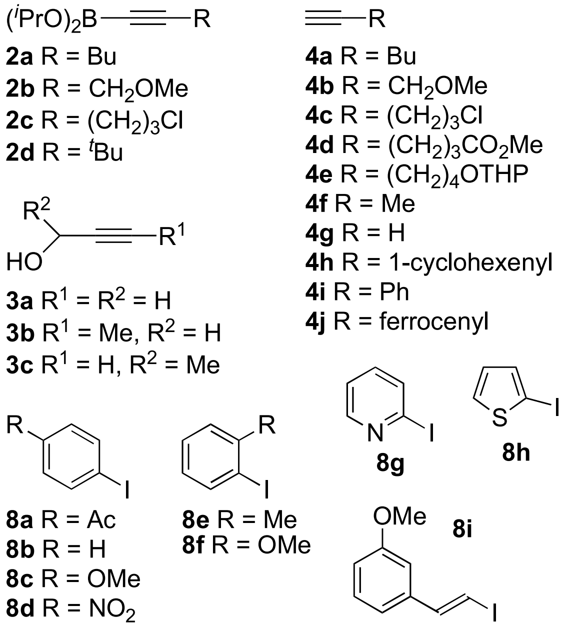
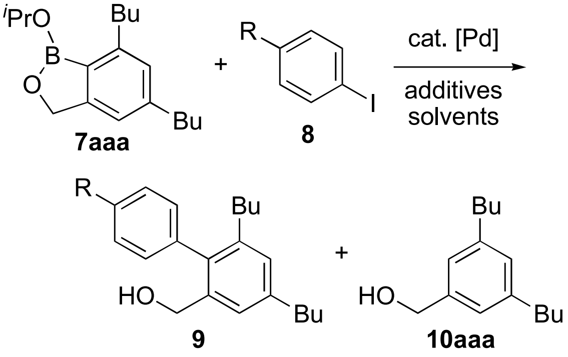


Figure 1. Starting materials used in this study.

2.2. Suzuki–Miyaura coupling of cyclotrimerization product

The newly prepared **7aaa** was subjected to the Suzuki–Miyaura coupling with aryl iodides as shown in Scheme 2 and Table 1. Upon treatment with 5 mol% Pd(PPh_3)$_4$, *p*-iodoacetophenone **8a** (1.5 equiv), and K_2CO_3 in refluxing THF/H_2O for 24 h, the desired **9aaaa** was obtained in 32% yield together with a protodeboration product **10aaa** in 22% yield (entry 1). Significantly, both of these products were obtained as a single regioisomer. To minimize the unwanted protodeboration, the cross coupling conditions were optimized. In the absence of water, protodeboration was effectively suppressed and **9aaaa** was obtained exclusively in 68% yield (entry 2). Furthermore, we found that the reaction reached to completion within 2 h in heterogeneous solvent system toluene/H_2O at 70 °C to afford **9aaaa** in 71% yield (entry 3). The couplings with less reactive iodobenzene **8b** and *p*-iodoanisole **8c** required prolonged reaction time of 20 h otherwise under the same reaction conditions (entries 4 and 5). In addition, the desired product **9aaac** was



Scheme 2.

Table 1. Coupling of arylboronate **7aaa** and aryliodides **8**

Entry	ArI (**8**) (1.5 equiv)	Catalyst	Conditions	**9** Yield (%)	**10aaa** Yield (%)
1	*p*-AcC_6H_4I (**8a**)	5 mol% $Pd(PPh_3)_4$	THF/H_2O, reflux, 24 h	**9aaaa**, 32	22
2	**8a**	5 mol% $Pd(PPh_3)_4$	THF, reflux, 24 h	**9aaaa**, 68	—
3	**8a**	5 mol% $Pd(PPh_3)_4$	$Toluene/H_2O$, 70 °C, 2 h	**9aaaa**, 71	—
4	PhI (**8b**)	5 mol% $Pd(PPh_3)_4$	$Toluene/H_2O$, 70 °C, 20 h	**9aaab**, 71	—
5	*p*-$MeOC_6H_4I$ (**8c**)	5 mol% $Pd(PPh_3)_4$	$Toluene/H_2O$, 70 °C, 20 h	**9aaab**, 19/**9aaac**, 54	—
6	**8c**	2.5 mol% $Pd_2(dba)_3$ / 11 mol% PCy_3	$Toluene/H_2O$, 70 °C, 6 h	**9aaac**, 70	—

accompanied by the phenyl-substituted product **9aaab** as a result of the aryl-group interchange between the phosphorus-bound phenyl groups and the *p*-methoxyphenyl ligand.[18] When the combination of tricyclohexylphosphine, PCy_3, and $Pd_2(dba)_3$ was employed instead of $Pd(PPh_3)_4$, the reaction completed within 6 h and **9aaac** was successfully obtained as a sole product in 70% yield (entry 6).

2.3. Scope and limitations of one-pot cyclotrimerization/Suzuki–Miyaura coupling process

Having optimized the cross coupling conditions, the generality of the one-pot cyclotrimerization/Suzuki–Miyaura coupling was examined as summarized in Table 2 and Figure 1. With shorter reaction time of 5 h, the cyclotrimerization of **2a**, **3a**, and **4a** proceeded satisfactorily, and the biphenyl derivative **9aaaa** was obtained in 73% yield, after the Suzuki–Miyaura coupling with **8a** using the optimal catalyst precursors $Pd_2(dba)_3$/PCy_3 (entry 1). The less reactive iodides **8b** and **8c**, or nitro-substituted **8d** bearing a high coordinating ability underwent cross coupling with the arylboronate intermediate **9aaa** to furnish **9aaab**, **9aaac**, and **9aaad** in similar yields (entries 3–5). In contrast, sterically demanding *o*-substituted aryl iodides failed to undergo Suzuki–Miyaura coupling. To overcome such an inefficiency, 2-dicyclohexylphosphino-2′,6′-dimethoxy-biphenyl reported by Buchwald et al.[19] was used instead of tricyclohexylphosphine to furnish biaryls **9aaae** and **9aaaf** in 55 and 67% yields, respectively, (entries 5 and 6). In addition to the iodobenzenes, 2-iodopyridine **8g** and 2-iodothiophene **8h** can be used for the present one-pot coupling. Although longer reaction time of 24 h was required to ensure the cross coupling with these heterocyclic components, the desired hetero-biaryls **9aaag** and **9aaah** were obtained in 53 and 69% yields, respectively, (entries 7 and 8). Stilbene derivative **9aaai** was synthesized by way of the coupling with *trans*-*p*-methoxy-2-iodostyrene **8i** albeit in a moderate yield (entry 9).

With respect to the third alkyne components, methyl propargyl ether **4b**, 5-chloropent-1-yne **4c**, methyl 5-hexynoate **4d**, and *O*-protected 5-hexyn-1-ol **4e** can be employed for the boron-tethered cyclotrimerization (entries 10–13). After the cross coupling with **8a**, the desired biaryls bearing a chloroalkyl, an ester, or a protected alcohol functionality were obtained in 68–76% yields. These results indicate that the boron-tethered diyne intermediate was selectively formed with propargyl alcohol **3a**. In addition, gaseous propyne **4f** or acetylene **4g** were also incorporated into the final products **9aafa** and **9aaga** selectively (entries 14 and 15). On the other hand, conjugated alkynes showed diminished reactivity. Actually, employing ethynylcyclohexene **4h** resulted in the moderate-yield formation of the corresponding product **9aaha** (entry 16), and what is worse, protodeboration product **10aai** was exclusively formed in 59% yield, when ethynylbenzene **4i** was used. The inability of Suzuki–Miyaura coupling for the aromatic alkynes was improved by the filtration of the crude cyclotrimerization product through a silica gel short column prior to the cross coupling. In this way, the desired teraryl **9aaia** was obtained albeit in lower yield together with **10aai** (entry 17). Similarly, the four-component coupling involving ethynylferrocene **4j** furnished ferrocene-substituted **9aaja** in 56% yield (entry 18).

In place of propargyl alcohol **3a**, 2-butyn-1-ol **3b**, and 3-butyn-2-ol **3c** were allowed to react with the boronate **2a**, and acetylene **4g** or 1-hexyne **4a**, although these alkynols require reaction time of 72 h for cyclotrimerization and/or the catalyst loading of 10 mol% (entries 19 and 20). The corresponding biaryls **9abga** and **9acaa** were obtained in 55 and 49% yields, respectively. These results are in striking contrast to those with 2-methyl-3-butyn-2-ol or propargyl amines, which proved to be totally ineffective.

Finally, two more alkynylboronates **2b** and **2c** bearing an ether or a chloroalkyl functionality were subjected to the one-pot coupling (entries 21 and 22). Although the cyclotrimerization of these boronates with **3a** and **4a** requires prolonged reaction time compared to that of **2a**, Suzuki–Miyaura coupling of the resultant arylboronate intermediates with **8a** successfully gave rise to biaryls **9baaa** and **9caaa** in 63 and 66% yields, respectively. These products were the regioisomers of **9aaba** or **9aacab** (entry10 vs 21, and entry 11 vs 22). In contrast, 3,3-dimethyl-1-propynylboronate **2d** failed to undergo cyclotrimerization with propargyl alcohol **3a** and 1-hexyne **4a**.

2.4. Extension to partially intramolecular reactions

The present ruthenium-catalyzed intermolecular alkyne cyclotrimerization with the boron temporary tether was further extended to the partially intramolecular versions of diynylboronate **11** or diynol **14**. The 1,6-octadiynylboronate **11** and 2-butyn-1-ol **3b** (2 equiv) were treated with 5 mol% **1** in DCE at room temperature for 24 h. The resultant cyclic boronate **12** was then allowed to react with *p*-iodoacetophenone **8a** under the optimal conditions to afford **13** in 72% yield with excellent regioselectivity (Scheme 3). In a similar way, 1-hexynylboronate **2a** and 2,8-heptadiyne-1-ol **14** (1.1 equiv) were converted to **16** in 60% yield via the corresponding tricyclic boronate intermediate **15** (Scheme 4). These partially intramolecular cyclotrimerizations proceeded with definite regioselectivity via temporarily connected triyne intermediates.

Table 2. One-pot four-component couplings

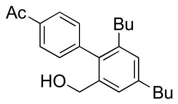
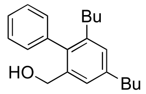
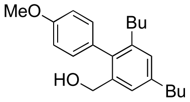
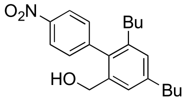
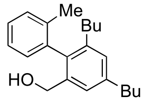
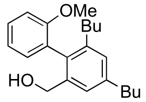
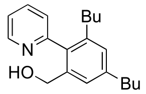
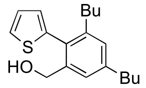
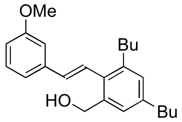
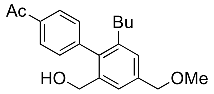
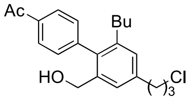
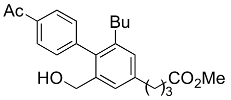
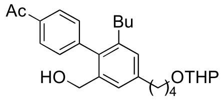
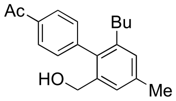
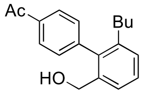
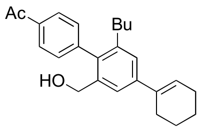
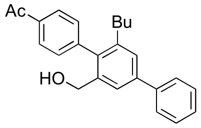
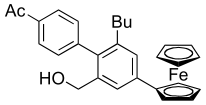
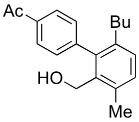
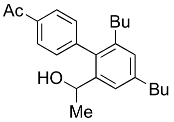
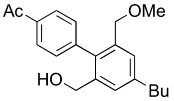
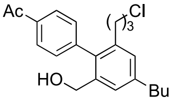
Entry	Cyclotrimerization alkynes/time (h)[a]	Suzuki–Miyaura coupling aryliodides/time (h)[b]	Products	Yield (%)
1	**2a**, **3a**, **4a**/5	**8a**/3		**9aaaa**, 73
2	**2a**, **3a**, **4a**/5	**8b**/6		**9aaab**, 71
3	**2a**, **3a**, **4a**/5	**8c**/6		**9aaac**, 70
4	**2a**, **3a**, **4a**/5	**8d**/4		**9aaad**, 71
5	**2a**, **3a**, **4a**/5	**8e**/5[c]		**9aaae**, 55
6	**2a**, **3a**, **4a**/5	**8f**/5[c]		**9aaaf**, 67
7	**2a**, **3a**, **4a**/5	**8g**/24		**9aaag**, 53
8	**2a**, **3a**, **4a**/5	**8h**/24		**9aaah**, 69
9	**2a**, **3a**, **4a**/5	**8i**/20		**9aaai**, 51
10	**2a**, **3a**, **4b**/5	**8a**/3		**9aaba**, 69
11	**2a**, **3a**, **4c**/5	**8a**/3		**9aaca**, 76
12	**2a**, **3a**, **4d**/5	**8a**/4		**9aada**, 73
13	**2a**, **3a**, **4e**/24	**8a**/6		**9aaea**, 68
14	**2a**, **3a**, **4f**/24[d]	**8a**/5		**9aafa**, 70
15	**2a**, **3a**, **4g**/24[d]	**8a**/4		**9aaga**, 67
16	**2a**, **3a**, **4h**/24	**8a**/6		**9aaha**, 56
17	**2a**, **3a**, **4i**/24	**8a**/24[e]		**9aaia**, 34

Table 2 (*continued*)

Entry	Cyclotrimerization alkynes/time (h)[a]	Suzuki–Miyaura coupling aryliodides/time (h)[b]	Products	Yield (%)
18	**2a**, **3a**, **4j**/24	**8a**/24[e]		**9aaja**, 56
19	**2a**, **3b**, **4g**/72[d]	**8a**/5		**9abga**, 55
20	**2a**, **3c**, **4a**/24	**8a**/4		**9acaa**, 49
21	**2b**, **3a**, **4a**/24	**8a**/4		**9baaa**, 63
22	**2c**, **3a**, **4a**/24	**8a**/4		**9caaa**, 66

[a] In 1,2-dichloroethane (4 mL), **2**, **3** (1.1 equiv), and **4** (4 equiv) were treated with 5 mol% **1** (10 mol% for entries 19 and 20) under Ar atmosphere at room temperature.

[b] Crude arylboronates were treated with **8** (1.5 equiv) in toluene/H_2O at 70 °C in the presence of 2.5 mol% $Pd_2(dba)_3$ and 11 mol% PCy_3.

[c] 2-Dicyclohexylphosphino-2′,6′-dimethoxybiphenyl was used instead of tricyclohexylphosphine.

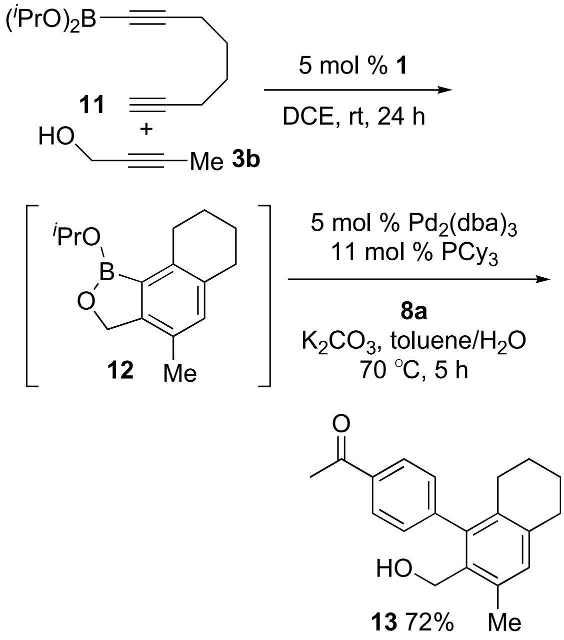
[d] Under 1 atm propyne or acetylene.

[e] Crude arylboronates were filtered through a silica gel short column before Suzuki–Miyaura coupling. The protodeboration product **10aai** was also obtained in 28% yield for entry 17.

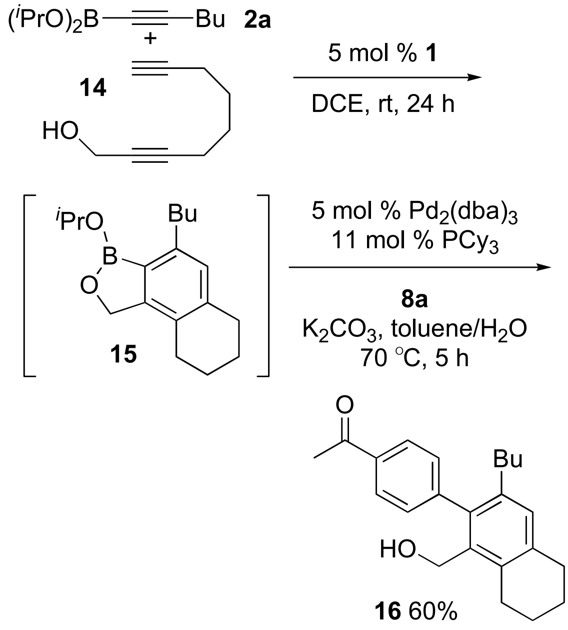
3. Conclusion

In conclusion, the catalytic intermolecular cyclotrimerization of three different unsymmetrical alkynes was accomplished by means of the ruthenium catalysis and the temporary tethering approach with the C–B–O linkage. The crude arylboronates were further applied to the Suzuki–Miyaura coupling with various aryl iodides using $Pd_2(dba)_3$/2PCy_3 as a catalyst precursor in aqueous toluene to afford biaryls. As a result, the novel four-component coupling approach to highly substituted biaryls was successfully established by combining these two operations into a sequential one-pot process.

The partially intramolecular versions of the temporary tethering cyclotrimerization were also realized using the diynylboronate or the diynol.



Scheme 3.



Scheme 4.

4. Experimental

4.1. General

Flash chromatography was performed with a silica gel column (Cica silica gel 60N) eluted with mixed solvents [hexane/AcOEt]. TLC analyses were performed with Merck TLC plate silica gel 60 F254. ^{1}H and ^{13}C NMR spectra were measured on a Varian Mercury 300 NMR spectrometer as $CDCl_3$ solutions at 25 °C. ^{1}H NMR chemical shifts are reported in terms of chemical shift (δ, ppm) relative to the singlet at 7.26 ppm for chloroform. Splitting patterns are designated as follows: s, singlet; d, doublet; t, triplet; q, quartet; sext, sextet; sept, septet; m, multiplet. Coupling constants are reported in Hz. ^{13}C NMR spectra were fully decoupled and are reported in terms of chemical shift (δ, ppm) relative to the triplet at $\delta=77.0$ ppm for $CDCl_3$. Infrared spectra were recorded on a JASCO FT/IR-230. Mass spectra were recorded on a JEOL JMS 700 mass spectrometer. Elemental analyses were performed at the Microanalytical Center of Kyoto University or Instrumental Analysis Facility of Nagoya University. Melting points were obtained by a Büchi Melting Point B-540 and are uncorrected. 1,2-Dichloroethane was distilled from CaH_2, and degassed before use. Cp*RuCl(cod),[20] $Pd_2(dba)_3 \cdot CHCl_3$,[21] and alkynylboronates[22] were prepared according to the literature procedures. Commercially available diisopropyl 3,3-dimethyl-1-propynylboronate and 2-dicyclohexylphosphino-2′,6′-dimethoxybiphenyl were purchased and used without further purifications.

4.1.1. Representative procedure for one-pot cyclotrimerization/Suzuki–Miyaura coupling: synthesis of biphenyl 9aaaa from 1-hexynylboronate 2a, propargyl alcohol 3,1-hexyne 4a, and *p*-iodoacetophenone 8a. To a solution of Cp*RuCl(cod) (**1**) (9.5 mg, 0.025 mmol), 1-hexynylboronate **2a** (105.1 mg, 0.50 mmol), and 1-hexyne **4a** (164.3 mg, 2.0 mmol) in dry degassed 1,2-dichloroethane (1 mL) was added a solution of propargyl alcohol **3a** (30.8 mg, 0.55 mmol) in dry degassed 1,2-dichloroethane (3 mL) over 15 min at room temperature under Ar atmosphere. The solution was stirred at room temperature under Ar atmosphere for 5 h, and then, the solvent was removed under reduced pressure. To the residue were added $Pd_2(dba)_3 \cdot CHCl_3$ (13.0 mg, 0.0125 mmol), PCy_3 (15.9 mg, 0.055 mmol), *p*-iodoacetophenone **8a** (184.5 mg, 0.75 mmol), toluene (3.5 mL), and 2 M aq K_2CO_3 (1.5 mL), and the reaction mixture was degassed at −78 °C under reduced pressure. After heating at 70 °C under Ar atmosphere for 3 h, the resultant solution was extracted with AcOEt (3 mL × 3) and the organic layer was dried with $MgSO_4$. The solvent was evaporated and the crude product was purified by silica gel flash column chromatography (hexane/AcOEt 6:1) to give biphenyl **9aaaa** (123.4 mg, 73%) as pale yellow oil (R_f 0.2, hexane/AcOEt 3:1); IR (neat) 3424, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.75 (t, $J=7.2$ Hz, 3H), 0.96 (t, $J=7.2$ Hz, 3H), 1.15 (sext, $J=7.5$ Hz, 2H), 1.32–1.47 (m, 4H), 1.60–1.70 (m, 2H), 1.85–2.00 (br s, 1H), 2.29 (t, $J=8.1$ Hz, 2H), 2.64 (t, $J=8.1$ Hz, 2H), 2.64 (s, 3H), 4.28 (s, 2H), 7.06 (d, $J=1.5$ Hz, 1H), 7.21 (d, $J=1.5$ Hz, 1H), 7.29 (dd, $J=8.5$, 2.1 Hz, 2H), 8.00 (dd, $J=8.5$, 2.1 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.82, 14.02, 22.50, 22.54, 26.60, 33.00, 33.54, 33.62, 35.51, 63.32, 125.05, 128.04, 128.27, 129.89, 135.53, 136.28, 138.04, 140.35, 142.50, 144.71, 197.69; MS (EI): *m/z* (%): 338 (100) [M$^+$], 323 (18) [M$^+$−Me], 295 (50) [M$^+$−COMe], 277 (70) [M$^+$−COMe–H_2O], 265 (25) [M$^+$−COMe–HCHO]; EA calcd (%) for $C_{23}H_{30}O_2$ (338.48): C, 81.61; H, 8.93; found: C, 81.51; H, 9.03.

4.1.2. Compound 9aaab. Yield 71%; oil (R_f 0.45, hexane/AcOEt 3.5:1); IR (neat) 3315, 1609 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.77 (t, $J=7.5$ Hz, 3H), 0.98 (t, $J=7.5$ Hz, 3H), 1.18 (sext, $J=7.5$ Hz, 2H), 1.34–1.49 (m, 4H), 1.58 (br s, 1H), 1.62–1.73 (m, 2H), 2.32 (t, $J=7.8$ Hz, 2H), 2.66 (t, $J=7.8$ Hz, 2H), 4.33 (s, 2H), 7.07 (s, 1H), 7.16–7.22 (m, 3H), 7.33–7.45 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.87, 14.10, 22.59, 22.66, 33.06, 33.64, 33.72, 35.58, 63.80, 125.05, 126.83, 128.10, 128.26, 129.48, 137.52, 138.45, 139.15, 140.91, 142.05; MS (EI): *m/z* (%): 296 (100) [M$^+$], 278 (11) [M$^+$−H_2O], 253 (40) [M$^+$−$(CH_2)_2CH_3$], 235 (90) [M$^+$−$(CH_2)_2CH_3$–H_2O], 220 (35) [M$^+$−C_6H_4]; EA calcd (%) for $C_{21}H_{28}O$ (296.45): C, 85.08; H, 9.52; found: C, 85.04; H, 9.55.

4.1.3. Compound 9aaac. Yield 70%; oil (R_f 0.3, hexane/AcOEt 3:1); IR (neat) 3326, 1607 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.80 (t, $J=7.2$ Hz, 3H), 0.98 (t, $J=7.5$ Hz, 3H), 1.20 (sext, $J=7.5$ Hz, 2H), 1.36–1.49 (m, 4H), 1.62–1.75 (m, 3H), 2.35 (t, $J=8.0$ Hz, 2H), 2.66 (t, $J=7.8$ Hz, 2H), 3.86 (s, 3H), 4.34 (s, 2H), 6.96 (d, $J=8.4$ Hz, 2H), 7.06 (d, $J=1.5$ Hz, 1H), 7.11 (d, $J=8.4$ Hz, 2H), 7.18 (d, $J=1.5$ Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.91, 14.07, 22.60, 22.63, 33.09, 33.64, 33.71, 35.55, 55.18, 63.79, 113.52, 124.97, 128.17, 130.45, 131.24, 137.13, 138.86, 141.32, 141.86, 158.26; MS (EI): *m/z* (%): 326 (100) [M$^+$], 308 (5) [M$^+$−H_2O], 283 (40) [M$^+$−$(CH_2)_2CH_3$], 265 (90) [M$^+$−$(CH_2)_2CH_3$–H_2O]; EA calcd (%) for $C_{22}H_{30}O_2$ (326.47): C, 80.94; H, 9.26; found: C, 80.96; H, 9.24.

4.1.4. Compound 9aaad. Yield 71%; oil (R_f 0.3, hexane/AcOEt 3:1); IR (neat) 3328, 1598, 1518, 1464, 1347 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.76 (t, $J=7.2$ Hz, 3H), 0.96 (t, $J=7.5$ Hz, 3H), 1.16 (t, $J=7.2$ Hz, 2H), 1.31–1.47 (m, 4H), 1.50 (br s, 1H), 1.60–1.71 (m, 2H), 2.25 (t, $J=7.8$ Hz, 2H), 2.65 (t, $J=7.5$ Hz, 2H), 4.29 (s, 2H), 7.08 (d, $J=1.5$ Hz, 1H), 7.21 (d, $J=1.5$ Hz, 1H), 7.39 (d, $J=8.7$ Hz, 2H), 8.28 (d, $J=8.7$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.84, 14.05, 22.52, 22.57, 33.05, 33.54, 33.64, 35.53, 63.33, 123.19, 125.38, 128.57, 130.71, 135.32, 137.77, 140.32, 143.13, 146.72, 146.79; MS (EI): *m/z* (%): 341 (100) [M$^+$], 298 (71) [M$^+$−$(CH_2)_2CH_3$], 280 (46) [M$^+$−$(CH_2)_2CH_3$–H_2O]; EA calcd (%) for $C_{21}H_{27}NO_3$ (341.44): C, 73.87; H, 7.97; N, 4.10; found: C, 73.78; H, 7.96; N, 4.01.

4.1.5. Compound 9aaae. Yield 55%; oil (R_f 0.4, hexane/AcOEt 3:1); IR (neat) 3300 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.77 (t, $J=7.5$ Hz, 3H), 0.98 (t, $J=7.5$ Hz, 3H), 1.12–1.24 (m, 2H), 1.34–1.49 (m, 4H), 1.57 (br s, 1H), 1.63–1.73 (m, 2H), 1.98 (s, 3H), 2.17 (dt, $J=13.5$, 7.8 Hz, 1H), 2.29 (dt, $J=13.5$, 7.8 Hz, 1H), 2.67 (t, $J=7.5$ Hz, 2H), 4.25 (s, 2H), 7.06–7.10 (m, 2H), 7.20 (d, $J=1.8$ Hz, 1H), 7.21–7.29 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.89, 14.11, 19.92, 22.61, 22.66, 32.77, 33.08, 33.70, 35.62, 63.70, 124.89, 125.58, 127.22, 128.13, 129.61, 129.83, 136.12, 136.38, 138.07, 138.55, 140.47, 141.85; MS (EI): *m/z* (%): 310 (41) [M^+], 292 (100) [M^+-H_2O], 267 (11) [M^+-COCH_3], 249 (43) [$M^+-COCH_3–H_2O$]; EA calcd (%) for $C_{22}H_{30}O$ (310.47): C, 85.11; H, 9.74; found: C, 85.24; H, 9.84.

4.1.6. Compound 9aaaf. Yield 67%; oil (R_f 0.25, hexane/AcOEt 3:1); IR (neat) 3389 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.76 (t, $J=7.5$ Hz, 3H), 0.98 (t, $J=7.5$ Hz, 3H), 1.17 (sext, $J=7.5$ Hz, 2H), 1.32–1.50 (m, 4H), 1.64–1.74 (m, 2H), 2.03 (br s, 1H), 2.20–2.40 (m, 2H), 2.67 (t, $J=7.5$ Hz, 2H), 3.74 (s, 3H), 4.26 (d, $J=12.0$ Hz, 1H), 4.31 (d, $J=12.0$ Hz, 1H), 6.99–7.10 (m, 4H), 7.20 (d, $J=1.8$ Hz, 1H), 7.36 (ddd, $J=8.4$, 7.2, 2.1 Hz, 1H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.90, 14.11, 22.53, 22.70, 33.14, 33.24, 33.58, 35.57, 55.35, 64.37, 110.80, 120.64, 125.77, 127.85, 128.50, 128.66, 131.28, 133.72, 138.92, 141.27, 142.07, 156.50; MS (EI): *m/z* (%): 326 (100) [M^+], 308 (36) [M^+-H_2O], 265 (12) [$M^+-COCH_3–H_2O$]; EA calcd (%) for $C_{22}H_{30}O_2$ (326.47): C, 80.94; H, 9.26; found: C, 80.92; H, 9.36.

4.1.7. Compound 9aaag. Yield 53%; oil (R_f 0.15, hexane/AcOEt 2:1); IR (neat) 3362 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.76 (t, $J=7.5$ Hz, 3H), 0.95 (t, $J=7.5$ Hz, 3H), 1.17 (sext, $J=7.5$ Hz, 2H), 1.32–1.46 (m, 4H), 1.59–1.69 (m, 2H), 2.47 (t, $J=7.8$ Hz, 2H), 2.63 (t, $J=7.8$ Hz, 2H), 4.18 (s, 2H), 4.45 (br s, 1H), 7.08 (d, $J=1.8$ Hz, 1H), 7.14 (d, $J=1.8$ Hz, 1H), 7.30 (ddd, $J=7.5$, 4.8, 1.2 Hz, 1H), 7.37 (dt, $J=7.5$, 1.0 Hz, 1H), 7.77 (dt, $J=7.5$, 1.8 Hz, 1H), 8.65 (ddd, $J=4.8$, 1.8, 0.9 Hz, 1H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.83, 14.07, 22.55 (2 C), 33.13, 33.56, 33.65, 35.47, 64.56, 121.92, 125.33, 127.41, 129.05, 136.06, 136.91, 139.78, 140.68, 143.26, 148.67, 158.53; MS (EI): *m/z* (%): 297 (100) [M^+], 279 (49) [M^+-H_2O], 268 (21) [$M^+-CH_2CH_3$], 250 (96) [$M^+-H_2O–CH_2CH_3$]; EA calcd (%) for $C_{20}H_{27}NO$ (297.43): C, 80.76; H, 9.15; N, 4.71; found: C, 80.39; H, 9.29; N, 4.40.

4.1.8. Compound 9aaah. Yield 69%; oil (R_f 0.35, hexane/AcOEt 3:1); IR (neat) 3330 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.83 (t, $J=7.5$ Hz, 3H), 0.97 (t, $J=7.5$ Hz, 3H), 1.25 (sext, $J=7.5$ Hz, 2H), 1.36–1.53 (m, 4H), 1.60–1.71 (m, 2H), 1.74 (br s, 1H), 2.43 (t, $J=7.8$ Hz, 2H), 2.65 (t, $J=7.8$ Hz, 2H), 4.45 (s, 2H), 6.89 (dd, $J=3.3$, 1.2 Hz, 1H), 7.07 (s, 1H), 7.10 (dd, $J=5.1$, 3.3 Hz, 1H), 7.20 (s, 1H), 7.38 (dd, $J=5.1$, 1.2 Hz, 1H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.94, 14.07, 22.60, 22.69, 33.23, 33.63, 34.12, 35.59, 63.74, 125.22, 125.56, 126.84, 127.36, 128.30, 129.19, 139.21, 140.64, 143.27, 143.33; MS (EI): *m/z* (%): 302 (100) [M^+], 284 (11) [M^+-H_2O], 269 (20) [$M^+-H_2O–CH_3$], 255 (42) [$M^+-H_2O–CH_2CH_3$], 241 (30) [$M^+-H_2O–CH_2CH_2CH_3$]; EA calcd (%) for $C_{19}H_{26}OS$ (302.48): C, 75.45; H, 8.66; found: C, 75.54; H, 8.47.

4.1.9. Compound 9aaai. Yield 51%; oil (R_f 0.35, hexane/AcOEt 3:1); IR (neat) 3363 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.93 (t, $J=7.5$ Hz, 3H), 0.97 (t, $J=7.5$ Hz, 3H), 1.39 (sept, $J=7.5$ Hz, 4H), 1.54–1.69 (m, 4H), 1.81 (br s, 1H), 2.62 (t, $J=7.5$ Hz, 2H), 2.69 (t, $J=7.5$ Hz, 2H), 3.89 (s, 3H), 4.74 (s, 2H), 6.66 (d, $J=16.5$ Hz, 1H), 6.86 (ddd, $J=8.1$, 2.7, 0.6 Hz, 1H), 7.02–7.06 (m, 2H), 7.12 (d, $J=7.8$ Hz, 1H), 7.18 (s, 1H), 7.21 (d, $J=16.5$ Hz, 1H), 7.29 (dd, $J=15.5$, 7.8 Hz, 1H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 14.08, 14.10, 22.57, 22.76, 33.26, 33.51, 33.71, 35.48, 55.26, 63.93, 111.76, 112.97, 118.92, 125.69, 125.97, 128.75, 129.52, 133.19, 134.06, 138.37, 138.75, 141.34, 141.81, 159.68; MS (EI): *m/z* (%): 352 (100) [M^+], 334 (27) [M^+-H_2O], 321 (13) [M^+-OCH_3], 291 (12) [$M^+-H_2O–COCH_3$]; EA calcd (%) for $C_{24}H_{32}O_2$ (352.51): C, 81.77; H, 9.15; found: C, 81.97; H, 9.17.

4.1.10. Compound 9aaba. Yield 69%; oil (R_f 0.3, hexane/AcOEt 2:1); IR (neat) 3384, 1681, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.74 (t, $J=7.5$ Hz, 3H), 1.14 (sext, $J=7.2$ Hz, 2H), 1.32–1.42 (m, 2H), 2.02 (br s, 1H), 2.30 (t, $J=7.5$ Hz, 2H), 2.64 (s, 3H), 3.43 (s, 3H), 4.28 (s, 2H), 4.48 (s, 2H), 7.21 (d, $J=1.8$ Hz, 1H), 7.27 (d, $J=8.1$ Hz, 2H), 7.35 (d, $J=1.8$ Hz, 1H), 8.00 (d, $J=8.1$ Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.82, 22.51, 26.66, 33.00, 33.46, 58.32, 63.20, 74.53, 124.30, 127.48, 128.13, 129.71, 135.73, 137.76, 138.33, 138.46, 140.80, 144.33, 197.66; MS (EI): *m/z* (%): 326 (100) [M^+], 311 (20) [M^+-CH_3], 295 (88) [M^+-OCH_3], 281 (14) [$M^+-CH_2OCH_3$], 265 (69) [$M^+-OCH_3–CH_2O$]; EA calcd (%) for $C_{21}H_{26}O_3$ (326.43): C, 77.27; H, 8.03; found: C, 77.11; H, 8.19.

4.1.11. Compound 9aaca. Yield 76%; oil (R_f 0.3, hexane/AcOEt 2:1); IR (neat) 3435, 1681, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.75 (t, $J=7.5$ Hz, 3H), 1.15 (sext, $J=7.2$ Hz, 2H), 1.31–1.41 (m, 2H), 1.56 (br s, 1H), 2.09–2.19 (m, 2H), 2.29 (t, $J=7.8$ Hz, 2H), 2.66 (s, 3H), 2.82 (t, $J=7.8$ Hz, 2H), 3.59 (t, $J=6.5$ Hz, 2H), 4.31 (s, 2H), 7.08 (d, $J=1.6$ Hz, 1H), 7.21 (d, $J=1.6$ Hz, 1H), 7.30 (d, $J=8.4$ Hz, 2H), 8.02 (d, $J=8.4$ Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.85, 22.52, 26.68, 32.70, 33.02, 33.55, 35.99, 44.35, 63.33, 125.14, 128.14, 128.48, 129.84, 135.72, 136.91, 138.36, 140.38, 140.79, 144.45, 197.66; MS (EI): *m/z* (%): 358 (100) [M^+], 343 (24) [M^+-CH_3], 297 (58) [MH^+-CH_2CHCl], 255 (64) [$MH^+-CH_2CHCl–CH_2CHCH_3$]; EA calcd (%) for $C_{22}H_{27}ClO_2$ (358.90): C, 73.62; H, 7.58; found: C, 73.54; H, 7.68.

4.1.12. Compound 9aada. Yield 73%; oil (R_f 0.3, hexane/AcOEt 1:1); IR (neat) 3448, 1736, 1683, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.75 (t, $J=7.5$ Hz, 3H), 1.14 (sext, $J=7.5$ Hz, 2H), 1.30–1.41 (m, 2H), 1.65 (br s, 1H), 2.01 (q, $J=7.5$ Hz, 2H), 2.28 (t, $J=7.8$ Hz, 2H), 2.38 (t, $J=7.2$ Hz, 2H), 2.65 (s, 3H), 2.69 (t, $J=7.5$ Hz, 2H), 3.68 (s, 3H), 4.29 (s, 2H), 7.05 (d, $J=1.8$ Hz, 1H), 7.20 (d, $J=1.8$ Hz, 1H), 7.30 (d, $J=8.1$ Hz, 2H), 8.01 (d, $J=8.1$ Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): δ 13.86, 22.55, 26.48, 26.69, 33.05, 33.57 (2 C), 35.01, 51.58, 63.40, 125.20, 128.13, 128.44, 129.87, 135.70, 136.81, 138.27, 140.70, 141.25, 144.53, 173.76, 197.66; MS (EI): *m/z* (%): 382 (5) [M^+], 364 (81) [M^+-H_2O], 333 (10) [$M^+-H_2O–OCH_3$], 321 (100) [$M^+-H_2O–CH_2CH_2CH_3$], 291 (72) [$M^+-H_2O–CH_2CO_2CH_3$]; EA calcd (%) for $C_{24}H_{30}O_4$ (382.49): C, 75.36; H, 7.91; found: C, 75.28; H, 7.99.

4.1.13. Compound 9aaea. Yield 68%; oil (R_f 0.4, hexane/AcOEt 1:1); IR (neat) 3444, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): δ 0.75 (t, $J=7.5$ Hz, 3H), 1.15 (sext, $J=7.2$ Hz, 2H), 1.31–1.41 (m, 2H), 1.49–1.88 (m, 11H), 2.28 (t, $J=7.8$ Hz, 2H), 2.65 (s, 3H), 2.68 (t, $J=7.2$ Hz, 2H), 3.40–3.54 (m, 2H), 3.75–3.91 (m, 2H), 4.29 (s, 2H), 4.57–4.59 (m, 1H), 7.06 (d, *J*=1.2 Hz, 1H), 7.20 (d, *J*=1.2 Hz, 1H), 7.30 (d, *J*=8.1 Hz, 2H), 8.01 (d, *J*=8.1 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.86, 19.74, 22.54, 25.53, 26.69, 28.08, 29.50, 30.80, 33.05, 33.58, 35.58, 62.38, 63.45, 67.41, 98.82, 125.19, 128.10, 128.41, 129.91, 135.65, 136.52, 138.11, 140.53, 142.15, 144.67, 197.69; MS (EI): *m*/*z* (%): 438 (5) [M$^+$], 420 (6) [M$^+$ −H$_2$O], 354 (100) [M$^+$ −H–THP], 336 (61) [M$^+$ −H–OTHP]; EA calcd (%) for $C_{28}H_{38}O_4$ (438.60): C, 76.68; H, 8.73; found: C, 76.54; H, 8.87.

4.1.14. Compound 9aafa. Yield 70%; oil (*R*$_f$ 0.3, hexane/AcOEt 2:1); IR (neat) 3798, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.75 (t, *J*=7.5 Hz, 3H), 1.15 (sext, *J*=7.2 Hz, 2H), 1.32–1.42 (m, 2H), 1.84 (br s, 1H), 2.28 (t, *J*=7.8 Hz, 2H), 2.34 (s, 3H), 2.64 (s, 3H), 4.28 (s, 2H), 7.07 (s, 1H), 7.20 (s, 1H), 7.29 (d, *J*=8.4 Hz, 2H), 8.00 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.85, 21.30, 22.54, 26.66, 32.97, 33.57, 63.33, 125.83, 128.10, 128.99, 129.92, 135.62, 136.21, 137.54, 138.10, 140.54, 144.61, 197.69; MS (EI): *m*/*z* (%): 296 (85) [M+], 281 (20) [M$^+$ −CH$_3$], 254 (22) [M$^+$ −CH$_2$CO], 235 (50) [M$^+$ −COCH$_3$–H$_2$O], 220 (25) [M$^+$ −COCH$_3$–H$_2$O–CH$_3$], 205 (100) [M$^+$ −COCH$_3$–H$_2$O–2CH$_3$]; EA calcd (%) for $C_{20}H_{24}O_2$ (296.40): C, 81.04; H, 8.16; found: C, 80.96; H, 8.24.

4.1.15. Compound 9aaga. Yield 67%; oil (*R*$_f$ 0.2, hexane/AcOEt 2:1); IR (neat) 3420, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.75 (t, *J*=7.5 Hz, 3H), 1.15 (sext, *J*=7.5 Hz, 2H), 1.32–1.42 (m, 2H), 1.76 (br s, 1H), 2.31 (t, *J*=7.5 Hz, 2H), 2.65 (s, 3H), 4.31 (s, 2H), 7.25 (dd, *J*=6.9, 2.1 Hz, 1H), 7.31 (d, *J*=8.7 Hz, 2H), 7.34–7.40 (m, 2H), 8.01 (d, *J*=8.7 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.86, 22.49, 26.70, 33.02, 33.49, 63.38, 125.05, 127.95, 128.16, 128.35, 129.70, 135.76, 138.23, 139.03, 140.62, 144.45, 197.68; MS (EI): *m*/*z* (%): 282 (100) [M$^+$], 267 (22) [M$^+$ −CH$_3$], 221 (64) [M$^+$ −COCH$_3$–H$_2$O]; EA calcd (%) for $C_{19}H_{22}O_2$ (282.38): C, 80.82; H, 7.85; found: C, 80.44; H, 8.02.

4.1.16. Compound 9aaha. Yield 56%; mp 110.9–111.3 °C (*R*$_f$ 0.35, hexane/AcOEt 2:1); IR (neat) 3421, 1678, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.75 (t, *J*=7.5 Hz, 3H), 1.16 (sext, *J*=7.5 Hz, 2H), 1.33–1.45 (m, 3H), 1.64–1.72 (m, 2H), 1.77–1.85 (m, 2H), 2.20–2.27 (m, 2H), 2.31 (t, *J*=7.5 Hz, 2H), 2.44–2.48 (m, 2H), 2.66 (s, 3H), 4.32 (d, *J*=6.0 Hz, 2H), 6.19 (sept, *J*=1.5 Hz, 1H), 7.26 (d, *J*=2.1 Hz, 1H), 7.31 (d, *J*=8.4 Hz, 2H), 7.39 (d, *J*=2.1 Hz, 1H), 8.02 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.90, 22.25, 22.60, 23.15, 25.99, 26.73, 27.54, 33.27, 33.66, 63.72, 121.96, 125.02, 125.11, 128.15, 129.89, 135.77, 136.17, 137.42, 138.05, 140.57, 142.39, 144.58, 197.63; MS (EI): *m*/*z* (%): 362 (100) [M$^+$], 331 (32) [M$^+$ −CH$_3$OH], 301 (16) [M$^+$ −COCH$_3$–H$_2$O]; EA calcd (%) for $C_{25}H_{30}O_2$ (362.50): C, 82.83; H, 8.34; found: C, 82.70; H, 8.37.

4.1.17. Compound 9aaia. Yield 34%; oil (*R*$_f$ 0.3, hexane/AcOEt 2:1); IR (neat) 3422, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.77 (t, *J*=7.5 Hz, 3H), 1.19 (sext, *J*=7.5 Hz, 2H), 1.38–1.48 (m, 2H), 1.64 (br s, 1H), 2.39 (t, *J*=7.5 Hz, 2H), 2.67 (s, 3H), 4.39 (d, *J*=5.4 Hz, 2H), 7.33–7.50 (m, 6H), 7.63–7.68 (m, 3H), 8.04 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.91, 22.57, 26.75, 33.22, 33.59, 63.52, 123.88, 127.03, 127.08, 127.31, 128.23, 128.67, 129.79, 135.84, 138.07, 138.77, 140.65, 140.82, 141.22, 144.24, 197.64; MS (EI): *m*/*z* (%): 358 (100) [M$^+$], 297 (28) [M$^+$ −COCH$_3$–H$_2$O], 255 (68) [M$^+$ −COCH$_3$–H$_2$O–CH$_2$=CHCH$_3$], 241 (68) [M$^+$ −COCH$_3$–H$_2$O–CH$_2$=CHCH$_2$CH$_3$]; EA calcd (%) for $C_{25}H_{26}O_2$ (358.47): C, 83.76; H, 7.31; found: C, 83.61; H, 7.46.

4.1.18. Compound 9aaja. Yield 56%; mp 161.8–162.4 °C (*R*$_f$ 0.2, hexane/AcOEt 2:1); IR (KBr) 3366, 1680, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.78 (t, *J*=7.5 Hz, 3H), 1.20 (sext, *J*=7.5 Hz, 2H), 1.36–1.46 (m, 2H), 1.76 (br s, 1H), 2.34 (t, *J*=7.5 Hz, 2H), 2.65 (s, 3H), 4.09 (s, 5H), 4.33 (t, *J*=1.5 Hz, 2H), 4.34 (d, *J*=1.5 Hz, 2H), 4.68 (t, *J*=1.5 Hz, 2H), 7.33 (d, *J*=8.4 Hz, 2H), 7.36 (d, *J*=1.8 Hz, 1H), 7.55 (d, *J*=1.8 Hz, 1H), 8.02 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.91, 22.47, 26.70, 33.05, 33.52, 63.45, 66.65, 68.90, 69.56, 85.21, 122.89, 126.15, 128.14, 129.83, 135.66, 136.66, 138.12, 138.90, 140.42, 144.57, 197.67; MS (EI): *m*/*z* (%): 466 (100) [M$^+$], 410 (15) [M$^+$ −CH$_2$=CHCH$_2$CH$_3$], 368 (27) [M$^+$ −COCH$_3$–CH$_2$=CHCH$_2$CH$_3$]; EA calcd (%) for $C_{29}H_{30}FeO_2$ (466.39): C, 74.68; H, 6.48; found: C, 74.64; H, 6.41.

4.1.19. Compound 9abga. Yield 55%; oil (*R*$_f$ 0.3, hexane/AcOEt 2:1); IR (neat) 3422, 1684, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.74 (t, *J*=7.5 Hz, 3H), 1.14 (sext, *J*=7.5 Hz, 2H), 1.25–1.42 (m, 2H), 1.59 (br s, 1H), 2.25 (t, *J*=7.8 Hz, 2H), 2.46 (s, 3H), 2.64 (s, 3H), 4.31 (s, 2H), 7.15 (d, *J*=8.1 Hz, 1H), 7.19 (d, *J*=8.1 Hz, 1H), 7.32 (d, *J*=8.4 Hz, 2H), 8.00 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.82, 19.19, 22.44, 26.64, 33.08, 33.45, 60.03, 127.92, 128.59, 129.82, 130.02, 134.93, 135.56, 135.73, 138.21, 140.72, 145.28, 197.64; MS (EI): *m*/*z* (%): 296 (75) [M$^+$], 278 (33) [M$^+$ −H$_2$O], 235 (100) [M$^+$ −H$_2$O–COCH$_3$], 193 (69) [M$^+$ −H$_2$O–COCH$_3$–CH$_2$=CHCH$_3$]; EA calcd (%) for $C_{20}H_{24}O_2$ (296.40): C, 81.04; H, 8.16; found: C, 80.85; H, 8.27.

4.1.20. Compound 9acaa. Yield 49%; oil (*R*$_f$ 0.45, hexane/AcOEt 2:1); IR (neat) 3436, 1684, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.74 (t, *J*=7.5 Hz, 3H), 0.96 (t, *J*=7.5 Hz, 3H), 1.14 (sext, *J*=7.5 Hz, 2H), 1.29 (d, *J*=6.3 Hz, 3H), 1.321.48 (m, 4H), 1.61–1.71 (m, 2H), 1.80 (br s, 1H), 2.24 (t, *J*=7.8 Hz, 2H), 2.65 (s, 3H), 4.52 (q, *J*=6.3 Hz, 3H), 7.03 (d, *J*=1.8 Hz, 1H), 7.23–7.26 (m, 1H), 7.30–7.34 (m, 2H), 8.00 (d, *J*=7.8 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$): *δ* 13.86, 14.08, 22.57, 22.65, 24.95, 26.69, 33.26, 33.59, 33.69, 35.72, 67.00, 122.18, 127.93, 128.01, 128.15, 129.80, 130.35, 135.37, 135.56, 140.14, 142.78, 143.19, 144.94, 197.66; MS (EI): *m*/*z* (%): 352 (100) [M$^+$], 337 (77) [M$^+$ −CH$_3$], 309 (39) [M$^+$ −COCH$_3$], 291 (45) [M$^+$ −H$_2$O–COCH$_3$], 277 (84) [M$^+$ −H$_2$O–(CH$_2$)$_3$CH$_3$]; EA calcd (%) for $C_{24}H_{32}O_2$ (352.51): C, 81.77; H, 9.15; found: C, 81.54; H, 9.22.

4.1.21. Compound 9baaa. Yield 53%; oil (*R*$_f$ 0.1, hexane/AcOEt 3:1); IR (neat) 3431, 1683, 1604 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$): *δ* 0.94 (t, *J*=7.5 Hz, 3H), 1.39 (sext, *J*=7.5 Hz, 2H), 1.59–1.70 (m, 2H), 2.05 (br s, 1H), 2.63 (s, 3H), 2.66 (t, $J=7.8$ Hz, 2H), 3.20 (s, 3H), 4.05 (s, 2H), 4.30 (s, 2H), 7.28 (s, 1H), 7.29–7.33 (m, 3H), 7.99 (d, $J=8.4$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.01, 22.52, 26.63, 33.57, 35.49, 58.15, 62.95, 72.34, 127.05, 127.56, 128.01, 129.74, 135.60, 137.78, 136.15, 138.16, 142.86, 143.46, 197.66; MS (EI): *m*/*z* (%): 326 (30) [M^+], 308 (22) [M^+-H_2O], 293 (41) [$M^+-H_2O–CH_3$], 277 (10) [$M^+-H_2O–OCH_3$], 265 (100) [$M^+-OCH_3–CH_2O$]; EA calcd (%) for $C_{21}H_{26}O_3$ (326.43): C, 77.27; H, 8.03; found: C, 77.07; H, 8.15.

4.1.22. Compound 9caaa. Yield 63%; oil (R_f 0.3, hexane/AcOEt 2:1); IR (neat) 3429, 1682, 1604 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.96 (t, $J=7.5$ Hz, 3H), 1.40 (sext, $J=7.2$ Hz, 2H), 1.60–1.70 (m, 2H), 1.73 (br s, 1H), 1.77–1.86 (m, 2H), 2.47 (t, $J=7.8$ Hz, 2H), 2.64 (s, 3H), 2.64 (t, $J=7.2$ Hz, 2H), 3.35 (t, $J=6.6$ Hz, 2H), 4.29 (s, 2H), 7.07 (d, $J=1.2$ Hz, 1H), 7.24 (d, $J=1.2$ Hz, 1H), 7.30 (d, $J=8.4$ Hz, 2H), 8.01 (d, $J=8.4$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.05, 22.56, 26.69, 30.53, 33.65, 33.80, 35.50, 44.30, 63.35, 125.71, 128.26, 128.49, 129.83, 135.81, 136.55, 138.33 (2 C), 142.88, 144.21, 197.59; MS (EI): *m*/*z* (%): 358 (100) [M^+], 343 (31) [M^+-CH_3], 315 (69) [$M^+-CH_2CH_2CH_3$], 297 (45) [$M^+-H_2O–CH_2CH_2CH_3$]; EA calcd (%) for $C_{22}H_{27}ClO_2$ (358.90): C, 73.62; H, 7.58; found: C, 73.52; H, 7.71.

4.1.23. Compound 10aaa. Yield 22%; oil (R_f 0.4, hexane/AcOEt 3.5:1); IR (neat) 3329, 1604 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.94 (t, $J=7.2$ Hz, 6H), 1.37 (sext, $J=7.2$ Hz, 4H), 1.55–1.65 (m, 4H), 1.72 (br s, 1H), 2.59 (t, $J=7.8$ Hz, 4H), 4.64 (s, 2H), 6.94 (s, 1H), 7.00 (s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.05, 22.54, 33.76, 35.65, 65.52, 124.29, 127.85, 140.54, 143.05; MS (EI): *m*/*z* (%): 220 (69) [M^+], 203 (3) [M^+-OH], 191 (12) [M^+-CHO], 177 (68) [$M^+-CH_2CH_2CH_3$], 160 (100) [$M^+-OH–CH_2CH_2CH_3$]; EA calcd (%) for $C_{15}H_{24}O$ (220.35): C, 81.76; H, 10.98; found: C, 81.90; H, 11.26.

4.1.24. Compound 10aai. Yield 28%; mp 41.9–42.3 °C (R_f 0.3, hexane/AcOEt 3:1); IR (neat) 3320, 1600 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.95 (t, $J=7.2$ Hz, 3H), 1.40 (sext, $J=7.2$ Hz, 2H), 1.60–1.71 (m, 2H), 1.77 (br s, 1H), 2.69 (t, $J=7.5$ Hz, 2H), 4.74 (s, 2H), 7.19 (s, 1H), 7.31–7.47 (s, 5H), 7.58–7.62 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.09, 22.53, 33.77, 35.77, 65.50, 123.11, 125.93, 126.62, 127.08, 127.15, 128.59, 141.01, 141.13, 141.38, 143.69; MS (EI): *m*/*z* (%): 240 (100) [M^+], 197 (35) [$M^+-(CH_2)_2CH_3$], 180 (28) [$M^+-CH_2{=}CHCH_3–H_2O$]; EA calcd (%) for $C_{17}H_{20}O$ (240.34): C, 84.96; H, 8.39; found: C, 84.83; H, 8.53.

4.1.25. Compound 13. Yield 72%; mp 158.1–158.8 °C (R_f 0.2, hexane/AcOEt 3:1); IR (neat) 3409, 1665, 1602 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.37 (br s, 1H), 1.61–1.77 (m, 4H), 2.21 (t, $J=6.0$ Hz, 2H), 2.44 (s, 3H), 2.65 (s, 3H), 2.79 (t, $J=6.0$ Hz, 2H), 4.32 (s, 2H), 7.01 (s, 1H), 7.29 (d, $J=8.4$ Hz, 2H), 8.02 (d, $J=8.4$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 19.08, 22.76, 23.42, 26.72, 28.37, 29.84, 59.99, 128.29, 129.52, 131.07, 132.35, 133.31, 134.49, 135.59, 137.23, 141.20, 145.62, 197.60; MS (EI): *m*/*z* (%): 294 (37) [M^+], 276 (12) [M^+-H_2O], 233 (100) [$M^+-H_2O–COCH_3$]; EA calcd (%) for $C_{20}H_{22}O_2$ (294.39): C, 81.60; H, 7.53; found: C, 81.65; H, 7.52.

4.1.26. Compound 16. Yield 60%; oil (R_f 0.35, hexane/AcOEt 2:1); IR (neat) 3417, 1678, 1604 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.75 (t, $J=7.5$ Hz, 3H), 1.15 (sext, $J=7.5$ Hz, 2H), 1.24–1.43 (m, 2H), 1.70 (br s, 1H), 1.77–1.91 (m, 4H), 2.24 (t, $J=7.8$ Hz, 2H), 2.65 (s, 3H), 2.83 (t, $J=5.7$ Hz, 2H), 2.93 (t, $J=5.7$ Hz, 2H), 4.30 (s, 2H), 7.01 (s, 1H), 7.33 (d, $J=8.4$ Hz, 2H), 8.01 (d, $J=8.4$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.80, 22.49, 22.78, 23.38, 25.87, 26.60, 30.02, 32.99, 33.49, 59.50, 127.87, 129.67, 129.97, 133.86, 135.37, 135.47, 137.15, 137.49, 138.42, 145.46, 197.65; MS (EI): *m*/*z* (%): 336 (49) [M^+], 318 (89) [M^+-H_2O], 275 (100) [$M^+-H_2O–COCH_3$]; EA calcd (%) for $C_{23}H_{28}O_2$ (336.47): C, 82.10; H, 8.39; found: C, 81.73; H 8.76.

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