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$FeCl_3$-Catalyzed Intramolecular Michael Reaction of Styrenes for the Synthesis of Highly Substituted Indenes

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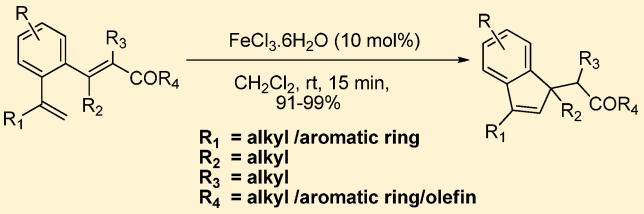
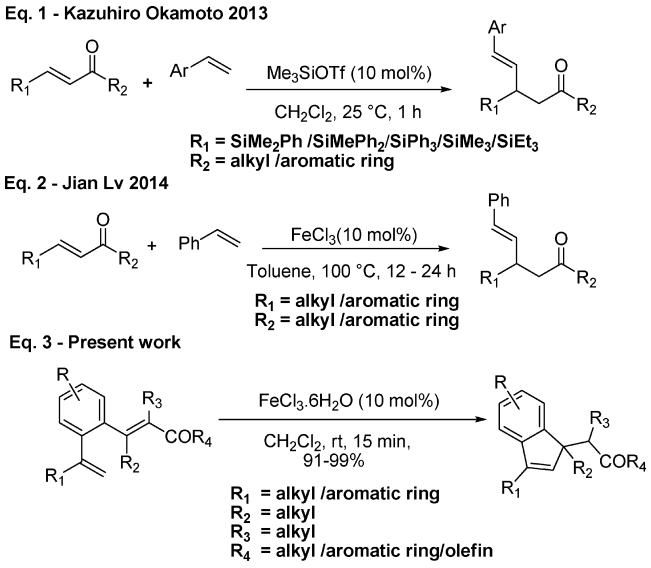
Supporting Information

ABSTRACT: An intramolecular $FeCl_3$-catalyzed Michael addition reaction of styrene, a poor nucleophile, onto α,β-unsaturated ketones was developed for the synthesis of highly substituted indene derivatives. The method was further applied to the total synthesis of the sesquiterpene natural products (±)-jungianol and 1-*epi*-jungianol.



The Michael addition reaction is a fundamental carbon−carbon bond forming reaction.[1] Over the decades many variants of this reaction have been developed. Intermolecular olefin-Michael addition reactions have been reported by various groups. In 1980 Snider and co-workers reported that a stoichiometric amount of a Lewis acid catalyzed the addition of alkenes to α,β-enones.[2a] Okamoto and Ohe described an acid-catalyzed addition of simple alkenes to β-silyl-substituted enones (Scheme-1, eq 1).[2b] Recently, Luo et al. reported an anionic ligand strategy to facilitate β-proton elimination by suppressing cationic olefin polymerization, thus enabling the β-vinylation of enones with a variety of simple alkenes (Scheme-1, eq 2).[2c] Although intermolecular Michael reactions have been well studied, the analogous intramolecular Michael reactions of olefins (alkene/styrene double bond) have rarely been explored due to the low nucleophilicity of olefin carbons and uncontrolled side reactions, as well as polymerization reactions in the case of styrene derivatives. A variety of naturally occurring molecules contain indene/indane as a basic unit (Figure 1).[3] Indene derivatives have various applications in pharmaceuticals[4] and materials chemistry[5] and have also been used as ligands for transition-metal complexes.[6] Due to the various applications of indene derivatives in diverse areas, it is a continuing subject of extensive study in organic synthesis and many methods for their synthesis have been reported.[7] With our ongoing interest in the development of novel methods for the synthesis of indene derivatives and their application in natural product synthesis by C−C bond forming reactions,[8a,b] earlier we tried to construct the indene motif by an intramolecular Michael reaction of the styrene double bond onto an α,β-unsaturated ester; surprisingly, the reaction went in

Scheme 1. Olefin-Michael Addition Reaction



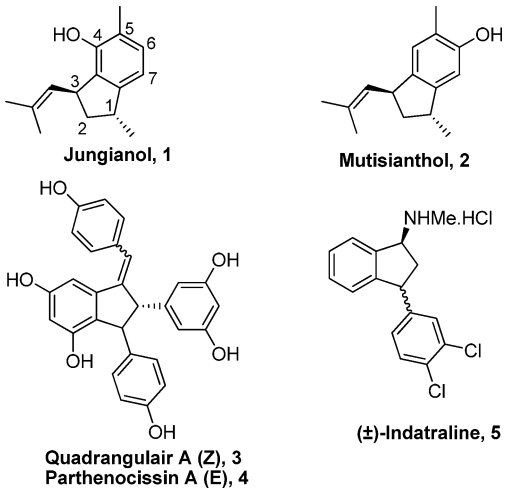


Figure 1. Indane-based natural products.

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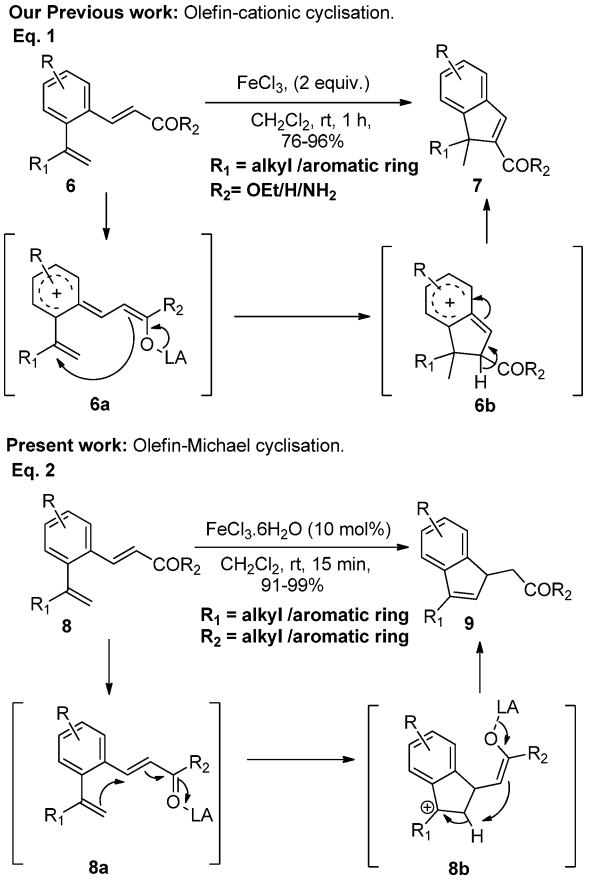
the reverse direction from what we had planned and generated indene derivatives by intramolecular olefin cation cyclization of cinnamates (Scheme 2).[8a]

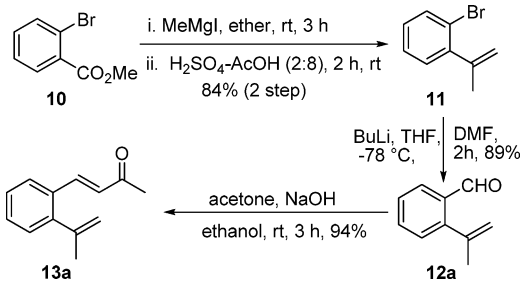
Scheme 2. Intramolecular Olefin-Cationic Cyclization and Intramolecular Olefin-Michael Cyclization



According to the proposed mechanism for this reaction, Lewis acid activates the ester group of cinnamate to generate intermediate **6a**, which undergoes intramolecular cyclization with olefin to form intermediate **6b**, which on subsequent rearomatization furnishes indene derivative **7** (Scheme 2, eq 1). After reporting the $FeCl_3$-mediated intramolecular olefin-cation cyclization of cinnamates, we were interested in extending this method to unsaturated ketones to see that whether the reaction would follow the same path and generate a similar type of indene motif.

To begin with, the desired α,β-unsaturated ketone **13a** was prepared from commercially available ethyl *o*-bromobenzoate (**10**) (Scheme 3). Treatment of **10** with MeMgI followed by dehydration under acidic conditions generated the styrene derivative **11**.[9a] Compound **11** on treatment with *n*-BuLi followed by quenching with DMF generated the aldehyde **12a**.[9b] An aldol reaction of aldehyde **12a** with acetone in the presence of NaOH in ethanol afforded the required ketone **13a** in 94% yield. After the ketone **13a** was in hand, it was treated with 2 equiv of $FeCl_3$ in CH_2Cl_2 as a solvent at room temperature, the best conditions found for the olefin-cation cyclization of cinnamates,[8a] but to our disappointment, this resulted in a complex reaction mixture and we could not isolate any compound from the mixture (Table 1, entry 1). The same result was obtained when **13a** was treated with 1 equiv of $FeCl_3$

Scheme 3. Synthesis of α,β-Unsaturated Ketone 13a



in CH_2Cl_2 as a solvent at room temperature (Table 1, entry 2). Due to decomposition of starting material with stoichiometric amount of $FeCl_3$, it was decided to decrease the catalyst loading and, surprisingly, we observed that when **13a** was treated with 50 mol % of $FeCl_3$ it generated olefin-Michael addition product **14a** in low yield (13%), instead of olefin-cation cyclization product as in the case of cinnamates. The yield of **14a** was improved to 53% when the catalyst loading was decreased to 10 mol %; a further decrease in catalyst loading also decreased the yield of the product **14a** (entries 3−6, Table 1). We then screened different Lewis acids for this transformation, as shown in Table 1. Different acid catalysts such as *p*-TSA, $Sc(OTf)_3$, AgOTf, $Cu(OTf)_2$, $AlCl_3$, $TiCl_3$, $TiCl_4$, and $ZnCl_2$ failed to generate any product and starting material **13a** was recovered. $SnCl_4$ generated the required cyclized compound **14a** in 50% yield. $Sn(OTf)_2$, $InCl_3$, $BiCl_3$, and $Fe(OTf)_3$ afforded **14a** with improved yield in comparison to $FeCl_3$ and $SnCl_4$ (entries 9, 18, 21, and 22, Table 1). $Cu(OTf)_2$ in DCE at 80 °C afforded the Michael addition product in poor yield (32%) (entry 25, Table 1). To our delight, ketone **13a** on treatment with a catalytic amount of $FeCl_3{\cdot}6H_2O$ in CH_2Cl_2 as a solvent at room temperature for 15 min generated indene derivative **14a** in almost quantitative yield (entry 12, Table 1). It is worth mentioning that to effect this transformation only a catalytic amount (10 mol %) of $FeCl_3{\cdot}6H_2O$ was required, unlike the case of cinnamate derivatives **6**, which required 2 equiv of $FeCl_3$ for the olefin-cationic cyclization reaction (Scheme 2, eq 1). The reaction was also found to be highly dependent on the solvent used; coordinative polar solvents such as THF, CH_3CN, and MeOH either generated a low yield or proved ineffective in promoting the cyclization reaction (entries 13−15, Table 1). A plausible reaction mechanism is depicted in Scheme 2 (eq 2). The Lewis acid activates the enone of compound **8**, which on a Michael reaction with the styrene double bond generates intermediate **8b**; subsequent deprotonation furnishes the indene derivative. After the reaction conditions were established, in order to expand the scope of the reaction, several chalcone derivatives **13b−g** were subjected to these standard reaction conditions, and all were converted smoothly into indene derivatives **14b−g** with excellent yields (Scheme 4). However, in case of α,β-unsaturated aldehyde **13h**, indene derivative **14h** was obtained in only 40% yield.

We prepared ketones **13i−n** and dienones **13s−u** having an aromatic ring or an electron-donating group on the aromatic ring; all of these compounds smoothly furnished cyclized products **14i−n** and **14s−u**, respectively, in very good yields (Schemes 4 and 5). Compounds **13o,p** containing ethyl and phenyl at the α-position of styrene converted into **14o,p** in 96% and 97% yields, respectively. Interestingly, **13q**, having an α substituent on the enone, converted into **14q** in 96% yield and **13r** ,having a β substituent on the enone, furnished compound

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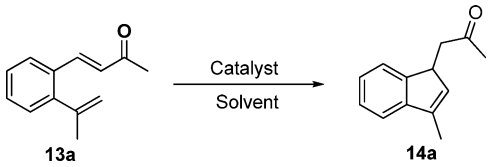
Table 1. Optimization of Olefin-Michael Cyclization Reaction



13a 14a

entry	catalyst	amt of catalyst, equiv	solvent	temp	time	yield, %[a]
1	$FeCl_3$	2	CH_2Cl_2	room temp	5 min	CRM
2	$FeCl_3$	1	CH_2Cl_2	room temp	5 min	CRM
3	$FeCl_3$	0.5	CH_2Cl_2	room temp	5 min	13
4	$FeCl_3$	0.25	CH_2Cl_2	room temp	5 min	29
5	$FeCl_3$	0.1	CH_2Cl_2	room temp	5 min	53
6	$FeCl_3$	0.05	CH_2Cl_2	room temp	5 min	45
7	$Sc(OTf)_3$	0.1	CH_2Cl_2	room temp	12 h	NR
8	$BF_3{\cdot}OEt_2$	0.1	CH_2Cl_2	room temp	15 min	68
9	$Sn(OTf)_2$	0.1	CH_2Cl_2	room temp	35 min	90
10	$SnCl_4$	0.1	CH_2Cl_2	room temp	40 min	50
11	$ZnCl_2$	0.5	CH_2Cl_2	room temp	24 h	NR
12	$FeCl_3{\cdot}6H_2O$	0.1	CH_2Cl_2	room temp	15 min	99
13	$FeCl_3{\cdot}6H_2O$	0.1	THF	room temp	12 h	NR
14	$FeCl_3{\cdot}6H_2O$	0.1	CH_3CN	room temp	12 h	70
15	$FeCl_3{\cdot}6H_2O$	0.1	MeOH	room temp	12 h	NR
16	AgOTf	0.1	CH_2Cl_2	room temp	5 h	NR
17	$TiCl_4$	0.1	CH_2Cl_2	room temp	5 h	NR
18	$InCl_3$	0.1	CH_2Cl_2	room temp	1 h	79
19	$TiCl_3$	0.1	CH_2Cl_2	room temp	5 h	NR
20	PTSA	0.5	CH_2Cl_2	room temp	12 h	NR
21	$BiCl_3$	0.1	CH_2Cl_2	room temp	3 h	70
22	$Fe(OTf)_3$	0.2	CH_2Cl_2	room temp	30 min	70
23	$Cu(OTf)_2$	0.1	CH_2Cl_2	room temp	24 h	NR
24	$AlCl_3$	0.2	CH_2Cl_2	room temp	12 h	NR
25	$Cu(OTf)_2$	0.5	DCE	80 °C	12 h	32

[a]Abbreviations: CRM, complex reaction mixture; NR, no reaction.

14r in 93% yield in a 3/4 diastereomeric mixture (Scheme 4). Next we applied this method to the total synthesis of sesquiterpene jungianol **1**, which was isolated by Bolhmann et al. in 1977 from a South American plant, *Jungia malvaefolia*. Jungianol is a sesquiterpene natural product containing a tetrasubstituted indene framework, having methyl and isobutene side chains at the 1- and 3-positions of the indane five-membered ring, respectively.[3a] The initial stereochemical assignments of side chains by isolation group was later revised unambiguously by Hashmi et al. by the first total synthesis of jungianol **1** and its epimer **17**.[10] Prior to their synthesis, Ho et al. in 1997[4e] reported the total synthesis and revision of another isomeric natural product, mutisianthol **2**, that differs only in the position of the phenolic hydroxyl group from jungianol **1**. Although the biological activity of jungianol **1** is not known, its isomer mutisianthol **2** exhibits moderate antitumor activity.[4k] Our group also reported the total synthesis of (±)-jungianol **1** and mutisianthol **2** using Prins-type and Nazarov cyclizations, respectively.[8c,b]

The retrosynthetic analysis of **1** is shown in Scheme 6. (±)-Jungianol **1** could be obtained from indene derivative **15** by regio- and stereoselective hydrogenation of an endocyclic double bond followed by deprotection of the phenolic hydroxyl group. Indene derivative **15** could be synthesized from the previously prepared Michael product **14d** (Scheme 4) through a Grignard reaction followed by elimination of tertiary alcohol. Accordingly, indene derivative **14d** on reaction with MeMgI, followed by elimination of the resulting tertiary alcohol, furnished a mixture of isomers **15** and **16** in 78% yield. The inseparable mixture of isomers **15** and **16** on treatment with a catalytic amount of *p*-TSA in CH_2Cl_2 at room temperature completely converted into olefin **15** by isomerization of the geminally disubstituted olefin to the more stable trisubstituted double bond. After having the required olefin **15** in hand, we subjected it to the selective hydrogenation of the benzylic endocyclic double bond using Li/liquid NH_3 at −78 °C in THF; deprotection of the resultant methyl ether furnished a mixture of jungianol **1** and its epimer **17**, which were carefully separated by silica gel column chromatography (Scheme 7). The spectral data of jungianol **1** and *epi*-jungianol **17** (IR, ^1H and ^{13}C NMR, and HRMS) were in complete agreement with those reported in the literature.[3a,10]

In conclusion, after varying the Michael acceptor from unsaturated ester/amide/acid to unsaturated ketone/aldehyde at the ortho position of styrene, an exclusive intramolecular olefin-Michael cyclization reaction occurred instead of intramolecular olefin-cationic cyclization. Various substituted indene derivatives were prepared from ortho-substituted unsaturated keto styrenes using $FeCl_3{\cdot}6H_2O$-catalyzed intramolecular olefin-Michael reaction. Further, this reaction was utilized for the total synthesis of jungianol **1** (30% overall yield) and 1-*epi*-jungianol **17** (30% overall yield).

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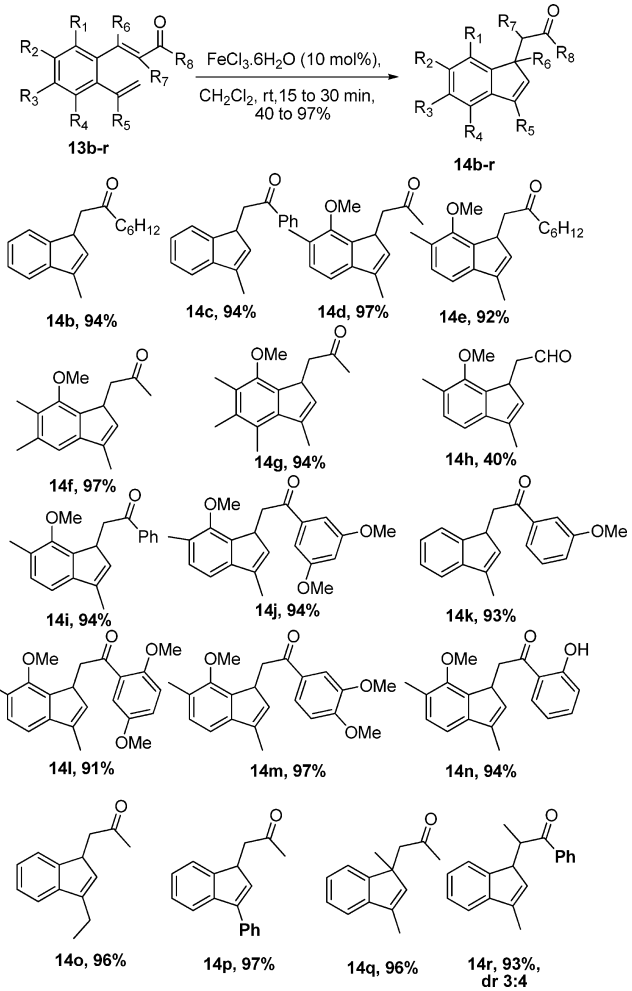
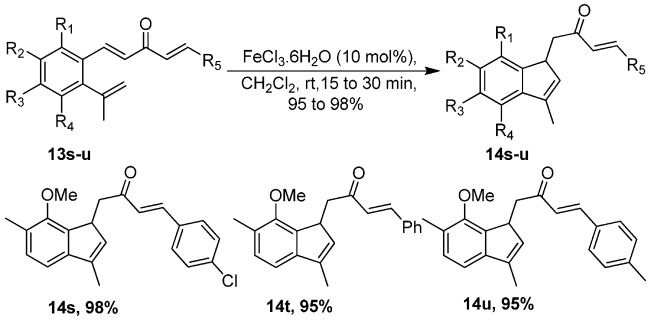
Scheme 4. Olefin-Michael Cyclization for Synthesis of Indene Derivative[a]



[a]Diastereoselectivities were determined from ^{1}H NMR of the crude reaction mixture.

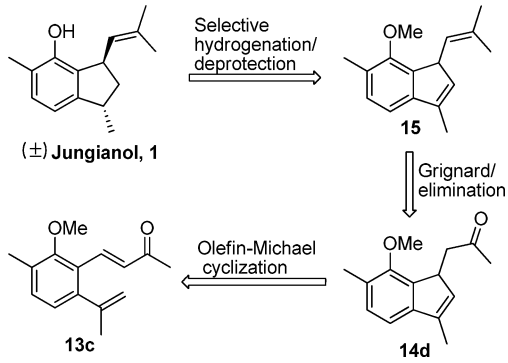
Scheme 5. Olefin-Michael Cyclization for Synthesis of Indene Derivatives from Keto-Dienone



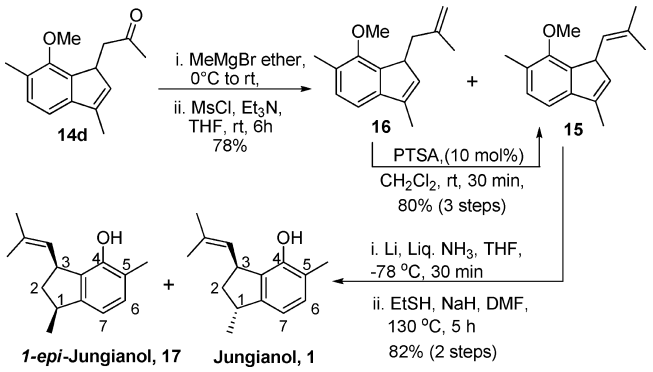
EXPERIMENTAL SECTION

General Aspects. All reactions were carried out under a nitrogen atmosphere with dry solvents under anhydrous conditions, unless otherwise mentioned. All chemicals were purchased commercially and used without further purification. Anhydrous THF and diethyl ether were distilled from sodium benzophenone, and dichloromethane was distilled from calcium hydride. Yields refer to chromatographically pure compounds, unless otherwise stated. Reactions were monitored by thin-layer chromatography (TLC) carried out on 0.25 mm silica gel plates (60F-254) using UV light as a visualizing agent and a *p*-anisaldehyde or ninhydrine stain and heat as developing agents. Silica gel (particle size 100−200 and 230−400 mesh) was used for flash column chromatography. Neat coumpounds were used for recording IR spectra. NMR spectra were recorded on either 400 (^{1}H, 400 MHz; ^{13}C, 100 MHz) or 500 MHz instruments (^{1}H, 500 MHz; ^{13}C, 125 MHz). Mass spectrometric data were obtained using Q-Tof-ESI. The following abbreviations are used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, ddd = doublet of doublets of doublets, dt = doublet of triplets, td = triplet of doublets, m = multiplet, br = broad.

Scheme 6. Retrosynthetic Analysis of (±)-Jungianol (1)



Scheme 7. Total Synthesis of (±)-Jungianol (1) and 1-*epi*-Jungianol (17)



General Procedure A for the Aldol Reaction. A mixture of the corresponding aldehyde (1 equiv) and the corresponding ketone (1 equiv) in anhydrous ethanol was stirred at room temperature for 5 min. Then NaOH (3 equiv) was added. The reaction mixture was stirred at room temperature until the aldehyde was consumed (usually up to 3 h). After that, HCl (10%) was added until pH 5 was obtained. Extraction was carried out with ethyl acetate (3 × 7 mL). The organic layer was washed with brine and dried over Na_2SO_4. Evaporation of the solvent and purification of the residue bysilica gel column chromatography using EtOAc/hexane as eluent furnished the unsaturated ketone.

*(E)-4-(2-(Prop-1-en-2-yl)phenyl)but-3-en-2-one (**13a**).* According to the general procedure A for the aldol reaction, 2-(prop-1-en-2-yl)benzaldehyde (**12a**; 1 g, 6.84 mmol), acetone (**18a**; 0.5 mL, 6.84 mmol), and NaOH (820 mg, 20 mmol) in ethanol (7 mL) were used to furnish the product **13a** (1.2 g, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2924, 2852, 1692, 1672, 1608, 1595, 1463, 1358, 1313, 1254, 1176, 981; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (d, J = 0.91 Hz, 3H), 2.36 (s, 3H), 4.88 (s, 1H), 5.36 (s, 1H), 6.65 (d, J = 16.3 Hz, 1H), 7.26−7.33 (m, 2H), 7.33−7.43 (m, 1H), 7.63 (d, J = 7.7 Hz, 1H), 7.78 (d, J = 16.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.9, 27.3, 117.6, 126.6, 127.4, 127.9, 128.3, 130.0, 131.7, 142.6, 143.7, 145.1, 198.6; HRMS m/z calcd for $C_{13}H_{15}O$ [(M + H)$^+$] 187.1123, found 187.1125.

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*(E)-1-(2-(Prop-1-en-2-yl)phenyl)non-1-en-3-one (**13b**).* According to the general procedure A for the aldol reaction, 2-(prop-1-en-2-yl)benzaldehyde (**12a**; 45 mg, 0.31 mmol), octan-2-one (**18b**; 37 mg, 0.31 mmol), and NaOH (35 mg, 0.92 mmol) in ethanol (2 mL) were used to furnish the product **13b** (66 mg, 86%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 3/97); IR (neat) ν_{max}/cm^{-1} 2956, 2929, 1691, 1667, 1609, 1595, 1480, 1452, 1303, 1174, 1074; ^1H NMR (400 MHz, $CDCl_3$) δ 0.89 (d, J = 14.0 Hz, 3H), 1.32 (m, 6H), 1.63−1.72 (m, 2H), 2.09 (s, 3H), 2.64 (t, J = 7.5 Hz, 2H), 4.86 (s, 1H), 5.35 (s, 1H), 6.64 (s, 1H), 7.26−7.39 (m, 3H), 7.62 (d, J = 8.2 Hz, 1H), 7.80 (d, J = 15.9 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0, 22.5, 24.5, 24.9, 29.0, 31.6, 40.6, 117.6, 126.5, 127.0, 127.3, 128.3, 129.8, 131.9, 141.5, 143.7, 145.1, 201.0; HRMS m/z calcd for $C_{18}H_{25}O$ $[(M + H)^+]$ 257.1905, found 257.1904.

*(E)-1-Phenyl-3-(2-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13c**).* According to the general procedure A for the aldol reaction, 2-(prop-1-en-2-yl)benzaldehyde (**12a**; 50 mg, 0.34 mmol), acetophenone (**18c**; 41 mg, 0.34 mmol), and NaOH (41 mg, 1.03 mmol) in ethanol (2 mL) were used to furnish the product **13c** (70 mg, 82%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 3/97); IR (neat) ν_{max}/cm^{-1} 3060, 1662, 1603, 1592, 1479, 1447, 1314, 1212, 1016; ^1H NMR (500 MHz, $CDCl_3$) δ 2.10 (s, 3H), 4.90 (s, 1H), 5.35 (d, J = 1.7 Hz, 1 H), 7.27−7.41 (m, 3H), 7.46−7.53 (m, 3H), 7.55−7.62 (m, 1H), 7.75 (d, J = 7.7 Hz, 1H), 7.96−8.04 (m, 2H), 8.06 (d, J = 15.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 24.9, 117.7, 122.7, 126.8, 127.3, 128.4, 128.5, 128.6, 130.0, 132.3, 132.7, 138.2, 143.7, 143.9, 143.9, 145.5, 190.6; HRMS m/z calcd for $C_{18}H_{17}O$ $[(M + H)^+]$ 249.1279, found 249.1272.

*(E)-4-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)but-3-en-2-one (**13d**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 1 g, 5.26 mmol), acetone (**18a**; 0.385 mL, 5.26 mmol), and NaOH (630 mg, 15.77 mmol) in ethanol (7 mL) were used to furnish the product **13d** (1.12 g, 93%) as a yellow oil: R_f = 0.23 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2927, 1670, 1456, 1327, 1251, 1093, 1014; ^1H NMR (400 MHz, $CDCl_3$) δ 2.01 (s, 3H), 2.30 (s, 3H), 2.35 (s, 3H), 3.67 (s, 3H), 4.89 (s, 1H), 5.23−5.26 (m, 1H), 6.90 (d, J = 7.8 Hz, 1H), 7.01 (d, J = 16.5 Hz, 1H), 7.14 (d, J = 7.8 Hz, 1H), 7.68 (d, J = 16.9 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.6, 27.4, 59.9, 116.8, 124.4, 125.0, 130.5, 131.2, 132.2, 139.0, 144.6, 144.8, 157.8, 199.4; HRMS m/z calcd for $C_{15}H_{19}O_2$ $[(M + H)^+]$ 231.1385, found 231.1380.

*(E)-1-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)non-1-en-3-one (**13e**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 45 mg, 0.23 mmol), octan-2-one (**18b**; 28 mg, 0.23 mmol), and NaOH (28 mg, 0.71 mmol) in ethanol (5 mL) were used to furnish the product **13e** (52 mg, 89%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2929, 1690, 1664, 1607, 1591, 1475, 1302, 1218, 1022; ^1H NMR (400 MHz, $CDCl_3$) δ 0.86−0.93 (m, 3H), 1.28−1.38 (m, 6H), 1.62−1.68 (m, 2H), 1.98−2.03 (m, 3H), 2.30 (s, 3H), 2.57−2.64 (m, 2H), 3.67 (s, 3H), 4.89 (dd, J = 1.8, 1.0 Hz, 1H), 5.24 (t, J = 1.8 Hz, 1H), 6.89 (d, J = 7.8 Hz, 1H), 7.04 (d, J = 16.5 Hz, 1H), 7.13 (d, J = 7.8 Hz, 1H), 7.70 (d, J = 16.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0, 15.9, 22.5, 24.5, 24.6, 29.0, 31.6, 41.1, 59.9, 116.8, 124.4, 125.3, 130.3, 130.4, 132.0, 137.8, 144.6, 144.8, 157.8, 201.7; HRMS m/z calcd for $C_{20}H_{29}O_2$ $[(M + H)^+]$ 301.2168, found 301.2162.

*(E)-4-(2-Methoxy-3,4-dimethyl-6-(prop-1-en-2-yl)phenyl)but-3-en-2-one (**13f**).* According to the general procedure A for the aldol reaction, 2-methoxy-3,4-dimethyl-6-(prop-1-en-2-yl)benzaldehyde (**12c**; 100 mg, 0.49 mmol), acetone (**18a**; 0.036 mL, 0.49 mmol), and NaOH (59 mg, 1.47 mmol) in ethanol (3 mL) were used to furnish the product **13f** (112 mg, 94%) as a yellow oil: R_f = 0.2 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2927, 1667, 1591, 1446, 1357, 1314, 1251, 1093, 1014; ^1H NMR (400 MHz, $CDCl_3$) δ 1.93−2.06 (m, 3H), 2.21 (s, 3H), 2.27 (s, 3H), 2.35 (s, 3H), 3.65 (s, 3H), 4.85−4.92 (m, 1H), 5.15−5.32 (m, 1H), 6.82 (s, 1H), 7.00 (d, J = 16.7 Hz, 1H), 7.68 (d, J = 16.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.1, 20.3, 24.7, 27.4, 60.2, 116.6, 122.4, 126.0, 129.3, 130.4, 139.3, 140.4, 143.9, 145.0, 157.8, 199.6; HRMS m/z calcd for $C_{16}H_{20}NaO_2$ $[(M + Na)^+]$ 267.1361, found 267.1369.

*(E)-4-(2-Methoxy-3,4,5-trimethyl-6-(prop-1-en-2-yl)phenyl)but-3-en-2-one (**13g**).* According to the general procedure A for the aldol reaction, 2-methoxy-3,4,5-trimethyl-6-(prop-1-en-2-yl)benzaldehyde (**12d**; 90 mg, 0.41 mmol), acetone (**18a**; 0.03 mL, 0.26 mmol), and NaOH (102 mg, 0.26 mmol) in ethanol (3 mL) were used to furnish the product **13g** (96 mg, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2926, 1665, 1600, 1572, 1453, 1358, 1250, 1102; ^1H NMR (500 MHz, $CDCl_3$) δ 1.94 (s, 3H), 2.18 (s, 3H), 2.23 (s, 3H), 2.25 (s, 3H), 2.32−2.34 (m, 3H), 3.61−3.64 (m, 3H), 4.81 (s, 1H), 5.38 (d, J = 1.1 Hz, 1H), 7.08 (d, J = 16.6 Hz, 1H), 7.67 (d, J = 16.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.7, 16.8, 16.9, 25.0, 27.4, 59.9, 116.9, 121.9, 128.9, 129.3, 130.4, 139.6, 140.0, 143.6, 144.4, 155.9, 199.9; HRMS m/z calcd for $C_{17}H_{23}O_2$ $[(M + H)^+]$ 259.1698, found 259.1690.

*(E)-3-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)-acrylaldehyde (**13h**). Step 1.* Benzyl chloride (0.72 mL, 6.3 mmol) was added to a stirred solution of LAH_4 (48 mg, 1.26 mmol) in dry THF (4 mL) at 0 °C, and the reaction mixture was stirred for 30 min at same temperature; then (*E*)-ethyl 3-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)acrylate (**19**; 110 mg, 0.42 mmol) in THF (1 mL) was added to this reaction mixture and the resultant mixture was stirred for 3 h. The reaction mixture was extracted with ethyl acetate, and the combined organic layers were washed with brine and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure. Evaporation of the solvent furnished the alcohol, which was used in the oxidation reaction without further purification.

Step 2. To a solution of the crude alcohol obtained in above reaction in ethyl acetate (4 mL) was added IBX (208 mg, 0.84 mmol) and refluxed for 3 h. Aqueous $NaHCO_3$ was added to the reaction mixture, and this mixture was extracted with ethyl acetate (3 × 15 mL). The organic extract was washed with brine and dried over Na_2SO_4. Evaporation of the solvent and purification of the residue by silica gel column chromatography using EtOAc/hexane as eluent furnished aldehyde **13h** (70 mg, 77%) as a yellow oil: R_f = 0.40 (EtOAc/hexane 15/85); IR (neat) ν_{max}/cm^{-1} 2934, 1681, 1616, 1593, 1477, 1303, 1216, 1121, 1017; ^1H NMR (400 MHz, $CDCl_3$) δ 2.02 (s, 3H), 2.31 (s, 3H), 3.68 (s, 3H), 4.91 (s, 1H), 5.27 (s, 1H), 6.92 (d, J = 7.8 Hz, 1H), 7.04 (dd, J = 16.3, 8.0 Hz, 1H), 7.19 (d, J = 7.8 Hz, 1H), 7.66 (d, J = 16.0 Hz, 1H), 9.66 (d, J = 7.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.7, 59.9, 117.1, 124.5, 130.6, 132.7, 133.3, 144.5, 144.8, 148.7, 158.0, 195.5; HRMS m/z calcd for $C_{14}H_{17}O_2$ $[(M + H)^+]$ 217.1229, found 217.1223.

*(E)-3-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)-1-phenyl-prop-2-en-1-one (**13i**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 63 mg, 0.33 mmol), acetophenone (**18c**; 40 mg, 0.33 mmol), and NaOH (40 mg, 1.00 mmol) in ethanol (3 mL) were used to furnish the product **13i** (78 mg, 81%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 15/85); IR (neat) ν_{max}/cm^{-1} 2923, 1612, 1491, 1448, 1254, 1216, 1180, 1156; ^1H NMR (400 MHz, $CDCl_3$) δ ^1H NMR (400 MHz, $CDCl_3$) δ 2.05 (s, 3H), 2.33 (s, 3H), 3.72 (s, 3H), 4.94 (s, 1H), 5.29 (s, 1H), 6.93 (d, J = 7.8 Hz, 1H), 7.17 (d, J = 7.8 Hz, 1H), 7.50 (t, J = 7.3 Hz, 2H), 7.58 (t, J = 7.3 Hz, 1H), 7.96 (d, J = 1.8 Hz, 2H), 8.01−8.09 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.8, 60.0, 116.9, 124.4, 125.9, 126.0, 128.5, 128.6, 145.0, 130.5, 132.2, 132.7, 138.3, 140.0, 145.0, 145.0, 158.0, 190.9; HRMS m/z calcd for $C_{20}H_{21}O_2$ $[(M + H)^+]$ 293.1542, found 293.1543.

*(E)-1-(3,5-Dimethoxyphenyl)-3-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13j**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 70 mg, 0.37 mmol), 1-(3,5-dimethoxyphenyl)ethanone (**18d**; 66 mg, 0.37 mmol), and NaOH (44 mg, 1.10 mmol) in ethanol (3 mL) were used to furnish the product **13j** (99 mg, 76%) as a yellow oil: R_f = 0.40 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2937, 1663, 1589, 1425, 1456, 1351, 1310, 1205, 1156, 1042; ^1H NMR (500 MHz, $CDCl_3$) δ 2.04 (s, 3H), 2.32 (s, 3H), 3.71 (s, 3H), 3.86 (s, 6H), 4.86−5.02 (m, 1H), 5.19−5.36 (m, 1H), 6.62−6.70 (m, 1H), 6.92 (d, J = 7.7 Hz, 1H), 7.11−7.21

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(m, 3H), 7.86 (d, J = 15.7 Hz, 1H), 7.96 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.7, 55.5, 60.0, 105.1, 106.1, 106.3, 116.8, 124.5, 125.7, 126.1, 130.5, 132.2, 140.1, 140.3, 144.9, 145.1, 158.0, 160.8, 190.5; HRMS m/z calcd for $C_{22}H_{24}NaO_4$ [(M + Na)$^+$] 375.1572, found 375.1570.

*(E)-1-(3-Methoxyphenyl)-3-(2-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13k**).* According to the general procedure A for the aldol reaction, 2-(prop-1-en-2-yl)benzaldehyde (**12a**; 40 mg, 0.27 mmol), 1-(3-methoxyphenyl) ethanone (**18e**; 41 mg, 0.27 mmol), and NaOH (32 mg, 0.82 mmol) in ethanol (2 mL) were used to furnish the product **13k** (55 mg, 81%) as a yellow oil: R_f = 0.23 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2937, 1661, 1588, 1450, 1429, 1318, 1267, 1195, 1027; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.10 (s, 3H), 3.89 (s, 3H), 4.89−4.91 (m, 1H), 5.35−5.37 (m, 1H), 7.11−7.15 (m, 1H), 7.28−7.43 (m, 4H), 7.46 (d, J = 15.5 Hz, 1H), 7.55 (s, 1H), 7.59−7.62 (m, 1H), 7.74 (d, J = 7.7 Hz, 1H), 8.06 (d, J = 15.7 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 24.9, 55.5, 112.8, 117.7, 119.2, 121.0, 122.8, 126.8, 127.3, 128.4, 130.0, 132.3, 139.6, 143.7, 144.0, 145.5, 159.9, 190.3; HRMS m/z calcd for $C_{19}H_{19}O_2$ [(M + H)$^+$] 279.1385, found 279.1388.

*(E)-1-(2,5-Dimethoxyphenyl)-3-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13l**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 80 mg, 0.42 mmol), 1-(2,5-dimethoxyphenyl)ethanone (**18f**; 76 mg, 0.42 mmol), and NaOH (50 mg, 1.26 mmol) in ethanol (3 mL) were used to furnish the product **13l** (114 mg, 77%) as a yellow oil: R_f = 0.40 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2937, 1654, 1581, 1493, 1463, 1412, 1301, 1276, 1222, 1042, 1022; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.02 (s, 3H), 2.30 (s, 3H), 3.70 (s, 3H), 3.80 (s, 3H), 3.84 (s, 3H), 4.91 (d, J = 0.9 Hz, 1H), 5.22 (d, J = 1.7 Hz, 1H), 6.87−6.93 (m, 2H), 7.01 (dd, J = 8.9, 3.1 Hz, 1H), 7.14 (d, J = 7.4 Hz, 1H), 7.19 (d, J = 3.1 Hz, 1H), 7.70 (d, J = 16.3 Hz, 1H), 7.81 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.6, 55.8, 56.3, 60.0, 113.1, 114.3, 116.6, 118.9, 124.4, 125.8, 129.8, 130.4, 130.7, 132.0, 138.9, 144.9, 145.1, 152.5, 153.5, 158.0, 193.3; HRMS m/z calcd for $C_{22}H_{24}NaO_4$ [(M + Na)$^+$] 375.1572, found 375.1573.

*(E)-1-(3,4-Dimethoxyphenyl)-3-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13m**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)benzaldehyde (**12b**; 56 mg, 0.29 mmol), 1-(3,4-dimethoxyphenyl)ethanone (**18g**; 53 mg, 0.29 mmol), and NaOH (35 mg, 0.88 mmol) in ethanol (3 mL) were used to furnish the product **13m** (79 mg, 76%) as a yellow oil: R_f = 0.20 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2935, 1655, 1594, 1580, 1514, 1463, 1417, 1304, 1265, 1162, 1023; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.05 (s, 3H), 2.33 (s, 3H), 3.71 (s, 3H), 3.97 (s, 6H), 4.95 (s, 1H), 5.28 (s, 1H), 6.92−6.94 (m, 2H), 7.15 (d, J = 7.7 Hz, 1H), 7.63−7.71 (m, 2H), 7.94 (s, 2H);^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.7, 55.9, 56.0, 60.0, 110.0, 110.7, 116.7, 123.0, 124.5, 125.7, 125.8, 130.4, 131.4, 132.0, 139.1, 144.8, 145.2, 149.1, 153.1, 157.9, 189.1; HRMS m/z calcd for $C_{22}H_{24}NaO_4$ [(M + Na)$^+$] 375.1572, found 375.1571.

*(E)-1-(2-Hydroxyphenyl)-3-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13n**).* According to the general procedure A for the aldol reaction, 2-methoxy-3-methyl-6-(prop-1-en-2-yl)-benzaldehyde (**12b**; 100 mg, 0.53 mmol), 1-(2-hydroxyphenyl)-ethanone (**18h**; 72 mg, 0.53 mmol), and NaOH (63 mg, 1.58 mmol) in ethanol (3 mL) were used to furnish the product **13n** (130 mg, 80%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 3391, 2935, 1636, 1579, 1486, 1443, 1395, 1360, 1271, 1252, 1218, 1156, 1021; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.06 (s, 3H), 2.34 (s, 3H), 3.73 (s, 3H), 4.95 (s, 1H), 5.33 (s, 1H), 6.91−6.96 (m, 2H), 7.03 (dd, J = 8.4, 1.1 Hz, 1H), 7.19 (d, J = 7.8 Hz, 1H), 7.50 (ddd, J = 8.4, 7.1, 1.8 Hz, 1H), 7.87 (dd, J = 8.0, 1.6 Hz, 1H), 8.02−8.07 (m, 1H), 8.08−8.14 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.8, 60.0, 117.1, 118.5, 118.8, 120.2, 124.2, 124.5, 125.3, 129.7, 130.6, 132.7, 136.2, 140.7, 144.9, 145.3, 158.2, 163.6, 194.7; HRMS m/z calcd for $C_{20}H_{21}O_3$ [(M + H)$^+$] 309.1491, found 309.1491.

*(E)-4-(2-(But-1-en-2-yl)phenyl)but-3-en-2-one (**13o**).* According to the general procedure A for the aldol reaction, 2-(but-1-en-2-yl)benzaldehyde (**12c**; 100 mg, 0.62 mmol), acetone (**18a**; 36 mg, 0.62 mmol), and NaOH (75 mg, 1.87 mmol) in ethanol (3 mL) were used to furnish the product **13o** (100 mg, 80%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2924, 1691, 1565, 1480, 1452, 1315, 1174; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.05 (t, J = 7.4 Hz, 3H), 2.33−2.36 (m, 3H), 2.36−2.45 (m, 2H), 4.88 (s, 1H), 5.33 (s, 1H), 6.64 (d, J = 16.3 Hz, 1H), 7.21 (dd, J = 7.5, 1.5 Hz, 1H), 7.30 (td, J = 7.5, 1.5 Hz, 1H), 7.36 (td, J = 7.4, 1.5 Hz, 1H), 7.63 (dd, J = 7.7, 1.2 Hz, 1H), 7.74 (d, J = 16.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.4, 27.2, 31.3, 115.2, 126.4, 127.3, 127.8, 128.7, 129.8, 132.1, 142.6, 144.8, 149.7, 198.6; HRMS m/z calcd for $C_{14}H_{17}O$ [(M + H)$^+$] 201.1279, found 201.1286.

*(E)-4-(2-(1-Phenylvinyl)phenyl)but-3-en-2-one (**13p**).* According to the general procedure A for the aldol reaction, 2-(1-phenylvinyl)-benzaldehyde (**12d**; 104 mg, 0.5 mmol), acetone (**18a**; 29 mg, 0.5 mmol), and NaOH (60 mg, 1.5 mmol) in ethanol (3 mL) were used to furnish the product **13p** (101 mg, 81%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2950, 1695, 1586, 1472, 1215; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.08 (s, 3H), 5.24 (d, J = 1.2 Hz, 1H), 5.88 (d, J = 1.1 Hz, 1H), 6.50 (d, J = 16.4 Hz, 1H), 7.22−7.26 (m, 2H), 7.26−7.33 (m, 4H), 7.35−7.43 (m, 2H), 7.50 (d, J = 16.4 Hz, 1H), 7.62−7.68 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.4, 117.1, 126.4, 126.9, 128.0, 128.1, 128.2, 128.5, 130.1, 130.7, 133.1, 140.9, 142.6, 142.9, 147.9, 198.8; HRMS m/z calcd for $C_{18}H_{17}O$ [(M + H)$^+$] 249.1279, found 249.1280.

*(E)-4-(2-(Prop-1-en-2-yl)phenyl)pent-3-en-2-one (**13q**).* A solution of diethyl 2-oxopropanephosphonate (242 mg, 1.25 mmol) in THF (2 mL) was slowly added to a suspension of NaH (50 mg, 1.25 mmol) in THF (3 mL) at 0 °C over a period of 30 min. The mixture was stirred at room temperature and became clear. 1-(2-(Prop-1-en-2-yl)phenyl)-ethanone (**18c**; 100 mg, 0.624 mmol) was added to the mixture at 0 °C, which was then stirred at room temperature for 30 h. After confirmation of consumption of starting material, a solution of saturated aqueous $NaHCO_3$ (3 mL) was added. THF was removed under reduced pressure, and the aqueous layer was extracted with dichloromethane (3 × 20 mL). The combined organic layers were washed with brine (2 mL) and dried with anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the residue was purified by flash column chromatography on silica gel to furnish the product **13q** (55 mg, 44%) as a yellow oil: R_f = 0.4 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 1655, 1589, 1465, 1314, 1265, 1262, 1023; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.03 (s, 3H), 2.24 (s, 3H), 2.41 (s, 3H), 4.98 (d, J = 1.4 Hz, 1H), 5.11−5.16 (m, 1H), 6.30 (d, J = 0.9 Hz, 1H), 7.13−7.17 (m, 1H), 7.23−7.25 (m, 1H), 7.27−7.34 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.0, 23.9, 32.0, 116.4, 126.7, 127.0, 127.8, 127.9, 128.0, 128.7, 141.5, 142.1, 145.1, 157.1, 198.8; HRMS m/z calcd for $C_{14}H_{17}O$ [(M + H)$^+$] 201.1279, found 201.1281.

*(E)-2-Methyl-1-phenyl-3-(2-(prop-1-en-2-yl)phenyl)prop-2-en-1-one (**13r**).* According to the general procedure A for the aldol reaction, 2-(prop-1-en-2-yl)benzaldehyde (**12a**; 50 mg, 0.34 mmol), propiophenone (**18b**; 46 mg, 0.34 mmol), and NaOH (41 mg, 1.03 mmol) in ethanol (3 mL) were used to furnish the product **13r** (68 mg, 76%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2924, 1692, 1660, 1595, 1368, 1224,; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.97 (s, 3H), 2.15 (d, J = 1.4 Hz, 3H), 4.84 (dd, J = 1.9, 1 Hz, 1H), 5.16−5.21 (m, 1H), 7.22−7.27 (m, 2H), 7.27−7.34 (m, 2H), 7.35−7.47 (m, 3H), 7.49−7.54 (m, 1H), 7.67−7.80 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 24.2, 116.8, 126.7, 127.8, 128.1, 128.3, 129.3, 129.4, 131.5, 133.4, 136.8, 138.5, 142.6, 143.9, 144.3, 199.4; HRMS m/z calcd for $C_{19}H_{19}O$ [(M + H)$^+$] 263.1436, found 263.1439.

*(1E,4E)-1-(4-Chlorophenyl)-5-(2-methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)penta-1,4-dien-3-one (**13s**).* According to the general procedure A for the aldol reaction, 4-chlorobenzaldehyde (**20a**; 70 mg, 0.30 mmol), ketone **13d** (43 mg, 0.30 mmol), and NaOH (37 mg, 0.91 mmol) in ethanol (3 mL) were used to furnish the product **13s** (95 mg, 89%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2927, 1656, 1612, 1490, 1406, 1318, 1218, 1090, 1012; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.03−2.04 (m, 3H), 2.32 (s, 3H), 3.70 (s, 3H), 4.92−4.93 (m, 1H), 5.28 (t, J = 1.8 Hz, 1H), 6.92 (d, J = 7.8 Hz, 1H), 7.01 (s, 1H), 7.16 (d, J = 7.8 Hz, 1H), 7.36−7.40

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(m, 2H), 7.43 (d, J = 16.0 Hz, 1H), 7.51−7.55 (m, J = 8.7 Hz, 2H), 7.64 (d, J = 16.0 Hz, 1H), 7.88 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.7, 60.0, 117.0, 124.4, 125.4, 126.5, 129.0, 129.2, 129.4, 130.5, 132.3, 133.3, 136.2, 139.0, 141.5, 144.8, 144.9, 157.9, 189.5; HRMS m/z calcd for $C_{22}H_{22}ClO_2$ [$(M + H)^+$] 353.1308, found 353.1309.

*(1E,4E)-1-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)-5-phenylpenta-1,4-dien-3-one (**13t**).* According to the general procedure A for the aldol reaction, benzaldehyde (**20b**; 90 mg, 0.40 mmol), ketone **13d** (42 mg, 0.40 mmol), and NaOH (47 mg, 1.17 mmol) in ethanol (3 mL) were used to furnish the product **13t** (98 mg, 79%) as a yellow oil: R_f = 0.29 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2931, 1652, 1616, 1475, 1444, 1394, 1332, 1218, 1098; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.04 (s, 3H), 2.33 (s, 3H), 3.71 (s, 3H), 4.94 (s, 1H), 5.29 (t, J = 1.4 Hz, 1H), 6.93 (d, J = 7.8 Hz, 1H), 7.03 (d, J = 16.0 Hz, 1H), 7.16 (d, J = 7.8 Hz, 1H), 7.41 (dd, J = 5.0, 1.8 Hz, 3H), 7.46 (d, J = 16.0 Hz, 1H), 7.58−7.63 (m, 2H), 7.71 (d, J = 16.0 Hz, 1H), 7.88 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.9, 24.7, 60.0, 116.9, 124.4, 125.5, 126.2, 128.3, 128.3, 128.9, 129.1, 130.4, 130.5, 132.2, 134.9, 138.8, 143.0, 144.9, 157.9, 189.8; HRMS m/z calcd for $C_{22}H_{23}O_2$ [$(M + H)^+$] 319.1698, found 319.1690.

*(1E,4E)-1-(2-Methoxy-3-methyl-6-(prop-1-en-2-yl)phenyl)-5-p-tolylpenta-1,4-dien-3-one (**13u**).* According to the general procedure A for the aldol reaction, 4-methylbenzaldehyde (**20c**; 80 mg, 0.35 mmol), ketone **13d** (42 mg, 0.35 mmol), and NaOH (42 mg, 1 mmol) in ethanol (3 mL) were used to furnish the product **13u** (92 mg, 77%) as a yellow oil: R_f = 0.30 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2931, 1651, 1614, 1511, 1448, 1325, 1258, 1179, 1096, 1037; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.04 (s, 3H), 2.33 (s, 3H), 2.39 (s, 3H), 3.71 (s, 3H), 4.89−4.99 (m, 1H), 5.26−5.29 (m, 1H), 6.92 (d, J = 7.8 Hz, 1H), 6.99 (d, J = 16.0 Hz, 1H), 7.16 (d, J = 7.3 Hz, 1H), 7.19−7.25 (m, J = 8.2 Hz, 2H), 7.45 (d, J = 16.5 Hz, 1H), 7.48−7.54 (m, J = 8.2 Hz, 2H), 7.69 (d, J = 16.0 Hz, 1H), 7.87 (d, J = 16.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 15.9, 21.5, 24.7, 59.9, 116.9, 124.4, 125.3, 125.6, 125.9, 128.3, 129.2, 129.6, 130.4, 132.1, 132.1, 138.5, 140.9, 143.1, 144.8, 144.9, 157.9, 189.9; HRMS m/z calcd for $C_{23}H_{24}NaO_2$ [$(M + Na)^+$] 355.1674, found 355.1674.

General Procedure B for the Olefin-Michael Cyclization Reaction. Under an argon atmosphere to a magnetically stirred solution of keto in CH_2Cl_2 was added $FeCl_3{\cdot}6H_2O$ (10 mol %), and the mixture was stirred for 15−30 min. When completion of the reaction was noted by TLC, a saturated solution of $NaHCO_3$ was added and the resultant reaction mixture was extracted with CH_2Cl_2. The combined organic extracts were washed with brine and dried over Na_2SO_4. Evaporation of solvent and purification of the residue on a silica gel column using EtOAc/hexane as eluent afforded the cyclized product.

*1-(3-Methyl-1H-inden-1-yl)propan-2-one (**14a**).* According to the general procedure B, compound **13a** (71 mg, 0.381 mmol) and $FeCl_3{\cdot}6H_2O$ (10.3 mg, 0.038 mmol) in CH_2Cl_2 (4 mL) were used to furnish the product **14a** (70 mg, 99%) as a yellow oil: R_f = 0.29 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2920, 1716, 1463, 1359, 1155; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.13 (s, 3H), 2.18 (s, 3H), 2.52 (dd, J = 17.3, 8.6 Hz, 1H), 2.85 (dd, J = 17.4, 6.4 Hz, 1H), 3.83−3.93 (m, 1H), 6.17 (s, 1H), 7.15−7.24 (m, 1H), 7.27−7.33 (m, 2H), 7.35 (d, J = 7.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 30.3, 43.9, 45.3, 119.1, 122.8, 124.9, 126.7, 133.3, 139.4, 145.4, 147.3, 207.7; HRMS m/z calcd for $C_{13}H_{15}O$ [$(M + H)^+$] 187.1123, found 187.1126.

*1-(3-Methyl-1H-inden-1-yl)octan-2-one (**14b**).* According to the general procedure B, compound **13b** (36 mg, 0.140 mmol) and $FeCl_3{\cdot}6H_2O$ (3.8 mg, 0.014 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14b** (34 mg, 94%) as a yellow oil: R_f = 0.4 (EtOAc/hexane 5/95); IR (neat): ν_{max}/cm^{-1} 2956, 2929, 2857, 1712, 1606, 1463, 1405, 1375, 1265, 1126, 1080; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.88 (s, 2H), 1.28 (br s, 4H), 1.59 (m, 3H), 2.12 (s, 3H), 2.41 (t, J = 7.5 Hz, 2H), 2.49 (dd, J = 17.2, 8.5 Hz, 1H), 2.80 (dd, J = 17.2, 6.5 Hz, 1H), 3.87−3.91 (m, 1H), 6.16 (s, 1H), 7.15−7.22 (m, 1H), 7.27−7.35 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 13.0, 14.0, 22.5, 23.8, 28.9, 29.7, 31.6, 43.2, 43.9, 44.3, 119.0, 122.8, 124.9, 126.6, 133.4, 139.3, 145.4, 147.5, 210.2; HRMS m/z calcd for $C_{18}H_{25}O$ [$(M + H)^+$] 257.1905, found 257.1903.

*2-(3-Methyl-1H-inden-1-yl)-1-phenylethanone (**14c**).* According to the general procedure B, compound **13c** (36 mg, 0.145 mmol) and $FeCl_3{\cdot}6H_2O$ (3.9 mg, 0.014 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14c** (34 mg, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2926, 1684, 1597, 1448, 1356, 1276, 1180, 1075; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.14 (s, 3H), 3.05 (dd, J = 17.3, 8.7 Hz, 1H), 3.39 (dd, J = 17.3, 6.2 Hz, 1H), 4.09 (br s, 1H), 6.26 (s, 1H), 7.20 (dt, J = 8.0, 4.0 Hz, 1H), 7.29−7.34 (m, 2H), 7.42 (d, J = 7.2 Hz, 1H), 7.46 (t, J = 7.7 Hz, 2H), 7.57 (t, J = 7.4 Hz, 1H), 7.98 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.9, 40.6, 44.2, 119.1, 123.0, 124.9, 126.7, 128.1, 128.6, 133.2, 133.7, 136.9, 139.3, 145.5, 147.6, 199.1; HRMS m/z calcd for $C_{18}H_{17}O$ [$(M + H)^+$] 249.1279, found 249.1272.

*1-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)propan-2-one (**14d**).* According to the general procedure B, compound **13d** (40 mg, 0.174 mmol) and $FeCl_3{\cdot}6H_2O$ (4.6 mg, 0.017 mmol), in CH_2Cl_2 (3 mL) were used to furnish the product **14d** (39 mg, 97%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2927, 1715, 1577, 1477, 1448, 1416, 1359, 1254, 1162, 1025; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.08 (br s, 3H), 2.17 (s, 3H), 2.23−2.28 (m, 1H), 2.31 (s, 3H), 3.39 (dd, J = 17.5, 4.3 Hz, 1H), 3.79 (s, 3H), 3.94−4.06 (m, 1H), 6.14 (br s, 1H), 6.96 (d, J = 7.4 Hz, 1H), 7.13 (d, J = 7.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 15.8, 30.3, 42.7, 43.4, 59.8, 114.9, 127.8, 130.1, 132.9, 137.5, 139.1, 145.7, 154.5, 208.1; HRMS m/z calcd for $C_{15}H_{19}O_2$ [$(M + H)^+$] 231.1385, found 231.1380.

*1-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)octan-2-one (**14e**).* According to the general procedure B, compound **13e** (40 mg, 0.133 mmol) and $FeCl_3{\cdot}6H_2O$ (3.6 mg, 0.013 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14e** (37 mg, 92%) as a yellow oil: R_f = 0.33 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2927, 2856, 1714, 1476, 1416, 1243, 1121, 1243, 1121, 1020; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.86−0.91 (m, 3H), 1.27−1.35 (m, 6H), 1.59−1.64 (m, 2H), 2.08 (br s, 3H), 2.23 (dd, J = 17.2, 10.4 Hz, 1H), 2.31 (s, 3H), 2.33−2.41 (m, 1H), 2.41−2.50 (m, 1H), 3.35 (dd, J = 17.4, 4.3 Hz, 1H), 3.79 (s, 3H), 3.97−4.05 (m, 1H), 6.13 (br s, 1H), 6.96 (d, J = 7.2 Hz, 1H), 7.13 (d, J = 7.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 14.0, 15.8, 22.5, 23.8, 28.9, 31.6, 42.4, 42.7, 43.2, 59.8, 114.9, 127.7, 130.0, 133.0, 137.6, 138.9, 145.7, 154.5, 210.6; HRMS m/z calcd for $C_{20}H_{28}NaO_2$ [$(M + Na)^+$] 323.1987, found 323.1981.

*1-(7-Methoxy-3,5,6-trimethyl-1H-inden-1-yl)propan-2-one (**14f**).* According to the general procedure B, compound **13f** (30 mg, 0.12 mmol) and $FeCl_3{\cdot}6H_2O$ (3.3 mg, 0.012 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14f** (29 mg, 97%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2927, 1715, 1475, 1458, 1426, 1244, 1025; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.07 (br s, 3H), 2.16 (s, 3H), 2.18−2.22 (m, 3H), 2.25 (d, J = 7.1 Hz, 1H), 2.31 (s, 3H), 3.38 (dd, J = 17.4, 4.3 Hz, 1H), 3.76 (s, 3H), 3.92−4.01 (m, 1 H), 6.12 (br s, 1H), 6.89 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 11.9, 12.9, 20.5, 30.3, 42.7, 43.5, 60.1, 116.7, 126.3, 132.9, 134.9, 137.4, 139.1, 144.7, 154.3, 208.3; HRMS m/z calcd for $C_{16}H_{21}O_2$ [$(M + H)^+$] 245.1542, found 245.1542.

*1-(7-Methoxy-3,4,5,6-tetramethyl-1H-inden-1-yl)propan-2-one (**14g**).* According to the general procedure B, compound **13g** (35 mg, 0.135 mmol) and $FeCl_3{\cdot}6H_2O$ (3.66 mg, 0.013 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14g** (33 mg, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2928, 1714, 1576, 1461, 1416, 1360, 1270, 1163, 1091, 1005; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.16 (s, 3H), 2.21 (s, 3H), 2.23 (s, 3H), 2.24 (br s, 1H), 2.30 (s, 3H), 2.44 (s, 3H), 3.41 (dd, J = 17.4, 4.3 Hz, 1H), 3.72 (s, 3H), 3.88 (m, 1H), 6.11 (br s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.7, 15.4, 16.1, 18.5, 30.3, 41.4, 43.8, 60.1, 126.2, 126.5, 134.9, 136.1, 136.3, 140.7, 141.7, 152.4, 208.5; HRMS m/z calcd for $C_{17}H_{23}O_2$ [$(M + H)^+$] 259.1698, found 259.1696.

*2-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)acetaldehyde (**14h**).* According to the general procedure B, compound **13h** (30 mg, 0.138 mmol) and $FeCl_3{\cdot}6H_2O$ (3.7 mg, 0.014 mmol), in CH_2Cl_2 (2.5 mL) were used to furnish the product **14h** (12 mg, 40%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2928, 2855,

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1722, 1479, 1453, 1416, 1257, 1213, 1174, 1021; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.32 (s, 3H), 2.49−2.57 (m, 1H), 3.21 (ddd, J = 17.2, 4.5, 1.8 Hz, 1H), 3.81 (s, 3H), 3.97 (td, J = 4.3, 1.8 Hz, 1H), 6.04−6.27 (m, 1H), 6.98 (d, J = 7.2 Hz, 1H), 7.15 (d, J = 7.2 Hz, 1H), 9.68 (t, J = 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.0, 15.9, 41.7, 43.4, 59.8, 115.1, 128.0, 130.4, 132.0, 132.0, 137.0, 139.8, 202.0; HRMS m/z calcd for $C_{14}H_{17}O_2$ [$(M + H)^+$] 217.1229, found 217.1220.

*2-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)-1-phenylethanone (**14i**).* According to the general procedure B, compound **13i** (40 mg, 0.136 mmol) and $FeCl_3{\cdot}6H_2O$ (3.7 mg, 0.014 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14i** (37 mg, 92%) as a yellow oil: R_f = 0.25 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2933, 1684, 1579, 1596, 1415, 1448, 1257, 1212, 1019; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.35 (s, 3H), 2.76 (dd, J = 17.6, 11.2 Hz, 1H), 3.84 (s, 3 H), 4.03 (dd, J = 17.4, 3.7 Hz, 1H), 4.21 (dt, J = 11.0, 1.8 Hz, 1H), 6.26 (t, J = 1.6 Hz, 1H), 7.00 (d, J = 7.8 Hz, 1H), 7.17 (d, J = 7.3 Hz, 1H), 7.44−7.49 (m, 2H), 7.54−7.59 (m, 1H), 7.98−8.02 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 15.8, 38.7, 42.9, 59.9, 114.9, 127.7, 128.1, 128.5, 130.1, 133.0, 133.2, 136.9, 137.7, 139.0, 145.8, 154.6, 199.4; HRMS m/z calcd for $C_{20}H_{21}O_2$ [$(M + H)^+$] 293.1542, found 293.1541.

*1-(3,5-Dimethoxyphenyl)-2-(7-methoxy-3,6-dimethyl-1H-inden-1-yl)ethanone (**14j**).* According to the general procedure B, compound **13j** (34 mg, 0.110 mmol) and $FeCl_3{\cdot}6H_2O$ (3.0 mg, 0.011 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14j** (32 mg, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2936, 1684, 1593, 1425, 1457, 1355, 1296, 1253, 1205, 1155, 1065; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.09 (br s, 3H), 2.34 (s, 3H), 2.72 (dd, J = 17.4, 11.0 Hz, 1H), 3.82 (s, 6H), 3.83 (s, 3H), 3.97 (dd, J = 17.4, 3.7 Hz, 1H), 4.18 (dt, J = 11.1, 1.5 Hz, 1H), 6.22 (s, 1H), 6.65 (t, J = 2.3 Hz, 1H), 6.99 (d, J = 7.8 Hz, 1H), 7.09−7.14 (m, 2H), 7.16 (d, J = 7.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.0, 15.8, 38.9, 43.0, 55.6, 59.9, 105.6, 105.8, 114.9, 127.7, 130.1, 133.2, 137.6, 138.8, 139.0, 145.8, 154.6, 160.8, 199.1; HRMS m/z calcd for $C_{22}H_{24}NaO_4$ [$(M + Na)^+$] 375.1573, found 375.1573.

*1-(3-Methoxyphenyl)-2-(3-methyl-1H-inden-1-yl)ethanone (**14k**).* According to the general procedure B, compound **13k** (55 mg, 0.201 mmol) and $FeCl_3{\cdot}6H_2O$ (5.4 mg, 0.02 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14k** (52 mg, 93%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2923, 1685, 1583, 1597, 1485, 1463, 1430, 1276, 1256, 1162, 1044, 1071; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.15 (s, 3H), 3.04 (dd, J = 17.3, 8.7 Hz, 1H), 3.38 (dd, J = 17.5, 6.0 Hz, 1H), 3.86 (s, 3H), 4.09 (br s, 1H), 6.25 (s, 1H), 7.12 (dt, J = 8.3, 1.1 Hz, 1H), 7.21 (dt, J = 7.5, 3.8 Hz, 1H), 7.30−7.34 (m, 2H), 7.34−7.38 (m, 1H), 7.42 (d, J = 7.4 Hz, 1H), 7.50−7.55 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 40.8, 44.2, 55.4, 112.2, 119.1, 119.7, 120.8, 123.0, 124.9, 126.7, 129.6, 133.7, 138.2, 139.3, 145.5, 147.6, 159.8, 198.8; HRMS m/z calcd for $C_{19}H_{19}O_2$ [$(M + H)^+$] 279.1385, found 279.1381.

*1-(2,5-Dimethoxyphenyl)-2-(7-methoxy-3,6-dimethyl-1H-inden-1-yl)ethanone (**14l**).* According to the general procedure B, compound **13l** (44 mg, 0.124 mmol) and $FeCl_3{\cdot}6H_2O$ (3.4 mg, 0.012 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14l** (40 mg, 91%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2937, 1672, 1609, 1579, 1495, 1464, 1413, 1278, 1222, 1162, 1021; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.07 (s, 3H), 2.31 (s, 3H), 2.81 (dd, J = 18.32, 10.99 Hz, 1H), 3.78 (s, 3H), 3.80 (s, 3H), 3.82 (s, 3H), 3.94 (dd, J = 17.9, 3.7 Hz, 1H), 4.18 (ddt, J = 10.9, 3.7, 1.8 Hz, 1H), 6.22 (t, J = 1.8 Hz, 1H), 6.86 (d, J = 9.2 Hz, 1H), 6.96 (d, J = 7.3 Hz, 1H), 6.98−7.04 (m, 1H), 7.13 (d, J = 7.8 Hz, 1H), 7.32 (d, J = 3.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 15.9, 43.4, 43.7, 55.8, 55.9, 59.8, 113.0, 113.9, 114.7, 154.7, 119.9, 127.6, 128.4, 129.9, 133.7, 138.5, 146.0, 153.2, 153.3, 201.2; HRMS m/z calcd for $C_{22}H_{24}NaO_4$ [$(M + Na)^+$] 375.1573, found 375.1572.

*1-(3,4-Dimethoxyphenyl)-2-(7-methoxy-3,6-dimethyl-1H-inden-1-yl)ethanone (**14m**).* According to the general procedure B, compound **13m** (39 mg, 0.11 mmol) and $FeCl_3{\cdot}6H_2O$ (3.0 mg, 0.011 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14m** (38 mg, 97%) as a yellow oil: R_f = 0.4 (EtOAc/hexane 20/80); IR (neat) ν_{max}/cm^{-1} 2934, 1673, 1586, 1514, 1463, 1417, 1345, 1267, 1153, 1023; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.08 (t, J = 1.6 Hz, 3H), 2.34 (s, 3H), 2.73 (dd, J = 17.3, 11.31 Hz, 1H), 3.84 (s, 3H), 3.92−3.95 (m, 6H), 3.97 (d, J = 3.4 Hz, 1H), 6.14−6.30 (m, 1H), 6.87 (d, J = 8.3 Hz, 1H), 6.99 (d, J = 7.4 Hz, 1H), 7.16 (d, J = 7.4 Hz, 1H), 7.52−7.65 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.0, 15.8, 38.2, 43.2, 56.0, 56.0, 59.9, 110.0, 110.1, 114.9, 122.8, 127.7, 130.1, 130.1, 133.4, 137.7, 138.9, 145.9, 148.9, 153.2, 154.6, 198.1; HRMS m/z calcd for $C_{22}H_{25}O_4$ [$(M + H)^+$] 353.1753, found 353.1758.

*1-(2-Hydroxyphenyl)-2-(7-methoxy-3,6-dimethyl-1H-inden-1-yl)-ethanone (**14n**).* According to the general procedure B, compound **13n** (50 mg, 0.162 mmol) and $FeCl_3{\cdot}6H_2O$ (4.2 mg, 0.016 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14n** (47 mg, 94%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 3350, 1691, 1638, 1612, 1579, 1485, 1446, 1349, 1255, 1207, 1156, 1020; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.34 (s, 3H), 2.76 (dd, J = 17.4, 11.0 Hz, 1H), 3.84 (s, 3H), 4.06 (dd, J = 17.4, 3.7 Hz, 1H), 4.11−4.22 (m, 1H), 6.23 (t, J = 1.6 Hz, 1H), 6.86 (td, J = 7.7, 1.1 Hz, 1H), 6.97−7.04 (m, 2H), 7.18 (d, J = 7.8 Hz, 1 H), 7.45−7.50 (m, 1H), 7.74 (dd, J = 8.0, 1.6 Hz, 1H), 12.42 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.0, 15.8, 38.5, 42.7, 59.9, 115.0, 118.4, 118.9, 119.4, 127.9, 130.1, 130.3, 132.7, 136.3, 137.3, 139.4, 145.7, 154.6, 162.4, 205.7; HRMS m/z calcd for $C_{20}H_{21}O_3$ [$(M + H)^+$] 309.1491, found 309.1488.

*1-(3-Ethyl-1H-inden-1-yl)propan-2-one (**14o**).* According to the general procedure B, compound **13o** (25 mg, 0.125 mmol) and $FeCl_3{\cdot}6H_2O$ (3.37 mg, 0.0125 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14o** (24 mg, 96%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2956, 1712, 1609, 1465, 1265, 1126, 1180; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26−1.28 (m, 3H), 2.18 (s, 3H), 2.46−2.58 (m, 3H), 2.86 (dd, J = 17.3, 6.2 Hz, 1H), 3.87 (tt, J = 6.3, 2.0 Hz, 1H), 6.17 (q, J = 1.7 Hz, 1H), 7.17−7.21 (m, 1H), 7.26−7.34 (m, 2H), 7.36 (dd, J = 7.4, 0.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.2, 20.6, 30.3, 43.8, 45.4, 119.1, 122.9, 124.9, 126.6, 131.2, 144.8, 145.6, 147.6, 207.7; HRMS m/z calcd for $C_{14}H_{17}O$ [$(M + H)^+$] 201.1279, found 201.1279.

*1-(3-Phenyl-1H-inden-1-yl)propan-2-one (**14p**).* According to the general procedure B, compound **13p** (42 mg, 0.17 mmol) and $FeCl_3{\cdot}6H_2O$ (4.6 mg, 0.017 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14p** (41 mg, 97%) as a yellow oil: R_f = 0.24 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2950, 1691, 1658, 1485, 1446, 1349, 1255, 1020; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.22 (s, 3H), 2.65 (dd, J = 17.2, 8.6 Hz, 1H), 2.97 (dd, J = 17.7, 6.3 Hz, 1H), 4.01−4.11 (m, 1H), 6.56 (d, J = 2.3 Hz, 1H), 7.24−7.28 (m, 1H), 7.30−7.35 (m, 1H), 7.35−7.40 (m, 1H), 7.42−7.47 (m, 3H), 7.52−7.61 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 30.3, 44.2, 45.2, 120.6, 123.3, 125.3, 126.8, 127.7, 127.8, 128.6, 135.3, 135.6, 143.2, 144.4, 147.8, 207.4; HRMS m/z calcd for $C_{18}H_{17}O$ [$(M + H)^+$] 249.1279, found 249.1285.

*1-(1,3-Dimethyl-1H-inden-1-yl)propan-2-one (**14q**).* According to the general procedure B, compound **13q** (25 mg, 0.124 mmol) and $FeCl_3{\cdot}6H_2O$ (3.3 mg, 0.0124 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14q** (24 mg, 96%) as a yellow oil: R_f = 0.33 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2942, 1694, 1666, 1580, 1420, 1256, 1020; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.36 (s, 3 H), 1.90 (s, 3 H), 2.09 (d, J = 1.8 Hz, 3H), 2.58 (d, J = 14.6 Hz, 1H), 2.89 (d, J = 15.1 Hz, 1H), 6.25 (s, 1H), 7.19−7.26 (m, 2H), 7.26−7.31 (m, 1H), 7.31−7.37 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.8, 22.9, 31.1, 49.7, 51.3, 119.4, 121.3, 125.2, 126.9, 137.2, 138.9, 144.1, 151.9, 207.6; HRMS m/z calcd for $C_{19}H_{19}O$ [$(M + H)^+$] 263.1436, found 263.1435.

*2-(3-Methyl-1H-inden-1-yl)-1-phenylpropan-1-one (**14r**).* According to the general procedure B, compound **13r** (30 mg, 0.11 mmol) and $FeCl_3{\cdot}6H_2O$ (3.0 mg, 0.0.011 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14r** (28 mg, 93%) as a yellow oil: R_f = 0.4 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2950, 2840, 1693, 1658, 1485, 1545, 1509, 1250, 1020; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.00 (d, J = 6.8 Hz, 2H), 1.21 (d, J = 6.8 Hz, 3H), 2.10 (t, J = 1.8 Hz, 3H), 2.15−2.17 (m, 2H), 3.60−3.66 (m, 1H), 3.72−3.97 (m, 3H), 6.08 (s, 1H), 6.23 (s, 1H), 7.11−7.22 (m, 2H), 7.26−7.31 (m, 4H), 7.31−7.36 (m, 1H), 7.42−7.51 (m, 5H), 7.52−7.63 (m, 2H), 7.93−7.97 (m, 2H), 7.99−8.04 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.9, 13.0, 13.9,

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14.7, 42.3, 42.8, 50.4, 50.9, 119.0, 119.0, 122.8, 124.4, 124.6, 124.9, 126.7, 128.4, 128.4, 128.6, 128.7, 130.1, 131.1, 132.7, 132.9, 133.0, 134.8, 136.5, 139.5, 140.4, 145.4, 145.9, 146.3, 146.4, 203.4, 203.6; HRMS m/z calcd for $C_{19}H_{19}O$ $[(M + H)^+]$ 263.1436, found 263.1442.

*(E)-4-(4-Chlorophenyl)-1-(7-methoxy-3,6-dimethyl-1H-inden-1-yl)but-3-en-2-one (**14s**).* According to the general procedure B, compound **13s** (40 mg, 0.113 mmol) and $FeCl_3{\cdot}6H_2O$ (3.0 mg, 0.011 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14s** (39 mg, 98%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat) ν_{max}/cm^{-1} 2928, 1691, 1665, 1612, 1490, 1349, 1244, 1198, 1122, 1088; ^1H NMR (500 MHz, $CDCl_3$) δ 2.09 (br s, 3H), 2.33 (s, 3H), 2.52 (dd, J = 17.2, 10.9 Hz, 1H), 3.63−3.69 (m, 1H), 3.84 (s, 4H), 4.02−4.20 (m, 1H), 6.19 (br s, 1H), 6.70 (d, J = 16.6 Hz, 1H), 6.98 (d, J = 7.4 Hz, 1H), 7.15 (d, J = 7.4 Hz, 1H), 7.36 (d, J = 8.6 Hz, 2H), 7.44 (d, J = 8.6 Hz, 2H), 7.49 (d, J = 16.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.0, 15.8, 40.6, 42.9, 59.9, 114.9, 126.8, 127.7, 129.2, 129.4, 130.1, 132.9, 136.3, 137.5, 139.1, 141.2, 141.2, 145.8, 154.5, 199.3; HRMS m/z calcd for $C_{22}H_{21}ClNaO_2$ $[(M + Na)^+]$ 375.1128, found 375.1120.

*(E)-1-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)-4-phenylbut-3-en-2-one (**14t**).* According to the general procedure B, compound **13t** (44 mg, 0.138 mmol) and $FeCl_3{\cdot}6H_2O$ (3.7 mg, 0.014 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14t** (42 mg, 95%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 10/90); IR (neat) ν_{max}/cm^{-1} 2927, 1661, 1609, 1449, 1250, 1198, 1017; ^1H NMR (400 MHz, $CDCl_3$) δ 2.09 (br s, Hz, 3H), 2.34 (s, 3H), 2.52 (dd, J = 16.8, 10.9 Hz, 1H), 3.68 (dd, J = 17.0, 3.8 Hz, 1H), 3.85 (s, 3H), 4.07−4.16 (m, 1H), 6.18−6.25 (m, 1H), 6.75 (d, J = 16.3 Hz, 1H), 6.98 (d, J = 7.7 Hz, 1H), 7.16 (d, J = 7.2 Hz, 1H), 7.36−7.43 (m, 3H), 7.50−7.60 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.0, 15.8, 40.4, 43.0, 59.9, 114.9, 126.4, 127.7, 128.2, 128.9, 130.1, 130.4, 133.1, 134.5, 137.6, 139.0, 142.8, 145.8, 154.5, 199.5; HRMS m/z calcd for $C_{22}H_{23}O_2$ $[(M + H)^+]$ 319.1698, found 319.1691.

*(E)-1-(7-Methoxy-3,6-dimethyl-1H-inden-1-yl)-4-p-tolylbut-3-en-2-one (**14u**).* According to the general procedure B, compound **13u** (42 mg, 0.126 mmol) and $FeCl_3{\cdot}6H_2O$ (2.42 mg, 0.012 mmol) in CH_2Cl_2 (3 mL) were used to furnish the product **14u** (40 mg, 95%) as a yellow oil: R_f = 0.3 (EtOAc/hexane 5/95); IR (neat): ν_{max}/cm^{-1} 2922, 1662, 1603, 1512, 1476, 1415, 1349, 1245, 1199, 1093; ^1H NMR (500 MHz, $CDCl_3$) δ 2.09 (br s, 3H), 2.33 (s, 3H), 2.38 (s, 3H), 2.47−2.55 (m, 1H), 3.67 (dd, J = 16.9, 3.7 Hz, 1H), 3.85 (s, 3H), 4.11 (dt, J = 10.9, 2.0 Hz, 1H), 6.21 (br s, 1H), 6.71 (d, J = 16.6 Hz, 1H), 6.98 (d, J = 7.4 Hz, 1H), 7.15 (d, J = 7.4 Hz, 1H), 7.18−7.22 (m, J = 8.0 Hz, 2H), 7.41−7.44 (m, J = 8.0 Hz, 2H), 7.53 (d, J = 16.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.0, 15.8, 21.5, 40.3, 43.0, 59.9, 114.9, 125.5, 127.7, 128.2, 129.7, 130.1, 131.7, 133.1, 137.6, 138.9, 141.0, 142.9, 145.8, 154.5, 199.6; HRMS m/z calcd for $C_{23}H_{24}NaO_2$ $[(M + Na)^+]$ 355.1674, found 355.1677.

7-methoxy-3,6-dimethyl-1-(2-methylprop-1-enyl)-1*H*-indene (15). *Step 1.* To a magnetically stirred solution of methylmagnesium iodide (prepared from magnesium turnings (25 mg, 1.05 mmol), catalytic iodine, and methyl iodide (0.09 mL, 139 mmol) in anhydrous diethyl ether), was added slowly to the ketone **13d** (80 mg, 0.35 mmol) in anhydrous diethyl ether. The reaction mixture was stirred for 2 h at room temperature. It was then quenched with aqueous NH_4Cl solution, extracted with ethyl acetate, washed with brine, and dried over Na_2SO_4. Evaporation of the solvent furnished the crude tertiary alcohol, which was used in the elimination reaction without further purification.

Step 2. To a magnetically stirred solution of crude tertiary alcohol in anhydrous THF (3 mL) at 0 °C was added triethylamine (0.24 mL, 1.73 mmol), and the mixture was stirred for 5 min; then mesyl chloride (0.08 mL, 1.04 mmol) was added slowly. The resultant mixture was warmed to room temperature and stirred for 6 h. It was then quenched with water, extracted with ethyl acetate, washed with brine, and dried over Na_2SO_4. Evaporation of the solvent furnished a mixture of crude **15** and **16** eliminated product, which was used directly for the isomerization reaction without further purification.

Step 3. Under an argon atmosphere, to a stirred solution of crude eliminated compound in CH_2Cl_2 was added a catalytic amount of *p*-TSA (6 mg, 0.035 mmol) at 0 °C, and the mixture was stirred for 30 min at room temperature. The reaction progress was monitored by TLC analysis and then the reaction was quenched with sodium bisulfate. The reaction mixture was extracted with CH_2Cl_2. The combined organic layers were washed with brine and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure. The crude product was purified by silica gel column chromatography using EtOAc/hexane as eluent to furnish **15** (64 mg, 81% (over three steps)) as a yellow oil: R_f = 0.6 (EtOAc/hexane 2/98); IR (neat) ν_{max}/cm^{-1} 2969, 2859, 1575, 1475, 1254, 1226; ^1H NMR (500 MHz, $CDCl_3$) δ 1.75 (s, 3H), 1.91 (s, 3H), 2.10 (s, 3H), 2.31 (s, 3H), 3.77 (s, 3H), 4.37 (d, J = 9.7 Hz, 1H), 4.71 (d, J = 8.0 Hz, 1H), 5.91 (s, 1H), 6.94 (d, J = 7.4 Hz, 1H), 7.12 (d, J = 7.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.0, 15.9, 18.3, 25.9, 47.1, 59.8, 114.5, 121.6, 127.7, 129.9, 132.8, 133.5, 138.4, 138.6, 146.3, 154.7; HRMS m/z calcd for $C_{16}H_{19}O$ $[(M - H)^+]$ 227.1436, found 227.1438.

Jungianol (1) and *epi*-Jungianol (17). *Step 1.* To 30 mL of anhydrous ammonia at −78 °C was added 20 mg (6.6 mmol) of lithium metal. A solution of 80 mg (0.22 mmol) of **15** in 4 mL of THF was then added at the same temperature, followed by stirring for 10 min. Quenching with ammonium chloride followed by evaporation of the ammonia gave a crude product which was used further reaction without purification.

Step 2. Under an argon atmosphere, NaH (440 mg, 11 mmol, 60% in mineral oil) was washed with anhydrous hexane (three times). After a few minutes, anhydrous DMF (4 mL) was added. To this mixture was slowly added a solution of EtSH (0.47 mL, 6.60 mmol) in anhydrous DMF (1 mL) at 0 °C, and the resulting yellow solution was stirred for 20 min at room temperature. A solution of crude product in anhydrous DMF (1 mL) was then added dropwise and the resulting mixture was stirred for 5 h at 130 °C. It was becoming slightly brown. The mixture was cooled to room temperature, and a saturated solution of NH_4Cl was added. The mixture was extracted with Et_2O, and then the organic phase was washed with H_2O and brine and dried over anhydrous Na_2SO_4. The solvent was removed under reduced pressure, and the resulting brown oil was purified by flash chromatography (EtOAc/hexanes, 3/97 as eluent) to give jungianol (**1**; 31 mg, 41%) as a yellow solid with R_f = 0.3 (EtOAc/hexane 1/99) and *epi*-jungianol (**17**; 31 mg, 41%) as a yellow solid with R_f = 0.3 (EtOAc/hexane 1/99).

*Jungianol (**1**):* IR (neat) ν_{max}/cm^{-1} 3380, 2910, 1582, 1480, 1443, 1271; ^1H NMR (400 MHz, $CDCl_3$) δ 1.20 (d, J = 7.2 Hz, 3H), 1.81 (d, J = 1.4 Hz, 3H), 1.88 (d, J = 1.4 Hz, 3H), 1.94 (ddd, J = 3.2, 7.6, 12.7 Hz, 1H), 2.0 (ddd, J = 8.1, 8.1, 12.7 Hz, 1H), 2.20 (s, 3H), 3.26 (m, J = 2.7, 7.2, 7.7, 3.2 Hz, 1H), 4.18 (dm, J = 10.4 Hz, 1H), 5.30 (dm, J = 10.4 Hz, 1H), 5.59 (s, 1 H), 6.68 (d, J = 7.7 Hz, 1H), 6.97 (d, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.3, 18.1, 21.5, 26.0, 38.6, 40.0, 42.0, 115.4, 122.4, 127.4, 129.0, 130.2, 135.0, 148.4, 151.4; HRMS m/z calcd for $C_{15}H_{21}O$ $[(M + H)^+]$ 217.1592, found 217.1598.

*1-epi-Jungianol (**17**):* IR (neat) ν_{max}/cm^{-1} 3390, 2920, 1572, 1475, 1453, 1263; ^1H NMR (400 MHz, $CDCl_3$) δ 1.30 (d, J = 6.8 Hz, 3H), 1.35 (ddd, J = 10.4, 10.4, 12.2 Hz, 1H), 1.83 (d, J = 0.91 Hz, 3H), 1.87 (d, J = 0.91 Hz, 3H), 2.19 (s, 3H), 2.19 (s, 3H), 3.06 (dm, J = 10.4 Hz, 1H), 4.00 (td, J = 7.2, 7.2, 10.4 Hz, 1H), 5.35 (dm, J = 10.0 Hz, 1H), 5.92 (s, 1H), 6.67 (d, J = 7.2 Hz, 1H), 6.98 (d, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.7, 18.7, 19.7, 26.4, 38.8, 41.5, 44.2, 115.1, 122.9, 128.1, 129.7, 130.3, 136.5, 148.2; HRMS m/z calcd for $C_{15}H_{21}O$ $[(M + H)^+]$ 217.1592, found 217.1598.

■ ASSOCIATED CONTENT

Supporting Information

Tables and figures giving characterization data for all new compounds and proton and carbon NMR spectra. The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b01071.

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Notes

The authors declare no competing financial interest.

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