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$FeCl_3$-Mediated One-Pot Domino Reactions for the Synthesis of 9-Aryl/9-Arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones from Propargylic Amines/Diaryl Amines and 1,3-Cyclohexanediones

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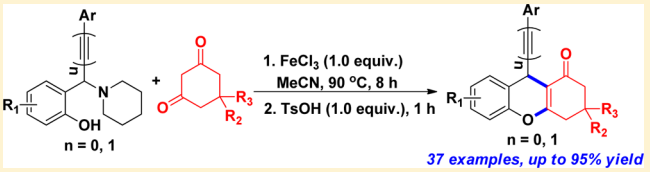
Supporting Information

ABSTRACT: An efficient, environmentally friendly and one-pot route to new 9-aryl/9-arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-one derivatives from inexpensive starting materials has been developed. This method proceeded by a domino nucleophilic-substitution/intramolecular cyclization/dehydration sequence of propargylic amines/diaryl amines and 1,3-cyclohexanediones under the promotion of $FeCl_3$, which involved the formation of two new σ (C−C and C−O) bonds in a single operation for the construction of novel tetrahydroxanthene skeletons in 68−95% yields.



INTRODUCTION

Xanthenes and their derivatives have attracted substantial research interest due to their various biological activities and antibacterial,[1] antioxidant,[2] anticancer,[3] antimalarial,[4] and anti-inflammatory properties.[5] Furthermore, some of these compounds have been widely used as lecodyes[6] and pH-sensitive fluorescent materials for visualization of biomolecules[7] and are utilized in laser technologies due to their unique photochemical and photophysical properties.[8] In particular, 9-substituted-2,3,4,9-tetrahydro-1*H*-xanthen-1-one derivatives have been identified as orally active neuropeptide Y Y5 and C CR1 receptor antagonists.[9] Conventional methods to produce tetrahydro-1*H*-xanthen-1-ones include the tandem Knoevenagel−Michael reaction of salicylaldehydes with dimedone using $CeCl_3$,[10] *p*-toluenesulfonic acid,[11] triethylbenzylammonium chloride,[12] tetra-*n*-butylammonium fluoride,[13] Zn[(L)-proline]$_2$,[14] and ZnO nanoparticles[15] as catalysts and copper(I)-catalyzed intramolecular *O*-arylation.[16] Over the years, only a few methods have been available for the efficient synthesis of 2,3,4,9-tetrahydro-1*H*-xanthen-1-ones.[17] Consequently, the development of an efficient, operationally simple, eco-friendly and practical method for the synthesis of 9-substituted-2,3,4,9-tetrahydro-1*H*-xanthen-1-one derivatives is in high demand.

In recent years, iron(III) chloride has emerged as an efficient, cheap and environmentally benign Lewis acid for a variety of domino reactions.[18] Previously, we developed an efficient synthetic approach to coumarins and polysubstituted pyridines using $FeCl_3$-catalyzed one-pot cascade and multicomponent reactions.[19] On the other hand, propargylic amines, which are products of the three-component reaction of aldehydes, amines, and alkynes (A^3-coupling), are versatile building blocks for the synthesis of *N*-containing biologically active compounds and are key intermediates for the synthesis of many natural products.[20] Our research group has been working on the synthesis of β-alkynyl ketones from propargylic amines using $FeCl_3$ as a catalyst.[21] As a continuation of our work to explore the synthetic utility of $FeCl_3$, we herein report a simple and efficient synthesis of 9-substituted-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones by $FeCl_3$-mediated one-pot domino reactions of propargylic amines or diarylamines and 1,3-cyclohexanediones (Scheme 1).

RESULTS AND DISCUSSION

Initially, 2-(3-phenyl-1-(piperidin-1-yl)prop-2-yn-1-yl)phenol (**1a**) and cyclohexane-1,3-dione (**2a**) served as model substrates for the optimization of the domino reaction conditions; the results are presented in Table 1. The domino

Scheme 1. Synthesis of β-Alkynyl Ketones and 9-Aryl/Arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones by $FeCl_3$-Mediated Domino Reactions of Propargylic Amines and 1,3-Diketones

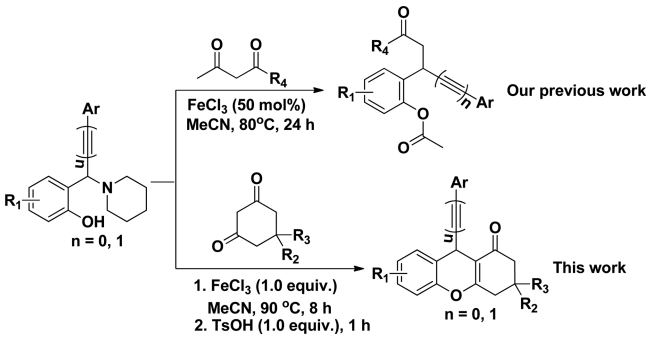


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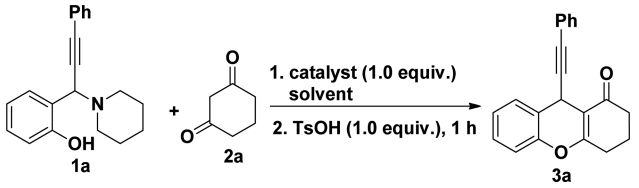
Table 1. Optimization of the Reaction Conditions[a]



entry	Lewis acid (1.0 equiv)	solvent	temp. (°C)	time (h)	yield (%)
1	$Sc(OTf)_3$	MeCN	90	8	75
2	$Cu(OAc)_2$	MeCN	90	8	trace
3	CuI	MeCN	90	8	35
4	$AgNO_3$	MeCN	90	8	65
5	$Pd(OAc)_2$	MeCN	90	8	78
6	$FeCl_3$	MeCN	90	8	85
7[b]	$FeCl_3$	MeCN	90	8	45
8[c]	$FeCl_3$	MeCN	90	8	trace
9	$FeCl_3$	toluene	90	8	60
10	$FeCl_3$	MeCN	rt	24	trace
11	$FeCl_3$	MeCN	60	8	67
12	$FeCl_3$	MeCN	90	2	20
13	$FeCl_3$	MeCN	90	5	55
14	$FeCl_3$	MeCN	90	10	80

[a]Reaction conditions: 2-(3-phenyl-1-(piperidin-1-yl)prop-2-yn-1-yl)-phenol **1a** (1.0 mmol), cyclohexane-1,3-dione **2a** (1.0 mmol), Lewis acid, solvent (5 mL); then TsOH (1.0 equiv) was added and stirred for another 1 h. [b]0.5 equiv of $FeCl_3$ was used. [c]2.0 equiv of $FeCl_3$ was used.

reaction proceeded in a one-pot two-step fashion as follows: the first step was promoted by a Lewis acid, whereas the second step was promoted by the addition of a Brønsted acid. Lewis acids such as $FeCl_3$, $Sc(OTf)_3$, $Cu(OAc)_2$, CuI, $AgNO_3$, and $Pd(OAc)_2$ were examined first (Table 1, entries 1−6). Of these, $FeCl_3$ (1.0 equiv) was found to be the best promoter, giving **3a** in 85% yield (Table 1, entry 6). Neither reducing the catalyst loading nor increasing the catalyst loading increased the yield further (Table 1, entries 7, 8). Particularly, when 2 equiv of $FeCl_3$ was used, the reaction system became very viscous and the reaction hardly took place (Table 1, entry 8). Further screening of the solvents showed that acetonitrile yielded the best result compared with H_2O, toluene, THF, DMF, 1,4-dioxane, ethanol, and methanol, as shown in Table S1 in the Supporting Information (SI) (Table S1, entries 9−15). In addition, the effects of temperature and reaction time were also investigated (Table 1, entries 10, 11 and 12−14). It was found that neither decreasing nor increasing the reaction temperature or time could improve the yield. Therefore, the optimum reaction conditions for the transformation were established as 1.0 equiv of $FeCl_3$, 8 h at 90 °C for the first step, followed by the addition of TsOH (1.0 equiv) and stirring for another 1 h at 90 °C in CH_3CN.

Having optimized the reaction conditions, the substrate scope was examined with various aromatic propargylic amines **1** and 1,3-cyclohexanediones **2**. The results are summarized in Table 2. In most cases, the desired 9-arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones were smoothly generated in 75−87% yields. Among the various propargylic amines **1** examined, the reaction showed good tolerance of the substituents on the Ar group of the alkyne moiety, and 75−83% yields were obtained regardless of their electronic nature (Table 2, entries 2−4, 6, 8, 11). For substituents on the benzene ring of the phenol moiety, substrates with a moderately electron-withdrawing R_1 group (e.g., F, Cl, Br) or a moderately electron-donating R_1 (e.g., CH_3) (Table 2, entries 5−9, 11) gave the desired products in 82−87% yields. However, the reaction failed to occur in cases of substrate **1j** bearing a strongly electron-withdrawing group ($-NO_2$) (Table 2, entry 10), substrate **1l** bearing a strongly electron-donating group ($-OCH_3$) (Table 2, entry 12) and substrate **1m** bearing two sterically demanding *tert*-butyl groups at the *ortho* and *para* positions of the hydroxyl of propargylic amines (Table 2, entry 13). Different 1,3-cyclohexanediones **2** were then examined (Table 2, entries 14−24). Compared with **2a**, the desired products were obtained in lower yields when R_2 was a methyl group (**2c**) or when R_2 and R_3 were both methyl groups (**2b**). The structure of the product **3e** was unambiguously confirmed by X-ray crystallographic analysis, as shown in Figure S1 in the Supporting Information (SI).

In contrast to our previous result,[21] the reaction between 2-(3-phenyl-1-(piperidin-1-yl)prop-2-yn-1-yl)phenol (**1a**) and acetylacetone in the optimized conditions only gave one product, 2-(5-oxo-1-phenylhex-1-yn-3-yl)phenyl acetate, which was detected by TLC after 8 h. No other product was detected by TLC by adding TsOH (1.0 equiv) and increasing the reaction time.

To expand the scope of the present approach, we next subjected 2-(aryl(piperidin-1-yl)methyl)phenols **4**, which are easily available by the Petasis boronic Mannich reaction of salicylaldehydes, phenylboronic acid, and piperidine,[22] to the otherwise identical reaction conditions as above. Pleasingly, the corresponding products 9-aryl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones **5** were obtained in 78−95% yields, and the results are summarized in Table 3. Likewise, various moderately electron-withdrawing or electron-donating groups on the benzene ring of phenols, such as Cl, Br, and CH_3, are well-tolerated in the reaction to afford the desired products in high yields (Table 3, entries 4−6, 10−12). Notably, unlike in the case of substrate **1**, substrates with a strongly electron-donating group ($-OCH_3$) in the *ortho* and *para* positions (Table 3, entries 2, 3) or a strongly electron-withdrawing group ($-NO_2$) in the *para* position (Table 3, entry 8), the hydroxyl of 2-(aryl(piperidin-1-yl)methyl)phenols was also tolerated in the reaction to give 78−87% yields. The structure of product **5b** was unambiguously confirmed by X-ray crystallographic analysis, as shown in Figure S2 in the Supporting Information (SI).

Some control experiments were then carried out to gain some insight into the mechanism of this reaction (Scheme 2). Terminating the reaction of **1a** with **2b** after the first step of the reaction produced an intermediate **3k′** in 70% yield (Scheme 2, eq 1). Under the reaction conditions in Table 3, **3k′** underwent dehydrative cyclization to give the final product **3k** in 75% yield (Scheme 2, eq 4). In contrast, in the absence of either $FeCl_3$ or TsOH, the cyclization step proceeded very poorly under otherwise identical reaction conditions (Scheme 2, eqs 2 and 3).

To further demonstrate the versatility of the present method, another propargylic amine such as 2-(1-(dimethylamino)-3-phenylprop-2-yn-1-yl)phenol and propargylic alcohol such as 2-(1-hydroxy-3-phenylprop-2-yn-1-yl)phenol were also used in the $FeCl_3$-meidated one-pot domino reaction under standard reaction conditions, but no desired product was obtained (Scheme S1).

On the basis of previous studies[23] and the experimental results described above, a plausible mechanism is proposed in

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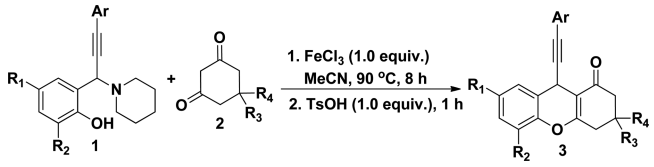
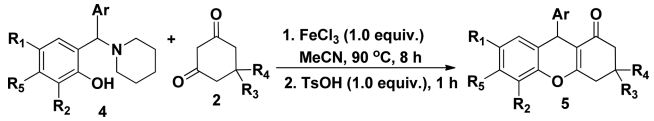
Table 2. $FeCl_3$-Mediated One-Pot Domino Reaction for the Formation of 9-Arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones[a]



entry	R_1, R_2, Ar	R_3, R_4	product **3**	yield (%)
1	**1a** (H, H, C_6H_5)	$R_3 = R_4 = H$ (**2a**)	**3a**	85
2	**1b** (H, H, 4-$CH_3C_6H_4$)	**2a**	**3b**	82
3	**1c** (H, H, 4-$CH_3OC_6H_4$)	**2a**	**3c**	75
4	**1d** (H, H, 4-ClC_6H_4)	**2a**	**3d**	78
5	**1e** (Br, H, C_6H_5)	**2a**	**3e**	87
6	**1f** (Br, H, 4-$CH_3C_6H_4$)	**2a**	**3f**	82
7	**1g** (Cl, H, C_6H_5)	**2a**	**3g**	85
8	**1h** (Cl, H, 4-$CH_3C_6H_4$)	**2a**	**3h**	83
9	**1i** (F, H, C_6H_5)	**2a**	**3i**	87
10	**1j** (NO_2, H, C_6H_5)	**2a**		NR[b]
11	**1k** (CH_3, H, 4-$CH_3C_6H_4$)	**2a**	**3j**	81
12	**1l** (H, OCH_3, C_6H_5)	**2a**		NR[b]
13	**1m** (*tert*-butyl, *tert*-butyl, C_6H_5)	**2a**		NR[b]
14	**1a** (H, H, C_6H_5)	$R_3 = R_4 = CH_3$ (**2b**)	**3k**	70
15	**1b** (H, H, 4-$CH_3C_6H_4$)	**2b**	**3l**	68
16	**1e** (Br, H, C_6H_5)	**2b**	**3m**	73
17	**1f** (Br, H, 4-$CH_3C_6H_4$)	**2b**	**3n**	76
18	**1g** (Cl, H, C_6H_5)	**2b**	**3o**	78
19	**1h** (Cl, H, 4-$CH_3C_6H_4$)	**2b**	**3p**	78
20	**1i** (F, H, C_6H_5)	**2b**	**3q**	80
21	**1k** (CH_3, H, 4-$CH_3C_6H_4$)	**2b**	**3r**	78
22	**1n** (H, H, 4-FC_6H_4)	**2b**	**3s**	70
23	**1a** (H, H, C_6H_5)	$R_2 = CH_3$, $R_3 = H$ (**2c**)	**3t**	80
24	**1b** (H, H, 4-$CH_3C_6H_4$)	**2c**	**3u**	73

[a]Reaction conditions: aromatic propargylic amines **1** (1.0 mmol), cyclic 1,3-diketones **2** (1.0 mmol), $FeCl_3$ (1.0 mmol), CH_3CN (5 mL), 90 °C, 8 h; then 1.0 equiv of TsOH was added and stirred for another 1 h. [b]No reaction.

Table 3. $FeCl_3$-Mediated One-Pot Domino Reaction for the Formation of 9-Aryl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones[a]



entry	R_1, R_5, R_2, Ar	R_3, R_4	product **5**	yield (%)
1	**4a** (H, H, H, C_6H_5)	$R_3 = R_4 = H$ (**2a**)	**5a**	95
2	**4b** (H, H, OCH_3, C_6H_5)	**2a**	**5b**	85
3	**4c** (H, OCH_3, H, C_6H_5)	**2a**	**5c**	87
4	**4d** (CH_3, H, H, C_6H_5)	**2a**	**5d**	92
5	**4e** (Cl, H, H, C_6H_5)	**2a**	**5e**	82
6	**4f** (Br, H, H, C_6H_5)	**2a**	**5f**	85
7	**4g** (Br, H, Br, C_6H_5)	**2a**	**5g**	83
8	**4h** (NO_2, H, H, C_6H_5)	**2a**	**5h**	78
9	**4i** (H, H, H, 4-$CH_3C_6H_4$)	**2a**	**5i**	90
10	**4j** (CH_3, H, H, 4-$CH_3C_6H_4$)	**2a**	**5j**	88
11	**4k** (Cl, H, H, 4-$CH_3C_6H_4$)	**2a**	**5k**	80
12	**4l** (Br, H, H, 4-$CH_3C_6H_4$)	**2a**	**5l**	80
13	**4m** (Br, H, Br, 4-$CH_3C_6H_4$)	**2a**	**5m**	78
14	**4a** (H, H, H, C_6H_5)	$R_3 = R_4 = CH_3$ (**2b**)	**5n**	92
15	**4n** (H, OCH_3, H, 4-$CH_3C_6H_4$)	**2b**	**5o**	82
16	**4k** (Cl, H, H, 4-$CH_3C_6H_4$)	**2b**	**5p**	80

[a]Reaction conditions: aromatic propargylic amines **4** (1.0 mmol), cyclic 1,3-diketones **2** (1.0 mmol), $FeCl_3$ (1.0 mmol), CH_3CN (5 mL), 90 °C, 8 h; then 1.0 equiv of TsOH was added and stirred for another 1 h.

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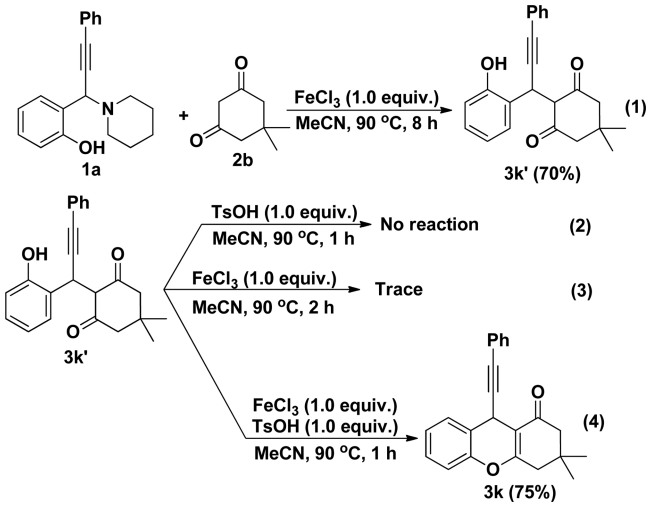
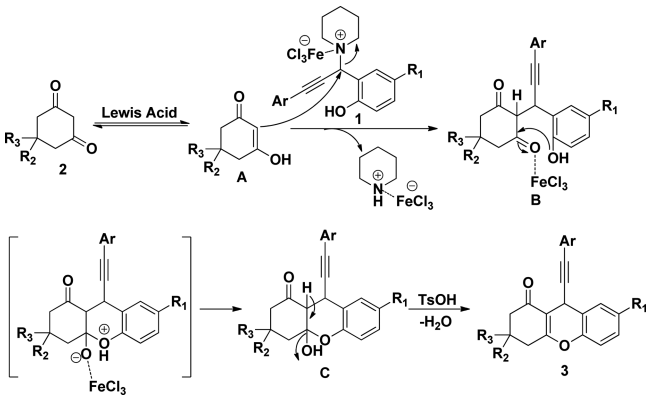
Scheme 2. Control Experiments



Scheme 3. First, the Lewis acid $FeCl_3$ would promote the nucleophilic substitution reaction between **A**, the enolate form

Scheme 3. Proposed Mechanism for the Formation of 9-Arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones via the One-Pot Domino Reactions



of 1,3-cyclohexanedione **2a**, and propargylic amine **1a** by coordination to the basic amine moiety. The resultant intermediate **B** could be readily converted to intermediate **C** via an intramolecular hemiketalization and elimination of a proton in the presence of the Lewis acid. Finally, after the loss of one molecule of H_2O, the intermediate **C** is transformed to the desired product **3** in the presence of both *p*-toluenesulfonic acid and $FeCl_3$.

CONCLUSION

In conclusion, a simple and efficient method for the synthesis of substituted 9-aryl/arylethynyl-2,3,4,9-tetrahydro-1*H*-xanthen-1-ones from easily accessible propargylic amines/diaryl amines and 1,3-cyclohexanediones as starting materials has been developed. The present method yielded the desired products in good to excellent yields (68−95%) and offers several notable advantages such as the use of an inexpensive and eco-friendly Lewis acid, the base/ligand-free conditions, and the simple operation under open air, which add to the practicality of this method for potential applications in organic synthesis and medicinal chemistry.

EXPERIMENTAL SECTION

General Comments. Unless otherwise specified, all reagents and starting materials were purchased from commercial sources and used as received, and the solvents were purified and dried using standard procedures. The chromatography solvents were technical grade and distilled prior to use. Flash chromatography was performed using 200−300 mesh silica gel with the indicated solvent system according to standard techniques. Element analyses were performed on an Elementar Vario El III. The ^1H and ^{13}C NMR data were recorded on 300 MHz NMR spectrometers, unless otherwise specified. Chemical shifts (δ) in parts per million are reported relative to the residual signals of chloroform (7.26 ppm for ^1H and 77.16 ppm for ^{13}C), and all ^{13}C NMR were recorded with proton broadband decoupling and indicated as $^{13}C\{^1H\}$NMR. Multiplicities are described as s (singlet), d (doublet), t (triplet), q (quartet), or m (multiplet), and the coupling constants (J) are reported in hertz. HRMS analysis with a quadrupole time-of-flight mass spectrometer yielded ion mass/charge (m/z) ratios in atomic mass units. IR spectra were measured as dry films (KBr), and the peaks are reported in terms of wavenumber (cm^{-1}).

General Procedure for the Synthesis of 9-(Phenylethynyl)-2,3,4,9-tetrahydro-1*H*-xanthen-1-one (3a). Anhydrous $FeCl_3$ (1.0 mmol, 81 mg) was added to a stirred solution of aromatic propargylic amine **1a** (1.0 mmol, 306 mg), and 1,3-cyclohexanedione **2a** (1.0 mmol, 112 mg) in acetonitrile (5 mL). The mixture was heated at 90 °C for 8 h in an oil bath. Then, *p*-toluenesulfonic acid (1.0 mmol, 172 mg) was added, and the reaction system was stirred at 90 °C for another 1 h. Upon completion of the reaction, the mixture was cooled to room temperature, diluted with CH_2Cl_2 (3 × 20 mL), and washed with water. The organic layers were combined, dried over Na_2SO_4, filtered, and then evaporated in vacuum. The residue was purified by flash column chromatography on silica gel with ethyl acetate and petroleum ether as the eluting solvent to produce product **3a** at a yield of 85%.

*9-(Phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3a**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 85% (255 mg, 0.85 mmol), mp 120−122 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.44 (d, J = 7.5 Hz, 1H), 7.31−7.35 (m, 2H), 7.13−7.27 (m, 5H), 7.03 (d, J = 8.1 Hz, 1H), 5.02 (s, 1H), 2.54−2.74 (m, 3H), 2.37−2.48 (m, 1H), 2.05−2.15 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.6, 166.6, 148.8, 131.7, 130.0, 128.4, 127.9, 127.7, 125.2, 123.3, 121.5, 116.6, 110.9, 91.1, 80.3, 36.8, 27.9, 24.4, 20.3 ppm; IR (KBr) ν 2955, 2928, 2887, 1639, 1584, 1489, 1445, 1371, 1234, 1172, 1132, 993, 850, 758, 694 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{16}O_2 + H]^+$ 301.1223, found 301.1228.

*9-(p-Tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3b**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 85% (266 mg, 0.85 mmol), mp 172−174 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.46 (d, J = 7.5 Hz, 1H), 7.12−7.26 (m, 4H), 7.00−7.05 (m, 3H), 5.01 (s, 1H), 2.53−2.75 (m, 3H), 2.35−2.48 (m, 1H), 2.28 (s, 3H), 2.04−2.16 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.6, 166.6, 148.8, 137.7, 131.6, 130.0, 128.7, 128.4, 125.2,121.7, 120.2, 116.6, 111.0, 90.3, 80.4, 36.8, 27.8, 24.4, 21.4, 20.3, ppm; IR (KBr) ν 2957, 2895, 2864, 1647, 1582, 1487, 1452, 1371, 1236, 1173, 999, 812, 764 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{18}O_2 + H]^+$ 315.1380, found 315.1385.

*9-((4-Methoxyphenyl)ethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3c**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 75% (247 mg, 0.75 mmol), mp 160−162 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.45 (d, J = 7.5 Hz, 2H), 7.22−7.30 (m, 3H), 7.13−7.19 (m, 1H), 7.03−7.06 (m, 1H), 6.70−6.77 (m, 2H), 5.01 (s, 1H), 3.77 (s, 3H), 2.56−2.75 (m, 4H), 2.39−2.49 (m, 1H), 2.09−2.17 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.0, 166.9, 159.6, 149.2, 133.5, 130.4, 128.7, 125.6, 122.2, 117.0, 115.9, 114.0, 111.5, 90.0, 80.6, 55.6, 37.2, 28.3, 24.8, 20.7 ppm; IR (KBr) ν 2957, 2837, 1647, 1603, 1582, 1566, 1508, 1454, 1371, 1284, 1169, 1132, 1034, 999, 831 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{18}O_3 + H]^+$ 331.1333, found 331.1329.

*9-((4-Chlorophenyl)ethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3d**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 78% (277 mg, 0.78 mmol), mp 185−187 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.42 (d, J = 7.5 Hz, 1H), 7.14−7.27 (m, 6H), 7.03 (d, J = 7.5 Hz, 1H), 5.01 (s, 1H), 2.54−2.74 (m, 4H), 2.38−2.48 (m, 1H), 2.08−2.12

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(m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.6, 165.8, 147.5, 133.4, 131.9, 128.9, 127.5, 127.2, 124.2, 121.1, 120.2, 115.7, 91.0, 80.2, 35.8, 26.8, 23.3, 19.2 ppm; IR (KBr) ν 2961, 2891, 1649, 1582, 1487, 1454, 1373, 1236, 1001, 841 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{15}O_2Cl + Na]^+$ 357.0658, found 357.0653.

*7-Bromo-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3e**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 87% (348 mg, 0.87 mmol), mp 185−187 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.56 (d, J = 6.8 Hz, 1H), 7.33−7.37 (m, 3H), 7.20−7.25 (m, 3H), 6.92 (d, J = 8.1 Hz, 1H), 4.97 (s, 1H), 2.53−2.73 (m, 3H), 2.37−2.48 (m, 1H), 2.06−2.15 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.4, 165.4, 147.1, 131.7, 130.9, 130.6, 127.1, 122.7, 122.1, 117.6, 116.6, 109.8, 89.4, 80.0, 35.9, 26.9, 23.4, 19.3 ppm; IR (KBr) ν 2949, 2889, 2876, 1645, 1576, 1479, 1371, 1234, 1167, 1138, 997, 883, 810 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{15}BrO_2 + Na]^+$ 401.0153, found 401.0147. Anal. Calcd for $C_{21}H_{15}BrO_2$: C, 66.51; H, 3.99. Found: C, 66.25; H, 3.65.

*7-Bromo-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3f**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 82% (339 mg, 0.82 mmol), mp 175−177 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.57 (s, 1H), 7.35 (d, J = 7.2 Hz, 1H), 7.23 (d, J = 7.8 Hz, 2H), 7.02 (d, J = 7.8 Hz, 2H), 6.91 (d, J = 8.4 Hz, 1H), 4.96 (s, 1H), 2.54−2.68 (m, 4H), 2.42−2.48 (m, 1H), 2.29 (s, 3H), 2.07−2.15 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.3, 165.2, 146.9, 136.9, 131.5, 130.6, 130.4, 127.7, 122.7, 118.8, 117.4, 116.4, 109.7, 88.5, 79.9, 35.7, 26.7, 23.2, 20.4, 19.2 ppm; IR (KBr) ν 2949, 1645, 1574, 1477, 1371, 1337, 1233, 1173, 1134, 997, 822 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{17}O_2Br + Na]^+$ 415.0308, found 415.0304.

*7-Chloro-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3g**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 85% (283 mg, 0.85 mmol), mp 178−180 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.42 (s, 1H), 7.34−7.36 (m, 2H), 7.19−7.23 (m, 4H), 6.98 (d, J = 8.7 Hz, 1H), 4.97 (s, 1H), 2.56−2.73 (m, 4H), 2.38−2.48 (m, 1H), 2.08−2.12 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.3, 165.3, 146.4, 130.7, 129.0, 128.5, 127.6, 127.0, 126.9, 122.1, 121.9, 117.1, 109.5, 89.2, 79.8, 35.7, 26.7, 23.3, 19.2 ppm; IR (KBr) ν 2947, 2889, 1645, 1483, 1373, 1234, 1171, 1136, 999, 808, 761 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{15}O_2Cl + H]^+$ 335.0838, found 335.0833.

*7-Chloro-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3h**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 83% (288 mg, 0.83 mmol), mp 159−161 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.42 (s, 1H), 7.17−7.25 (m, 3H), 6.96−7.04 (m, 3H), 4.96 (s, 1H), 2.54−2.72 (m, 4H), 2.39−2.47 (m, 1H), 2.28 (s, 3H), 2.07−2.13 (m, 2H), ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.3, 165.2, 146.4, 136.9, 130.6, 128.9, 128.6, 127.7, 127.5, 122.2, 118.9, 117.0, 109.6, 88.5, 79.9, 35.7, 26.7, 23.3, 20.4, 19.2 ppm; IR (KBr) ν 2963, 1647, 1578, 1481, 1372, 1261, 1333, 1096, 1024, 802 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{17}O_2Cl + H]^+$ 349.0995, found 349.0990.

*7-Fluoro-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3i**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 87% (276 mg, 0.87 mmol), mp 115−117 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.36 (d, J = 6.3 Hz, 2H), 7.15−7.24 (m, 4H), 6.92−7.05 (m, 2H), 5.00 (s, 1H), 2.57−2.73 (m, 3H), 2.38−2.49 (m, 1H), 2.08−2.12 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.8, 166.9, 160.9 ($^1J_{CF}$ = 243.2 Hz), 145.4, 132.1, 128.4 ($^3J_{CF}$ = 10.6 Hz), 123.5, 118.5 ($^3J_{CF}$ = 8.0 Hz), 116.4 ($^2J_{CF}$ = 23.6 Hz), 116.0 ($^2J_{CF}$ = 23.8 Hz), 110.5, 90.7, 81.2, 37.2, 28.2, 25.1, 20.7 ppm; IR (KBr) ν 2938, 2872, 1645, 1489, 1371, 1194, 999, 831, 758 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{15}O_2F + H]^+$ 319.1134, found 319.1129.

*7-Methyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3j**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 81% (265 mg, 0.81 mmol), mp 114−116 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.23 (d, J = 8.1 Hz, 3H), 7.01 (d, J = 7.8 Hz, 3H), 6.92 (d, J = 8.1 Hz, 1H), 4.96 (s, 1H), 2.54−2.69 (m, 4H), 2.37−2.48 (m, 1H), 2.33 (s, 3H), 2.29 (s, 3H), 2.07−2.11 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.0, 167.1, 147.2, 138.1, 135.2, 132.0, 130.5, 129.5, 129.4, 129.1, 121.7, 120.7, 116.7, 111.4, 90.9, 80.7, 37.3, 28.3, 24.8, 21.7, 21.2, 20.7 ppm; IR (KBr) ν 2963, 2922, 1643, 1562, 1487, 1261, 1229, 1016, 804 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{20}O_2 + H]^+$ 329.1538, found 329.1536.

*3,3-Dimethyl-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3k**).* Petroleum ether/ethyl acetate 16:1, Yellow oil; Yield 70% (229 mg, 0.70 mmol), ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.47 (d, J = 9.0 Hz, 1H), 7.15−7.32 (m, 7H), 7.05 (d, J = 6.0 Hz, 1H), 5.01 (s, 1H), 2.44−2.58 (m, 2H), 2.30−2.39 (m, 2H), 1.17 (s, 3H), 1.13 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.4, 164.9, 149.0, 131.7, 130.0, 128.4, 127.9, 127.7, 125.2, 123.3, 121.5, 116.7, 109.8, 90.8, 80.5, 50.7, 41.5, 32.2, 28.9, 27.6, 24.3 ppm; IR (KBr) ν 2959, 2928, 2852, 1697, 1653, 1487, 1375, 1232, 1172, 1024, 755, 692, 535 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{20}O_2 + H]^+$ 329.1536, found 329.1531.

*3,3-Dimethyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3l**).* Petroleum ether/ethyl acetate 16:1, Yellow oil; Yield 68% (232 mg, 0.68 mmol), ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.44 (d, J = 7.8 Hz, 1H), 7.12−7.27 (m, 4H), 6.99−7.05 (m, 3H), 5.00 (s, 1H), 2.44−2.58 (m, 2H), 2.30−2.43 (m, 2H), 1.17 (s, 3H), 2.28 (s, 3H), 1.13 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.5, 163.8, 147.9, 136.7, 130.5, 129.0, 128.0, 127.7, 127.4, 124.4, 124.2, 120.6, 119.2, 115.7, 108.8, 89.0, 79.6, 49.6, 40.5, 31.1, 27.9, 26.5, 23.2, 20.3 ppm; IR (KBr) ν 2957, 2868, 1672, 1643, 1487, 1464, 1319, 1229, 1159, 814, 756 cm^{-1}; HRMS (ESI) calcd for $[C_{24}H_{22}O_2 + H]^+$ 343.1698, found 343.1693.

*7-Bromo-3,3-dimethyl-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3m**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 73% (296 mg, 0.73 mmol), mp 133−135 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.57 (s, 1H), 7.31−7.36 (m, 3H), 7.21−7.25 (m, 3H), 6.94 (d, J = 8.4 Hz, 1H), 4.95 (s, 1H), 2.30−2.57 (m, 4H), 1.16 (s, 3H), 1.12 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.3, 163.7, 147.2, 131.7, 130.9, 130.6, 127.1, 122.7, 122.1, 117.7, 116.6, 108.6, 89.1, 80.2, 49.8, 40.5, 31.3, 28.1, 26.6, 23.3 ppm; IR (KBr) ν 2963, 1651, 1477, 1371, 1261, 1231, 1173, 1098, 1016, 802 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{19}BrO_2 + H]^+$ 407.0641, found 407.0644.

*7-Bromo-3,3-dimethyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3n**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 76% (319 mg, 0.76 mmol), mp 156−158 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.57 (s, 1H), 7.37 (d, J = 8.4 Hz, 1H), 7.24 (d, J = 7.5 Hz, 2H), 7.05 (d, J = 7.8 Hz, 2H), 6.94 (d, J = 8.7 Hz, 1H), 4.95 (s, 1H), 2.36−2.57 (m, 4H), 2.29 (s, 3H), 1.16 (s, 1H), 1.13 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.5, 164.9, 148.5, 138.3, 133.0, 132.0, 131.8, 129.1, 129.0, 124.2, 120.4, 118.9, 117.9, 110.1, 89.7, 81.6, 51.1, 41.8, 32.6, 32.5, 29.3, 29.2, 27.9, 24.6, 21.8 ppm; IR (KBr) ν 2955, 2868, 1645, 1572, 1476, 1371, 1236, 1169, 1028, 829 cm^{-1}; HRMS (ESI) calcd for $[C_{24}H_{21}O_2Br + H]^+$ 421.0802, found 421.0798.

*7-Chloro-3,3-dimethyl-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3o**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 78% (282 mg, 0.78 mmol), mp 141−143 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.43 (s, 1H), 7.31−7.34 (m, 2H), 7.18−7.25 (m, 4H), 6.97 (d, J = 9.0 Hz, 1H), 4.96 (s, 1H), 2.30−2.56 (m, 4H), 1.16 (s, 3H), 1.12 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.1, 163.6, 146.5, 130.7, 129.0, 128.5, 127.6, 127.0, 126.9, 122.1, 122.0, 117.1, 108.4, 89.0, 80.0, 49.6, 40.3, 31.1, 27.9, 26.4, 23.3 ppm; IR (KBr) ν 2963, 2866, 1651, 1481, 1371, 1233, 1177, 1028, 1016, 820, 764 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{19}O_2Cl + H]^+$ 363.1148, found 363.1146.

*7-Chloro-3,3-dimethyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3p**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 78% (293 mg, 0.78 mmol), mp 152−154 °C; ^{1}HNMR ($CDCl_3$, 300 MHz) δ 7.42 (s, 1H), 7.17−7.25 (m, 3H), 6.96−7.04 (m, 3H), 4.94 (s, 1H), 2.35−2.57 (m, 4H), 2.29 (s, 3H), 1.16 (s, 3H), 1.13 (s, 3H) ppm; ^{13}CNMR (75 MHz, $CDCl_3$) δ 195.2, 163.5, 146.5, 136.9, 130.6, 128.9, 128.5, 127.7, 127.5, 122.2, 118.9, 117.1, 108.5, 88.2, 80.1, 49.6, 40.3, 31.1, 27.9, 26.5, 23.2, 20.4 ppm; IR (KBr) ν 2955, 2870, 1645, 1576, 1508, 1479, 1373, 1236, 1172, 1028, 876, 831 cm^{-1}; HRMS (ESI) calcd for $[C_{24}H_{21}ClO_2 + H]^+$ 377.1309, found 377.1303.

*7-Fluoro-3,3-dimethyl-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3q**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 80% (276 mg, 0.80 mmol), mp 174−176 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.34 (s, 1H), 7.23−7.26 (m, 3H), 7.15 (d, J = 8.4 Hz, 1H), 6.92−7.05 (m, 2H), 4.98 (s, 1H), 2.31−2.58 (m, 4H), 1.17 (s, 3H), 1.14 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.6, 165.1, 160.8 ($^1J_{CF}$ = 233.2 Hz), 145.5, 132.1, 128.4 ($^3J_{CF}$ = 11.7 Hz), 123.5 ($^3J_{CF}$ = 7.1 Hz), 118.5, 116.5 ($^2J_{CF}$ = 23.5 Hz), 116.1 ($^2J_{CF}$ = 24.0 Hz),

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109.4, 90.4, 81.4, 51.1, 41.9, 32.6, 29.3, 27.9, 25.0 ppm; IR (KBr) ν 2957, 2868, 1647, 1491, 1373, 1260, 1211, 1196, 1030, 918, 822 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{19}O_2F + H]^+$ 347.1142, found 347.1147.

*3,3,7-Trimethyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3r**).* Petroleum ether/ethyl acetate 16:1, White oil; Yield 78% (277 mg, 0.78 mmol), mp 134−136 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.23 (d, J = 7.8 Hz, 3H), 7.02 (d, J = 7.5 Hz, 3H), 6.94 (d, J = 8.1 Hz, 1H), 4.95 (s, 1H), 2.35−2.50 (m, 4H), 2.32 (s, 3H), 2.28 (s, 3H), 1.16 (s, 3H), 1.12 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.4, 165.0, 146.9, 137.7, 134.8, 131.6, 130.1, 129.1, 128.7, 125.5, 121.2, 120.3, 116.4, 109.8, 90.2, 80.5, 50.7, 41.5, 32.1, 28.9, 27.8, 27.5, 24.3, 21.4, 20.8 ppm; IR (KBr) ν 2949, 2864, 1647, 1591, 1508, 1494, 1373, 1231, 1207, 1026, 820 cm^{-1}; HRMS (ESI) calcd for $[C_{25}H_{24}O_2 + H]^+$ 357.1853, found 357.1849.

*9-((4-Fluorophenyl)ethynyl)-3,3-dimethyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3s**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 70% (257 mg, 0.70 mmol), mp 103−105 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.44 (d, J = 7.2 Hz, 1H), 7.24−7.33 (m, 3H), 7.15−7.20 (m, 1H), 7.04 (d, J = 8.1 Hz, 1H), 6.87−6.95 (m, 2H), 4.99 (s, 1H), 2.32−2.60 (m, 4H), 1.18 (s, 3H), 1.14 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.8, 165.3, 163.5 ($^1J_{CF}$ = 246.7 Hz), 149.3, 134.0 ($^3J_{CF}$ = 7.8 Hz), 130.3, 128.9, 125.7, 119.8, 117.2, 115.7 ($^2J_{CF}$ = 21.3 Hz), 110.1, 90.9, 79.9, 51.1, 41.9, 32.6, 29.3, 28.0, 24.7 ppm; IR (KBr) ν 2957, 2868, 1643, 1582, 1506, 1377, 1233, 1148, 1034, 1015, 835 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{19}O_2F + Na]^+$ 369.1266, found 369.1261.

*3-Methyl-9-(phenylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3t**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 91% (285 mg, 0.91 mmol), mp 134−136 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.47 (d, J = 7.5 Hz, 1H), 7.31−7.35 (m, 2H), 7.13−7.28 (m, 5H), 7.02−7.06 (m, 1H), 5.00 (s, 1H), 2.07−2.72 (m, 5H), 1.12 (t, J = 5.7 Hz, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.6, 166.3, 165.6, 148.9, 148.8, 131.7, 130.0, 128.5, 128.4, 128.3, 128.0, 127.8, 125.3, 123.3, 121.6, 121.3, 116.7, 110.6, 110.3, 91.1, 80.4, 45.1, 35.9, 28.5, 27.7, 24.5, 20.8 ppm; IR (KBr) ν 2957, 2897, 1638, 1582, 1487, 1456, 1379, 1231, 1165, 1132, 1018, 754 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{18}O_2 + H]^+$ 315.1380, found 315.1385.

*3-Methyl-9-(p-tolylethynyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**3u**).* Petroleum ether/ethyl acetate 16:1, White solid; Yield 73% (289 mg, 0.73 mmol), mp 120−122 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.47 (d, J = 7.5 Hz, 1H), 7.12−7.26 (m, 4H), 6.96−7.05 (m, 3H), 4.99 (s, 1H), 2.37−2.72 (m, 4H), 2.35 (s, 3H), 2.07−2.34 (m, 1H), 1.12 (t, J = 6.0 Hz, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.7, 165.4, 164.6, 148.0, 136.8, 130.7, 129.2, 128.2, 127.8, 127.5, 124.6, 124.3, 120.9, 120.6, 119.4, 115.8, 109.9, 109.5, 89.5, 79.6, 44.3, 35.1, 27.6, 26.8, 23.6, 20.5, 20.0 ppm; IR (KBr) ν 2949, 2918, 2870, 1668, 1651, 1580, 1487, 1456, 1342, 1234, 1171, 1018, 889, 812, 762 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{20}O_2 + H]^+$ 329.1536, found 329.1535.

*9-Phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5a**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 95% (262 mg, 0.95 mmol), mp 122−123 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.02−7.25 (m, 9H), 5.06 (s, 1H), 2.59−2.76 (m, 2H), 2.29−2.47 (m, 2H), 1.97−2.10 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.4, 166.7, 148.8, 146.6, 130.5, 128.8, 128.3, 128.0, 126.8, 125.8, 125.5, 116.9, 115.1, 38.2, 37.4, 28.3, 20.8 ppm; IR (KBr) ν 2947, 2364, 1653, 1636, 1486, 1374, 1236, 1224, 1171, 991, 768, 712, 528, 482 cm^{-1}; HRMS (ESI) calcd for $[C_{19}H_{16}O_2 + H]^+$ 277.1223, found 277.1220.

*5-Methoxy-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5b**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 85% (260 mg, 0.85 mmol), mp 156−157 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.11−7.26 (m, 5H), 6.96 (t, J = 8.1 Hz, 1H), 6.76(d, J = 8.1 Hz,1H), 6.69(d, J = 7.8 Hz, 1H), 5.04 (s, 1H), 3.92 (s, 3H), 2.64−2.87 (m, 2H), 2.35−2.45 (m, 2H), 2.00−2.06 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.4, 166.4, 148.2, 146.4,139.5, 128.8, 128.3, 126.8, 126.8, 125.2, 121.9, 115.1, 110.2, 56.5, 38.2, 37.4, 28.3, 20.8 ppm; IR (KBr) ν 3007, 2944, 2891, 1637, 1610, 1581, 1484, 1385, 1327, 1276, 1227, 1186, 1097, 765, 731, 537 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{18}O_3 + H]^+$ 307.1329, found 307.1325. Anal. Calcd for $C_{20}H_{18}O_3$: C, 78.41; H, 5.92. Found: C, 78.74; H, 5.63.

*6-Methoxy-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5c**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 87% (266 mg, 0.87 mmol), mp 144−145 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.20−7.26 (m, 4H), 7.08−7.18 (m, 1H), 6.97−7.00 (m, 1H), 6.59−6.62 (m, 2H), 4.99 (s, 1H), 3.78 (s, 3H), 2.63−2.75 (m, 2H), 2.34−2.41 (m, 2H), 1.98−2.08 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.4, 166.4, 159.4, 146.8, 131.0, 128.8, 128.2, 126.6, 117.9, 115.5, 112.1, 101.8, 55.9, 37.6, 37.4, 28.3, 20.8 ppm; IR (KBr) ν 2964, 2934, 1637, 1508, 1370, 1288, 1218, 1108, 1031, 995, 850, 794, 695, 540, 503 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{18}O_3 + H]^+$ 307.1329, found 307.1326.

*7-Methyl-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5d**).* Petroleum ether/ethyl acetate 8:1, Gray solid; Yield 92% (266 mg, 0.92 mmol), mp 141−142 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.21−7.25 (m, 3H), 7.10−7.14 (m, 1H), 6.96 (s, 2H), 6.88 (s, 1H), 5.00 (s, 1H), 2.62−2.74 (m, 2H), 2.33−2.43 (m, 2H), 2.20 (s, 3H), 1.98−2.06 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.3, 166.7, 147.9, 146.7, 135.0, 130.6, 128.8, 128.7, 128.3, 126.7, 125.4, 116.5, 115.1, 38.3, 37.4, 28.3, 21.1, 20.8 ppm; IR (KBr) ν 2886, 1642, 1588, 1494, 1455, 1375, 1218, 1126, 997, 920, 813, 750, 717, 617, 528 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{18}O_2 + H]^+$ 291.1380, found 291.1384.

*7-Chloro-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5e**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 82% (254 mg, 0.82 mmol), mp 170−172 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.15−7.24 (m, 5H), 7.00−7.12 (m, 3H), 5.00 (s, 1H), 2.63−2.72 (m, 2H), 2.35−2.41 (m, 2H), 2.02−2.06 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.1, 166.3, 148.4, 145.9, 130.2, 130.1, 129.0, 128.3, 128.2, 127.4, 127.1, 118.3, 114.7, 38.3, 37.3, 28.2, 20.7 ppm; IR (KBr) ν 3075, 2964, 2896, 1668, 1649, 1576, 1477, 1378, 1230, 1177, 1133, 999, 927, 845, 699, 593, 528 cm^{-1}; HRMS (ESI) calcd for $[C_{19}H_{15}ClO_2 + H]^+$ 311.0833, found 311.0830.

*7-Bromo-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5f**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 85% (300 mg, 0.85 mmol), mp 183−184 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.15−7.29 (m, 7H), 6.96 (d, J = 8.7 Hz, 1H), 5.00 (s, 1H), 2.57−2.77 (m, 2H), 2.29−2.41 (m, 2H), 1.97−2.11 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.1, 166.3, 148.9, 145.9, 133.1, 131.1, 129.0, 128.3, 127.9, 127.1, 118.7, 117.8, 114.8, 38.2, 37.3, 28.2, 20.7 ppm; IR (KBr) ν 3084, 2964, 2920, 2867, 1666, 1644, 1569, 1472, 1453, 1373, 1334, 1232, 1181, 1167, 1128, 1068, 997, 925, 886, 828, 693, 593, 525 cm^{-1}; HRMS (ESI) calcd for $[C_{19}H_{15}BrO_2 + H]^+$ 355.0328, found 355.0326. Anal. Calcd for $C_{19}H_{15}BrO_2$: C, 64.14; H, 4.26. Found: C, 64.19; H, 4.38.

*5,7-Dibromo-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5g**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 83% (358 mg, 0.83 mmol), mp 173−174 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.55 (s, 1H), 7.17−7.26 (m, 6H), 5.00 (s, 1H), 2.70−2.85 (m, 2H), 2.36−2.42 (m, 2H), 2.00−2.11 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.9, 166.1, 146.1, 145.3, 134.2, 132.2, 129.1, 128.2, 127.3, 117.6, 115.2, 112.0, 38.7, 37.3, 28.0, 20.7 ppm; IR (KBr) ν 3070, 2954, 1666, 1651, 1588, 1554, 1491, 1448, 1375, 1235, 1177, 1002, 862, 729, 678, 625, 537, 482 cm^{-1}; HRMS (ESI) calcd for $[C_{19}H_{14}Br_2O_2 + H]^+$ 432.9433, found 432.9430.

*7-Nitro-9-phenyl-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5h**).* Petroleum ether/ethyl acetate 8:1, Yellow solid; Yield 78% (250 mg, 0.78 mmol), mp 242−243 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 8.02−8.09 (m, 2H), 7.15−7.34 (m, 6H), 5.09 (s, 1H), 2.69−2.82 (m, 2H), 2.38−2.49 (m, 2H), 2.03−2.14 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.8, 165.6, 153.9, 145.2, 145.0, 129.2, 128.2, 127.5, 126.6, 123.9, 117.9, 114.9, 38.3, 37.3, 28.0, 20.7 ppm; IR (KBr) ν 3099, 3056, 2944, 1673, 1654, 1576, 1518, 1450, 1370, 1341, 1240, 1277, 1126, 997, 922, 842, 702, 530 cm^{-1}; HRMS (ESI) calcd for $[C_{19}H_{15}NO_4 + H]^+$ 322.1074, found 322.1072.

*9-(p-Tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5i**).* Petroleum ether/ethyl acetate 8:1, Yellow solid; Yield 90% (261 mg, 0.90 mmol), mp 120−121 °C; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.05−7.17 (m, 5H), 6.99−7.02 (m, 3H), 5.01 (s, 1H), 2.59−2.74 (m, 2H), 2.31−2.43 (m, 2H), 2.24 (s, 3H), 1.96−2.07 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.4, 166.5, 149.8, 143.8, 136.3, 130.4, 129.5, 128.2, 127.9, 126.0, 125.4, 116.8, 115.3, 37.8, 37.4, 28.3, 21.4, 20.8 ppm; IR (KBr) ν

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2944, 2900, 2866, 1639, 1949, 1918, 1806, 1637, 1610, 1578, 1508, 1487, 1455, 1378, 1336, 1252, 1240, 1179, 1128, 995, 867, 838, 825, 755, 637, 620, 598 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{18}O_2 + H]^+$ 291.1380, found 291.1385.

*7-Methyl-9-(p-tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5j**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 88% (267 mg, 0.88 mmol), mp 127−128 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.02−7.13 (m, 4H), 6.95 (s, 2H), 6.88(s, 1H), 4.97 (s, 1H), 2.61−2.69 (m, 2H), 2.33−2.38 (m, 2H), 2.25 (s, 3H), 2.20 (s, 3H), 2.00−2.04 (m, 2H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 197.5, 166.7, 147.8, 143.9, 136.2, 135.0, 130.6, 129.5, 128.6, 128.2, 125.6, 116.5, 115.2, 37.8, 37.4, 28.3, 21.4, 21.2, 20.8 ppm; IR (KBr) ν 2959, 2867, 1654, 1634, 1586, 1491, 1375, 1249, 1213, 1126, 995, 823, 779, 615, 520, 496 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{20}O_2 + H]^+$ 305.1536, found 305.1531.

*7-Chloro-9-(p-tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5k**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 80% (259 mg, 0.80 mmol), mp 172−173 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.99−7.13 (m, 7H), 4.96 (s, 1H), 2.59−2.75 (m, 2H), 2.33−2.44 (m, 2H), 2.26 (s, 3H), 1.97−2.10 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 166.2, 148.3, 143.1, 136.7, 130.2, 130.1, 129.7, 128.1, 128.0, 127.7, 118.3, 114.8, 37.9, 37.3, 28.2, 21.4, 20.7 ppm; IR (KBr) ν 2954, 1665, 1644, 1576, 1508, 1477, 1375, 1227, 1186, 1174, 1128, 999, 917, 840, 823, 726, 670, 615, 525, 508, 453 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{17}ClO_2 + H]^+$ 325.0990, found 325.0989.

*7-Bromo-9-(p-tolyl)--2,3,4,9-tetrahydro-1H-xanthen-1-one (**5l**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 80% (294 mg, 0.80 mmol), mp 184−186 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.18−7.27 (m, 2H), 7.03−7.14 (m, 4H), 6.95 (d, J = 8.7 Hz, 1H), 4.96 (s,1H), 2.62−2.70 (m, 2H), 2.32−2.40 (m, 2H), 2.26 (s, 3H), 1.96−2.07 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 166.2, 148.3, 143.1, 136.7, 130.2, 130.1, 129.7, 128.1, 128.0, 127.7, 118.3, 114.8, 37.9, 37.3, 28.2, 21.4, 20.7 ppm; IR (KBr) ν 2959, 2920, 1666, 1644, 1569, 1472, 1375, 1232, 1179, 1167, 1128, 999, 915, 830, 724, 605, 547, 528 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{17}BrO_2 + H]^+$ 369.0485, found 369.0480.

*5,7-Dibromo-9-(p-tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5m**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 78% (347 mg, 0.78 mmol), mp 148−149 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.54 (s, 1H), 7.05−7.17 (m, 5H), 4.97 (s,1H), 2.70−2.85 (m, 2H), 2.32−2.46 (m, 2H), 2.27 (s, 3H), 2.02−2.08 (m, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.9, 166.0, 146.1, 142.5, 137.0, 134.1, 132.2, 129.8, 129.4, 128.1, 117.6, 115.3, 112.0, 38.3, 37.3, 28.0, 21.4, 20.7 ppm; IR (KBr) ν 3070, 2944, 2886, 1671, 1651, 1557, 1511, 1450, 1368, 1242, 1181, 999, 830, 811, 620, 532, 506 cm^{-1}; HRMS (ESI) calcd for $[C_{20}H_{16}Br_2O_2 + H]^+$ 446.9590, found 446.9585.

*3,3-Dimethyl-9-phenyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5n**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 92% (280 mg, 0.92 mmol), mp 141−142 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.05−7.25 (m, 9H), 5.03 (s,1H), 2.55 (s, 2H), 2.25 (m, 2H), 1.12 (s, 3H), 1.03 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 164.9, 149.8, 146.5, 130.5, 128.8, 128.2, 128.0, 126.7, 125.8, 125.4, 116.9, 113.9, 51.2, 42.0, 38.3, 32.5, 30.0, 27.8 ppm; IR (KBr) ν 2964, 2935, 1664, 1644, 1579, 1487, 1453, 1373, 1237, 1012, 765, 699, 542 cm^{-1}; HRMS (ESI) calcd for $[C_{21}H_{20}O_2 + H]^+$ 305.1536, found 305.1531.

*6-Methoxy-3,3-dimethyl-9-(p-tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5o**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 82% (285 mg, 0.82 mmol), mp 132−133 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.97−7.22 (m, 5H), 6.61 (m, 2H), 4.96 (s, 1H), 3.77 (s, 3H), 2.54 (s, 2H), 2.24 (m, 2H), 1.12 (s, 3H), 1.03 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.2, 164.7, 159.4, 150.4, 146,7, 131.0, 128.7, 128.2, 126.6, 117.9, 114.2, 112.1, 101.9, 55.8, 51.2, 42.0, 37.8, 32.5, 29.6, 27.8 ppm; IR (KBr) ν 2959, 1644, 1508, 1373, 1286, 1218, 1165, 1143, 1116, 1036, 867, 784, 697, 557, 525 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{24}O_3 + H]^+$ 349.1798, found 349.1794.

*7-Chloro-3,3-dimethyl-9-(p-tolyl)-2,3,4,9-tetrahydro-1H-xanthen-1-one (**5p**).* Petroleum ether/ethyl acetate 8:1, White solid; Yield 80% (281 mg, 0.80 mmol), mp 146−147 °C; ^1H NMR ($CDCl_3$, 300 MHz) δ 6.98−7.11 (m, 7H), 4.93 (s, 1H), 2.54 (s, 2H), 2.17−2.30 (m, 5H), 1.12 (s, 3H), 1.03 (s, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.0, 164.5, 148.3, 143.0, 136.6, 130.2, 130.1, 129.7, 128.1, 128.0, 118.3, 113.5, 51.2, 41.8, 38.0, 32.6, 29.7, 27.8, 21.4 ppm; IR (KBr) ν 2959, 1671, 1651, 1482, 1472, 1373, 1230, 1172, 1123, 1019, 881, 828, 724, 654, 593, 540, 518 cm^{-1}; HRMS (ESI) calcd for $[C_{22}H_{21}ClO_2 + H]^+$ 353.1300, found 353.1303.

*2-(1-(2-Hydroxyphenyl)-3-phenylprop-2-yn-1-yl)-5,5-dimethylcyclohexane-1,3-dione (**3k′**).* Petroleum ether/ethyl acetate 8:1, Yellow oil, Yield 70% (242 mg, 0.70 mmol), ^1H NMR ($CDCl_3$, 300 MHz) δ 9.02 (s, 1H), 7.59−7.61 (m, 2H), 7.35−7.40 (m, 2H), 7.16−7.28 (m, 3H), 7.04−7.06 (m, 1H), 6.89−6.94 (m, 1H), 5.70 (d, J = 1.8 Hz, 1H), 5.30 (s, 1H), 2.61 (s, 2H), 2.32 (s, 2H), 1.17 (s, 3H), 1.10 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$) δ 196.6, 175.6, 157.3, 155.2, 134.4, 130.4, 129.1, 129.0, 128.9, 128.1, 127.5, 122.2, 120.4, 118.3, 108.5, 50.6, 43.3, 35.1, 29.1, 29.0 ppm; IR (KBr) ν 3448, 2964, 1680, 1627, 1593, 1455, 1419, 1402, 1278, 1227, 1024, 884, 755, 690 cm^{-1}; HRMS (ESI) calcd for $[C_{23}H_{22}O_3 + H]^+$ 347.1642, found 347.1641.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b00001.

Spectral data for all compounds and crystallographic data of compounds **3e** and **5b** (PDF)

Crystallographic data of compound **3e** (CIF)

Crystallographic data of compound **5b** (CIF)

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Notes

The authors declare no competing financial interest.

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In Table 3, entry 15, compound number **4c** was changed to **4n**; the correct version reposted on February 24, 2016.

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