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One-Pot Synthesis of 1,5-Diketones under a Transition-Metal-Free Condition: Application in the Synthesis of 2,4,6-Triaryl Pyridine Derivatives

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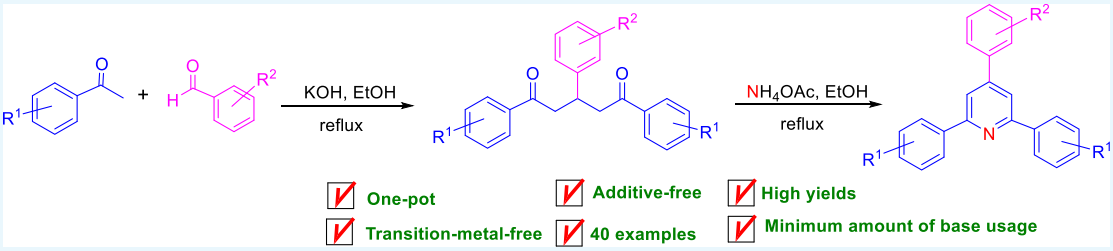

ABSTRACT: We developed a facile and green one-pot synthetic method for substituted 1,3,5-triaryl-1,5-diketones by Claisen–Schmidt condensation following Michael addition reaction of aryl ketones and aryl aldehydes under a transition-metal-free condition. This convenient one-pot synthetic strategy has several advantages, including being transition-metal-free, having no extra additives or reagents, having a broad substrate scope, having a high isolated yield, having a minimum amount of base employment, having a shorter reaction time, use of cheap starting materials, cost-effectiveness, and being environment friendly. Some of the chemical structures of 1,5-diketones were confirmed by X-ray single-crystal diffraction analysis. The application of 1,5-diketones was demonstrated in the preparation of 2,4,6-triaryl pyridine derivatives under a catalyst-free system using ammonium acetate as a nitrogen source.

INTRODUCTION

In the construction of natural products, medicinal compounds, functionalized five- or six-membered-ring heterocycles, and polycyclic aromatic compounds, 1,5-diketones have been used as important building blocks.[1−3] In particular, 1,5-diones are key intermediates in the synthesis of various heterocyclic compounds such as substituted pyridines,[1,4−9] quinolines,[10,11] pyrylium,[12] pyrylogen,[13,14] and 2-aroyl-3,5-diarylthiophenes.[15] These heterocycles have important applications in modern drug design and in the chemistry of functional materials.[6] Consequently, much effort has been devoted to the chemical synthesis of 1,5-diketones.[8,9,16] The most common classical methods of 1,5-diones synthesis are (i) Claisen–Schmidt condensation following Michael addition reaction of aryl methyl ketones and benzaldehyde derivatives under a basic condition[17−25] and using silica vanadic acid as a heterogeneous catalyst[26] (Scheme 1a), (ii) catalyzed Michael reactions of chalcones (α,β-unsaturated ketones) with aryl methyl ketones,[27] silyl enol ethers,[28,29] and diphenacyl sulfides[30] (Scheme 1b), (iii) from α,β-unsaturated ketones via base-induced retro-aldol and Michael addition using copper and cobalt as catalysts,[31,32] (Scheme 1c), (iv) via nickel on silica-alumina-catalyzed direct α-alkylation of aryl methyl ketones with benzyl alcohol[33] (Scheme 1d), and (v) silver- and rhodium-catalyzed reactions of aromatic and aliphatic aldehydes with cyclopropanol and cyclobutanol derivatives.[1,34] However, these synthetic methods use expensive catalysts and additives, toxic organic solvents, and air- and moisture-sensitive materials. Additionally, the yields of 1,5-diketones through these reactions were low either due to by-product formation such as aromatic aldehydes[31,32] or no product formation at all under base-mediated condensation.[22] Hence, the search for an efficient synthetic method for 1,5-diketones based on inexpensive starting materials should be given high attention in organic chemistry.

Over the past decades, one-pot or multi-component reactions have been widely employed in organic synthesis because of their synthetic efficiency relative to the step-wise reactions.[5,35−37] Moreover, these synthetic strategies have several advantages, including cost-effectiveness, high product yield, intrinsic atom economy, short reaction time, simple experimental procedure, and minimum wastage. Although there have been significant developments in the one-pot synthetic method, the previous approaches for 1,5-diketone synthesis were conducted in the

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Scheme 1. Synthetic Methods of 1,5-Diketones

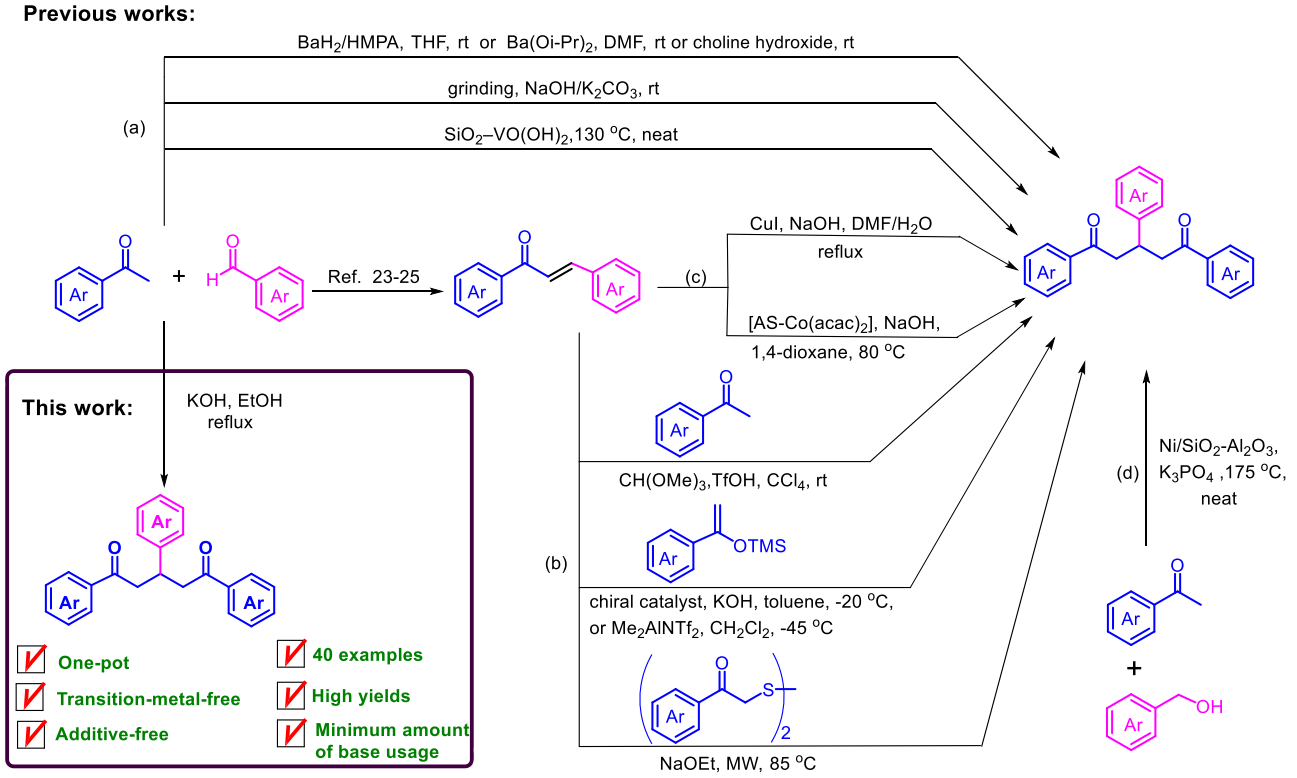
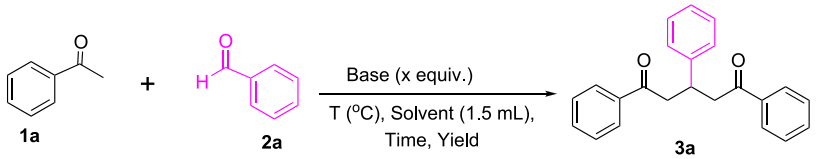


Table 1. Optimization of the Reaction Conditions for Synthesis of 3a[a] in One Pot



entry	base (equiv)	*T* (°C)	solvent	time (h)	yield (%)[b]
1	KOH (1.0)	Rt	EtOH	18	37
2	KOH (2.0)	Rt	EtOH	18	40
3	KOH (2.0)	Rt	EtOH	12	36
4	KOH (1.0)	reflux	EtOH	3	62
5	KOH (2.0)	reflux	EtOH	3	49
6	KOH (1.0)	reflux	MeOH	3	49
7	KOH (1.0)	reflux	MeCN	3	60
8	NaOH (1.0)	reflux	EtOH	3	55
9	NaOH (1.0)	reflux	MeOH	3	47
10	NaOH (2.0)	reflux	EtOH	3	52

[a]Reaction conditions: **1a** (1.88 mmol, 2.0 equiv), 2a (0.94 mmol, 1.0 equiv). [b]Isolated yields.

presence of additives or ligands as well as expensive and toxic catalysts (Scheme 1a,d). To overcome such limitations, the development of a facile, inexpensive, expedient, and efficient synthetic method is yet to be explored.

In continuation of our efforts on the development of efficient synthetic methods for the generation of heterocyclic compounds,[38−40] we report here a facile and green one-pot synthetic method for substituted 1,3,5-triaryl-1,5-diketones through aldol condensation of aryl ketones and aryl aldehydes with subsequent Michael addition reaction under the transition-metal-free condition.

RESULTS AND DISCUSSION

Initially, we selected relatively low-cost acetophenone (**1a**) and benzaldehyde (**2a**) as model substrates for the synthesis of 1,5-dione **3a** in one pot. Accordingly, 2 equiv of compound **1a** were dissolved in anhydrous ethanol in the presence of 1 equiv of aqueous KOH and the reaction mixture was stirred for 0.25 h at 0 °C. After the enol formation was ensured, 1 equiv of benzaldehyde (**2a**) was added and the reaction temperature was raised to room temperature (rt) to afford the well-known 1,5-diketone **3a**[31] at a yield of 37% over 18 h (Table 1, entry 1). The yield of 1,5-dione **3a** was slightly improved to 40% upon employing 2 equiv of KOH under the same temperature and

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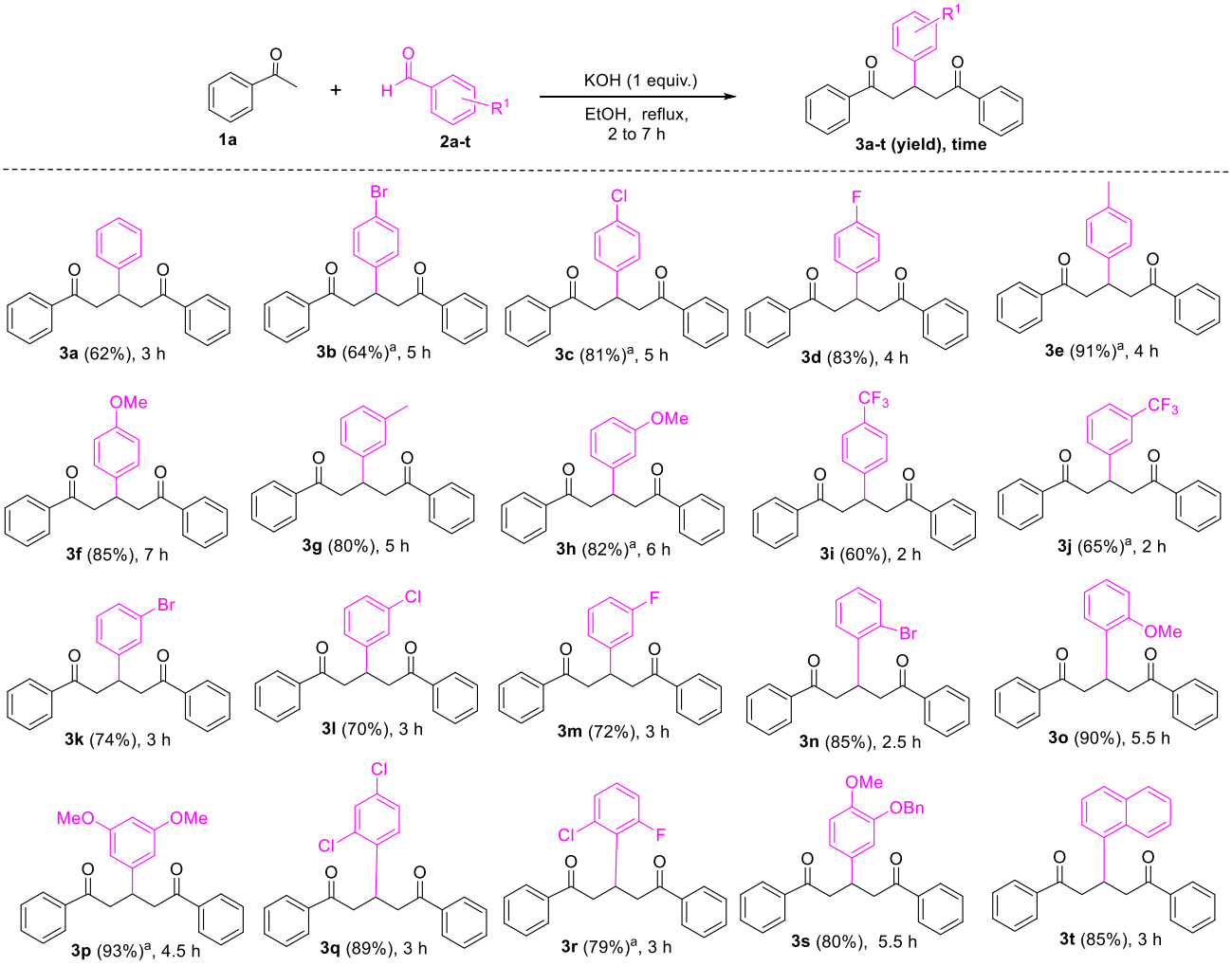
Table 2. Substrate Scope with Respect to Aryl Aldehydes 2



[a]Dichloromethane (0.5 mL) was added to dissolve the aldehydes **2b**, **2c**, **2e**, **2h**, **2j**, **2p**, and **2r**.

reaction time (Table 1, entry 2); however, the yield declined to 36% with a shorter reaction time (Table 1, entry 3).

To further prepare 1,5-diketone **3a** in a high yield, we refluxed the reaction mixture under a reduced reaction time. Gratifyingly, 62% yield of **3a** was produced using 1 equiv of KOH under refluxing for 3 h (Table 1, entry 4). However, the reaction yield decreased to 49% with an increased amount of KOH at the same reaction time. We also evaluated the effect of solvent types on the product yield under the same length of reaction time (Table 1, entries 6−10). In line with this, acetonitrile (MeCN) gave better efficiency (60%) than methanol (49%) with the same quantity of KOH (1 equiv). Changing bases such as NaOH did not significantly improve the yield of **3a** in the different solvents (Table 1, entries 8−10) with the exception of a relatively better yield in ethanol than in methanol.

Therefore, the optimized reaction conditions for the one-pot synthesis of **3a** were taken to be 1 equiv of KOH as base, ethanol as solvent, and refluxing (Table 1, entry 4). The one-pot synthetic strategy produced compound **3a** in line with the principles of green chemistry.[41] The ^{1}H NMR, ^{13}C NMR, and mass spectrometry data of **3a** are in good agreement with the reported data.[34]

After having established the optimized reaction conditions for the one-pot synthesis of **3a**, we studied the substrate scope of KOH-mediated reactions using several substituted aryl aldehydes (**2b-t**) and acetophenone (**1a**), and the results are summarized in Table 2. Thus, the Claisen−Schmidt condensation-Michael addition reaction of aryl methyl ketone (**1a**) with aryl aldehydes (**2c−h** and **2n−s**), which bear different mono- or di-substituents such as bromide at the ortho-position and chlorides, fluorides, methyl, and methoxy at different positions on their benzene ring reacted smoothly to produce the corresponding 1,5-diketones **3c−h** and **3n−s** in high yields ranging from 79 to 93% under the same reaction condition.

Similarly, benzaldehyde derivatives containing trifluoromethyl functionality at both para- and meta-positions (**2i** and **2j**), chloro and fluoro substituents at the meta-position (**2l** and **2m**), and bromo groups at both para- and meta-positions (**2b** and **2k**) offered good yields (60−74%) of the respective products (**3b**, **3i−m**). Similarly, the yield of 1,5-dicarbonyl **3t** was 85% through the aldol reaction of **1a** with the aldehyde bearing two fused benzene rings (**2t**) followed by a Michael reaction. The reaction time of aryl ketone **1a** with benzaldehyde derivatives **2** possessing an electron-withdrawing group was observed to be shorter (2−3 h) than those aldehydes which contained electron-donating substituents (4−7 h). This observation was also supported by Kamble and Shankarling.[22]

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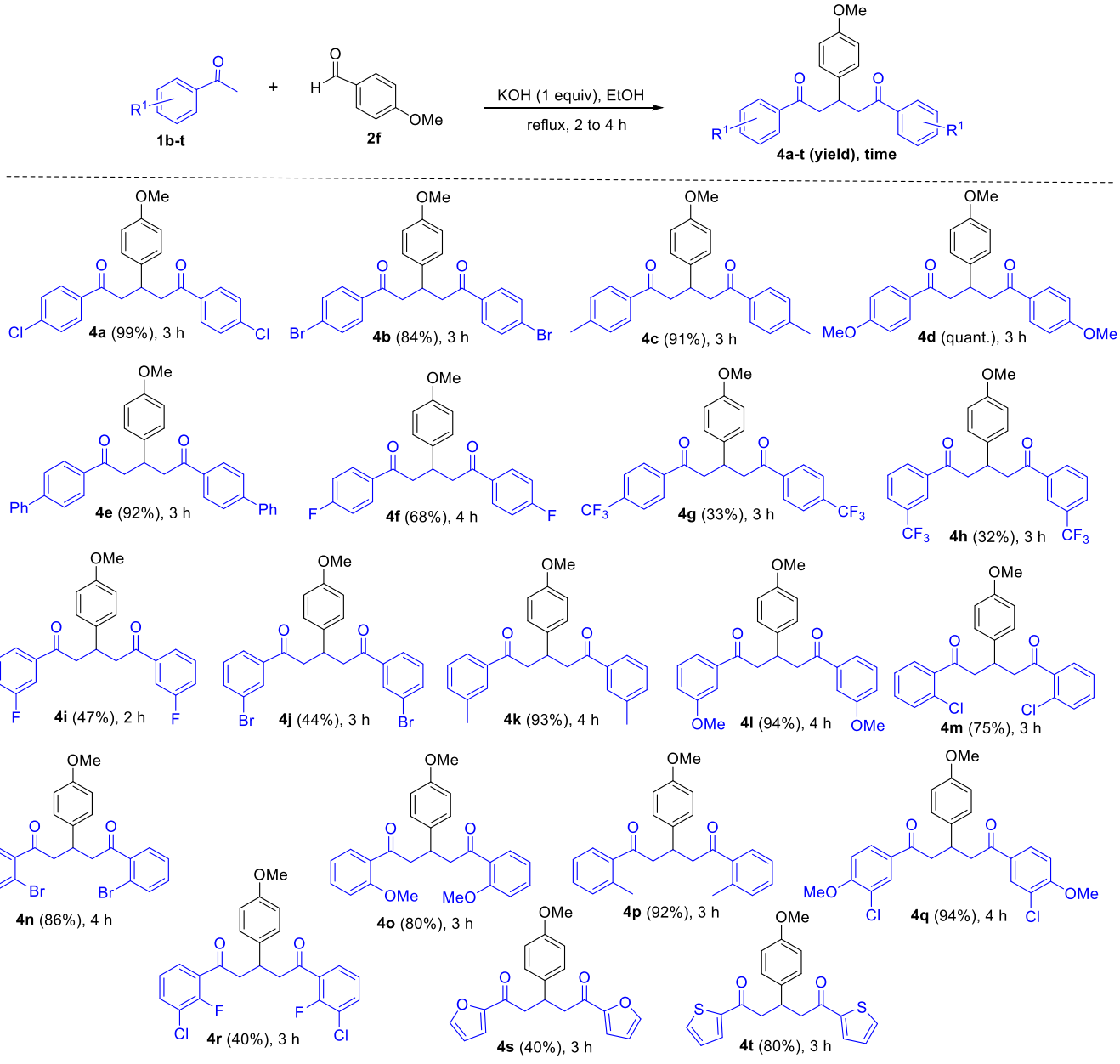
Table 3. Substrate Scope of Substituted Aryl Ketones 1



Next, we evaluated the aldol condensation reaction of 4-methoxybenzaldehyde (**2f**) with numerous aryl methyl ketones (**1b−t**) having electron-donating and electron-withdrawing substituents on the aromatic rings under the established optimized condition (Table 3).

The reaction of aryl methyl ketones with methyl, methoxy, phenyl, bromo, and chloro groups present on the aryl rings occurred efficiently with the aldehyde **2f** to produce the corresponding 1,5-diketones **4a−e**, **4k**, **4l**, and **4n−q** in very good to excellent yields (80% to quantitative) regardless of the presence of their substituents at the para-, meta-, and ortho-positions. On the other hand, the sequential Claisen−Schmidt condensation-Michael addition reaction of **2f** with substituted acetophenones such as 4′-fluoroacetophenone (**1f**), 4′-(trifluoromethyl)acetophenone (**1g**), 3′-(trifluoromethyl)-acetophenone (**1h**), 3′-fluoroacetophenone (**1i**), 3′-bromoacetophenone (**1j**), and 3′-chloro-2′-fluoroacetophenone (**1r**) produced poor to moderate yields (32−68%) of 1,5-dicarbonyls **4f−j** and **4r**. The poor yields of the products such as **4g**, **4h**, and **4r** may be attributed to the high electron-withdrawing nature of the substituents on the aryl substrates. The scope of the reaction was further examined on simple heterocyclic aromatic compounds. Therefore, the condensation reaction of **2f** with 2-acetylthiophene (**1t**) offered a very good yield (80%) of **4t**, whereas the reaction of 2-acetylfuran (**1s**) with **2f** produced 1,5-dione **4s** in unsatisfactory yield (40%).

The chemical structures of 1,5-dicarbonyls **3o**, **3q**, **3t**, **4e**, and **4r** were confirmed by single X-ray crystallography (Figure 1).[42]

Upon comparison with the previous reports,[19,22,27] we propose a possible reaction mechanism for the KOH-promoted synthesis of 1,5-diketones in one pot (Scheme 2). Initially, KOH abstracts the α-proton of **1a** to give the enolate specie **A**. Next, nucleophilic addition of enol **A** to the carbonyl carbon of **2a** affords the oxyanion **B**, which is then protonated from water to

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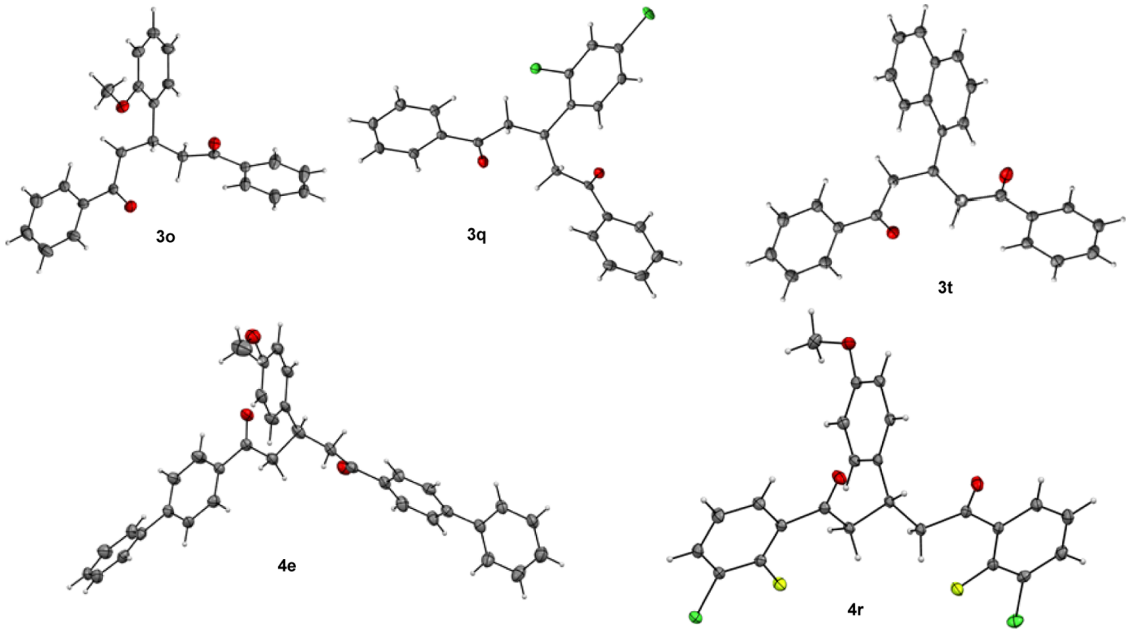


Figure 1. Single X-ray crystal structure of 1, 5-dicarbonyls **3o**, **3q**, **3t**, **4e**, and **4r**.

Scheme 2. Plausible Mechanism for the One-Pot Synthesis of 1, 5-Diketone 3a

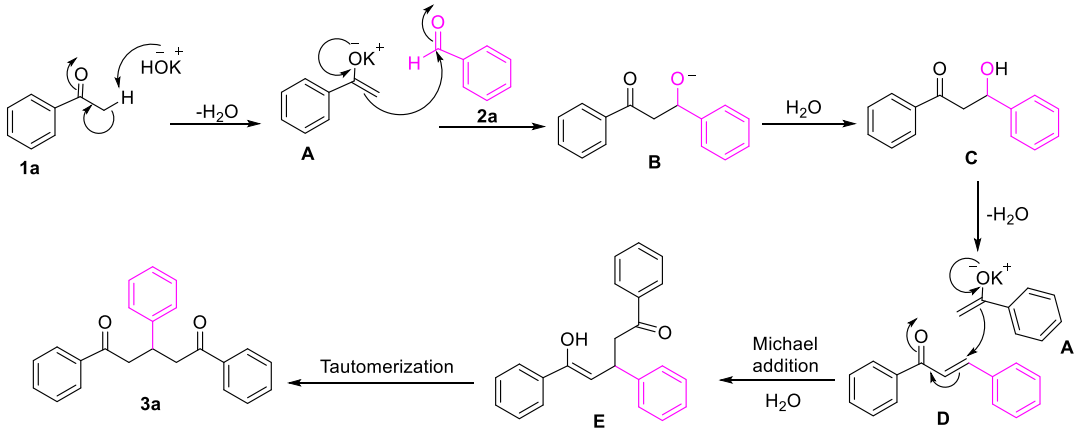
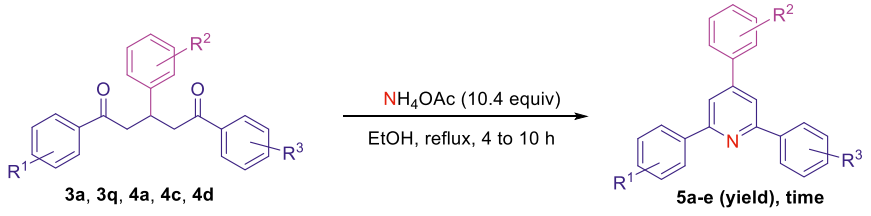
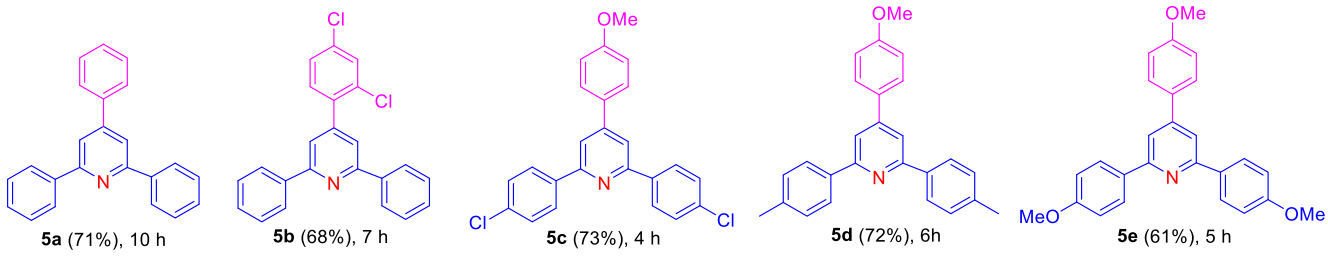


Table 4. Catalyst-Free Cyclization of 1,5-Diketones into 2,4,6-Triaryl Pyridine Derivatives





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provide the aldol addition product **C**. The β-hydroxy-ketone **C** is then subjected to dehydration reaction under heating to generate the chalcone **D**. Subsequently, a second nucleophile **A** attacks the β-position of the α,β-unsaturated ketone **D** through Michael addition and hydrolysis reaction to generate the enol **E**. Finally, tautomerization of **E** affords the desired 1,5-diketone **3a**.

As stated above, 1,5-diketones are versatile intermediates for the synthesis of heterocyclic compounds that have significant applications in modern drug design and in functional material chemistry. Functionalized pyridines are among the most common heterocyclic compounds that have been used in therapeutic drugs,[5,43] chemosensors,[44] photosensitizers,[45] as ligands for catalysis,[46] and as starting materials in the synthesis of agricultural chemicals such as insecticides, herbicides, and surfactants.[47] Thus, several synthetic methods have been established to produce 2,4,6-triaryl pyridine derivatives.[48−56] The most common approach for the synthesis of substituted pyridine is ammonium acetate (NH_4OAc)-mediated cyclization of 1,5-diketones.[54,57−62] Accordingly, the treatment of 1,5-diketones **3** and **4** with NH_4OAc as a nitrogen source successfully produced good yields of the reported pyridine-based molecules **5a−e**[53,55,63,64] within a moderate reaction time under a catalyst-free system (Table 4). Our finding reveals that 1,5-diones with weak electron-donating groups, such as methyl and chloro groups, on the aromatic ring could provide relatively higher yields of the corresponding 2,4,6-triaryl-substituted pyridines (**5a−d**) than those substrates with strong electron-donating groups, such as the methoxy group (**5e**). These results are in accordance with those reported by Chen et al., who synthesized numerous polysubstituted pyridines using a one-pot protocol with $Cu(OTf)_2$ as the catalyst.[53−55]

CONCLUSIONS

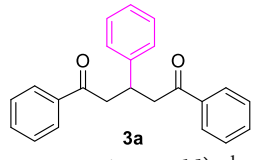
In conclusion, we report here a highly efficient, facile, and green one-pot synthesis of highly substituted 1,5-diketones via Claisen−Schmidt condensation-Michael addition reaction of numerous aryl methyl ketones with diversified aryl aldehydes in the absence of transition-metal catalysts. This one-pot synthetic strategy has several advantages, including additives or transition-metal-free condition, minimum amount of base associated to promote the reaction, wide substrate scope, short reaction time, good to excellent yields, use of inexpensive starting materials, eco-friendliness, and simple workup and reaction procedure. Moreover, the application of the synthesized 1,3,5-triaryl-1,5-diketones was demonstrated in the generation of 2,4,6-triaryl pyridines in good yields using NH_4OAc as the nitrogen source.

EXPERIMENTAL SECTION

General Information. All reactions were conducted in flame-dried glassware under a nitrogen atmosphere. All reagents obtained from commercial sources were used without purification unless otherwise mentioned. Flash column chromatography was carried out by Silica Gel Geduran Si 60 (0.040−0.063 mm, E. Merck). Thin-layer chromatography (TLC) was performed on pre-coated glass plates of Silica Gel 60 F254 (0.25 mm, E. Merck); detection was executed by spraying with a solution of $Ce(SO_4)_2$, $(NH_4)_2MoO_4$, and H_2SO_4 in water and subsequently heating on a hot plate. UV light for TLC analysis was a UVGL-25 compact UV lamp (4 W/254 nm). Melting points were determined with a MP-2D melting apparatus. ^{1}H NMR, ^{13}C NMR, and DEPT spectra were recorded by Bruker DRX500 and AVIII 500. Chemical shifts are in ppm from Me_4Si, generated from the $CDCl_3$ lock signal at δ 7.24 and 77.16 ppm for ^{1}H and ^{13}C NMR, respectively. Multiplicities are reports by using the following abbreviations: s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, br = broad, dd = doublet of doublets, dt = doublet of triplets, td = triplet of doublets; J = coupling constant values in Hertz. High-resolution mass spectrometry (HR-MS) was performed on a Waters Premier XE instrument with an ESI source. Structural assignments were made with additional information from selective 1D-TOCSY, 2D-HSQC, 2D-HMBC, and X-ray experiments.

General Procedure for the One-Pot Synthesis of 1,5-Diketones.[17,22−25,65,66] To a stirred solution of acetophenone derivatives **1a−t** (0.540−0.832 mmol, 1 equiv) in ethanol (EtOH) (1.5 mL), 60% aqueous solution of KOH (0.54−0.832 mmol, 1 equiv) was added and the mixture was stirred at 0 °C for 0.25 h. After the enol is formed, the aldehydes **2a−t** (0.54−0.832 mmol, 1 equiv) were added to the reaction solution at the same temperature. Less amount of dichloromethane (0.5 mL) was added to dissolve for those aldehydes such as **2b**, **2c**, **2e**, **2h**, **2j**, **2p**, and **2r**, which were not soluble in EtOH. Upon raising the reaction temperature to rt, the resulting mixture was stirred for 1 h till complete consumption of the starting materials. After TLC showed the formation of the corresponding chalcone intermediates via Claisen−Schmidt condensation, other acetophenone derivatives **1a−t** (1.08−1.664 mmol, 2 equiv) were added for the preparation of the desired 1,5-diketones **3a−t** and **4a−t** through Michael addition reaction and the resulting reaction mixture was stirred at rt over 1−2 h. Those Michael addition reactions in which their starting materials could not be consumed at rt were refluxed at 100 °C from 2 to 7 h depending on the reactivity of the ketone and aldehyde functionality. The progress of the reaction was monitored using TLC analysis under UV light. Then, EtOH was removed using a rotary vacuum evaporator and the resulting crude products were dissolved in ethyl acetate and cooled to 0 °C using ice. Next, 1 N HCl solution was added drop-wise till the pH of the solution became 4, which was then neutralized again by the addition of distilled water. The required products were extracted from the aqueous phases with ethyl acetate and the combined organic phases were washed with saturated brine solution. Next, the organic layers were separated and dried over anhydrous $MgSO_4$, filtered, and concentrated in rotary vacuum to give the crude products. Purification of the crude products by flash column chromatography using 3−15% ethyl acetate in hexane afforded the corresponding pure 1,5-diketones **3a−t** and **4a−t**.

*1,3,5-Triphenylpentane-1,5-dione (**3a**).*[31]



3a

Colorless syrup (192.0 mg, 62% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93 (d, J = 7.9 Hz, 4H, ArH), 7.53 (t, J = 7.4 Hz, 2H, ArH), 7.42 (t, J = 7.4 Hz, 4H, ArH), 7.28−7.26 (m, 4H, ArH), 7.17−7.15 (m, 1H, ArH), 4.05 (p, J = 7.1 Hz, 1H, CH), 3.48 (dd, J = 7.1, 16.7 Hz, 2H, CH_2), 3.34 (dd, J = 7.0, 16.6 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.7 (CO), 143.9 (C), 137.0 (C), 133.2 (C), 128.8 (CH), 128.7 (CH), 128.3 (CH), 127.6 (CH), 126.8 (CH), 45.0 (CH_2), 37.3

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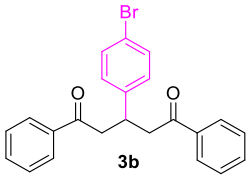
(CH); HRMS (ESI) m/z: calcd for $C_{23}H_{20}O_2Na$ $[M + Na]^+$, 351.1356; found, 351.1346.

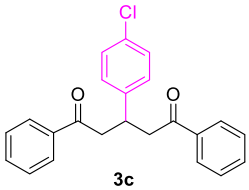
*3-(4-Bromophenyl)-1,5-diphenylpentane-1,5-dione (**3b**).*[31]



3b

White solid (142 mg, 64% yield); mp 110−112 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.92 (dd, J = 1.3, 8.5 Hz, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.44−7.41 (m, 4H, ArH), 7.38−7.36 (m, 2H, ArH), 7.17−7.14 (m, 2H ArH), 4.03 (p, J = 7.0 Hz, 1H, CH), 3.46 (dd, J = 6.7, 16.8 Hz, 2H, CH_2), 3.31 (dd, J = 7.3, 16.8 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.3 (CO), 143.0 (C), 136.9 (C), 133.4 (CH), 131.8 (CH), 129.4 (CH), 128.8 (CH), 128.2 (CH), 120.5 (C), 44.8 (CH_2), 36.6 (CH); HRMS (EI) m/z: calcd for $C_{23}H_{19}BrO_2Na$ $[M^+]$, 406.0572; found, 406.0568.

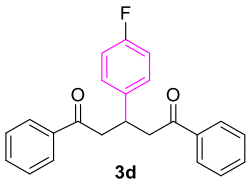
*3-(4-Chlorophenyl)-1,5-diphenylpentane-1,5-dione (**3c**).*[23,31]



3c

White solid (207.9 mg, 81% yield); mp 100−102 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.92 (dd, J = 0.8, 8.0 Hz, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.44−7.41 (m, 4H, ArH), 7.23−7.20 (m, 4H, ArH), 4.04 (p, J = 7.0 Hz, 1H, CH), 3.46 (dd, J = 6.7, 16.7 Hz, 2H, CH_2), 3.31 (dd, J = 7.2, 16.7 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.4 (CO), 142.4 (C), 136.9 (C), 133.4 (CH), 132.5 (C), 129.0 (CH), 128.9 (CH), 128.8 (CH), 128.2 (CH), 44.9 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}ClO_2Na$ $[M + Na]^+$, 385.0966; found, 385.0958.

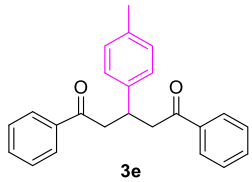
*3-(4-Flurophenyl)-1,5-diphenylpentane-1,5-dione (**3d**).*[19]



3d

White powder (213.6 mg, 83% yield); mp 88−90 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.86 (dd, J = 1.0, 8.3 Hz, 4H, ArH), 7.47 (t, J = 7.4 Hz, 2H, ArH), 7.37 (t, J = 7.5 Hz, 4H, ArH), 7.18−7.16 (m, 2H, ArH), 6.87 (t, J = 8.7 Hz, 2H, ArH), 3.99 (p, J = 7.1 Hz, 1H, CH), 3.40 (dd, J = 6.8, 16.7 Hz, 2H, CH_2), 3.25 (dd, J = 7.3, 16.7 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.5 (CO), 162.6 (C), 160.7 (C), 139.6 (C), 139.6 (C), 137.0 (C), 133.3 (CH), 129.1 (CH), 129.1 (CH), 128.8 (CH), 128.2 (CH), 115.6 (CH), 115.4 (CH), 45.1 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}FO_2Na$ $[M^+]$, 346.1369; found, 346.1369.

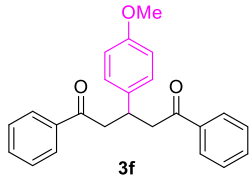
*3-(4-Methylphenyl)-1,5-diphenylpentane-1,5-dione (**3e**).*[31]



3e

Colorless syrup (260.2 mg, 91% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.87 (dd, J = 1.2, 8.5 Hz, 4H, ArH), 7.48−7.45 (m, 2H, ArH), 7.38−7.35 (m, 4H, ArH), 7.10−7.08 (m, 2H, ArH), 7.01−7.00 (m, 2H, ArH), 3.95 (p, J = 7.0 Hz, 1H, CH), 3.40 (dd, J = 7.0, 16.6 Hz, 2H, CH_2), 3.25 (dd, J = 7.1, 16.6 Hz, 2H, CH_2), 2.21 (s, 3H, CH_3); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.8 (CO), 140.9 (C), 137.1 (C), 136.3 (C), 133.2 (CH), 129.4 (CH), 128.7 (CH), 128.3 (CH), 127.4 (CH), 45.2 (CH_2), 37.0 (CH), 21.1 (CH_3); HRMS (ESI) m/z: calcd for $C_{24}H_{22}O_2Na$ $[M + Na]^+$, 365.1512; found, 365.1506.

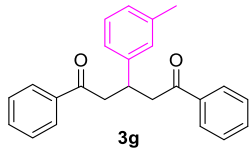
*3-(4-Methoxyphenyl)-1,5-diphenylpentane-1,5-dione (**3f**).*[23,31]



3f

Colorless syrup (223.8 mg, 85% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93 (dd, J = 1.0, 8.2 Hz, 4H, ArH), 7.54−7.51 (m, 2H, ArH), 7.44−7.41 (m, 4H, ArH), 7.18−7.16 (m, 2H, ArH), 6.80−6.77 (m, 2H, ArH), 4.00 (p, J = 7.1 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.45 (dd, J = 6.8, 16.5 Hz, 2H, CH_2), 3.30 (dd, J = 7.2, 16.5 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.9 (CO), 158.4 (C), 137.1 (C), 135.9 (C), 133.2 (CH), 128.7 (CH), 128.5 (CH), 128.3 (CH), 114.1 (CH), 55.3 (OCH_3), 45.3 (CH_2), 36.7 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{22}O_3Na$ $[M + Na]^+$, 381.1461; found, 381.1452.

*3-(3-Methylphenyl)-1,5-diphenylpentane-1,5-dione (**3g**).*



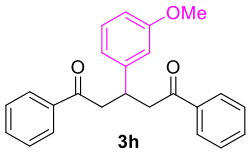
3g

Colorless syrup (229.3 mg, 91% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93 (dd, J = 0.9, 8.1 Hz, 4H, ArH), 7.54−7.51 (m, 2H, ArH), 7.44−7.41 (m, 4H, ArH), 7.15 (t, J = 7.52 Hz, 1H, ArH), 7.06 (d, J = 8.6 Hz, 2H, ArH), 7.00 (d, J = 7.6 Hz, 1H, ArH), 4.01 (p, J = 7.0 Hz, 1H, CH), 3.46 (dd, J = 7.0, 16.5 Hz, 2H, CH_2), 3.33 (dd, J = 7.0, 16.7 Hz, 2H, CH_2), 2.29 (s, 3H, CH_3); ^{13}C {H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.8 (CO), 143.9 (C), 138.3 (C), 137.1 (C), 133.2 (CH), 128.7 (CH), 128.6 (CH), 128.4 (CH), 128.3 (CH), 127.6 (CH), 45.1 (CH_2), 37.2 (CH), 21.6 (CH_3); HRMS (ESI) m/z: calcd for $C_{24}H_{22}O_2Na$ $[M + Na]^+$, 365.1512; found, 365.1503.

https://dx.doi.org/10.1021/acsomega.0c05328
ACS Omega 2021, 6, 7296−7311

*3-(3-Methoxyphenyl)-1,5-diphenylpentane-1,5-dione (**3h**)*

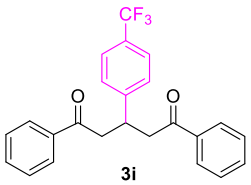
.



3h

Colorless syrup (215.0 mg, 82% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93 (dd, J = 1.2, 7.2 Hz, 4H, ArH), 7.54−7.51 (m, 2H, ArH), 7.42 (t, J = 7.9 Hz, 4H, ArH), 7.18 (t, J = 7.8 Hz, 1H, ArH), 6.86 (d, J = 7.6 Hz, 1H 2H, ArH), 6.80 (t, J = 2.1 Hz, 1H, ArH), 6.70 (dd, J = 2.4, 8.2 Hz, 1H, ArH), 4.03 (p, J = 7.0 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.45 (dd, J = 7.0, 16.6 Hz, 2H, CH_2), 3.33 (dd, J = 7.0, 16.6 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.7 (CO), 159.8 (C), 145.7 (C), 137.1 (C), 133.2 (CH), 129.8 (CH), 128.7 (CH), 128.3 (CH), 119.9 (CH), 113.7 (CH), 111.9 (CH), 55.3 (OCH_3), 45.0 (CH_2), 37.3 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{22}O_3Na$ $[M + Na]^+$, 381.1461; found, 381.1452.

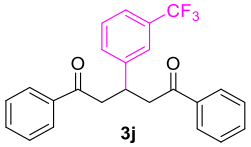
*3-(4-Trifluoromethylphenyl)-1,5-diphenylpentane-1,5-dione (**3i**).*[23]



3i

White solid (136.6 mg, 60% yield); mp 127−129 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.92 (dd, J = 1.2, 8.4 Hz, 4H, ArH), 7.56−7.51 (m, 4H, ArH), 7.45−7.40 (m, 6H, ArH), 4.14 (p, J = 7.0 Hz, 1H, CH), 3.50 (dd, J = 6.8, 17.0, Hz, 2H, CH_2), 3.36 (dd, J = 7.3, 17.0, Hz, 2H, CH_2); ^{13}C {H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.1 (CO), 148.2 (C), 136.8 (C), 133.4 (CH), 128.8 (CH), 128.2 (CH), 128.1 (CH), 125.7 (CH), 125.7 (CH), 44.6 (CH_2), 36.9 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{19}F_3O_2Na$ $[M + Na]^+$, 419.1229; found, 419.1222.

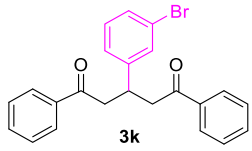
*3-(3-Trifluoromethylphenyl)-1,5-diphenylpentane-1,5-dione (**3j**).*



3j

Colorless syrup (148.9 mg, 65% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93−7.91 (m, 4H, ArH), 7.56−7.49 (m, 4H, ArH), 7.45−7.42 (m, 5H, ArH), 7.40−7.36 (m, 1H, ArH), 4.14 (p, J = 7.0 Hz, 1H, CH), 3.51 (dd, J = 6.7, 16.9, Hz, 2H, CH_2), 3.35 (dd, J = 7.1, 16.9, Hz, 2H, CH_2); ^{13}C {H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.2 (CO), 145.0 (C), 136.9 (C), 133.4 (CH), 131.5 (CH), 129.2 (CH), 128.8 (CH), 128.2 (CH), 124.3 (CH), 124.2 (CH), 123.8 (CH), 123.7 (CH), 123.7 (CH), 44.7 (CH_2), 36.9 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{19}F_3O_2Na$ $[M + Na]^+$, 419.1229; found, 419.1234.

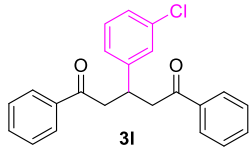
*3-(3-Bromophenyl)-1,5-diphenylpentane-1,5-dione (**3k**).*



3k

Colorless syrup (162.1 mg, 74% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.92 (dd, J = 1.4, 8.6 Hz, 4H, ArH), 7.56−7.52 (m, 2H, ArH), 7.45−7.42 (m, 5H, ArH), 7.30−7.28 (m, 1H, ArH), 7.23−7.22 (m, 1H ArH), 7.12 (t, J = 7.8 Hz, 1H ArH), 4.03 (p, J = 7.0 Hz, 1H, CH), 3.46 (dd, J = 6.8, 16.9 Hz, 2H, CH_2), 3.32 (dd, J = 7.1, 16.8 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.2 (CO), 146.5 (C), 136.9 (C), 133.4 (CH), 130.6 (CH), 130.3 (CH), 130.0 (CH), 128.8 (CH), 128.3 (CH), 126.6 (CH), 122.8 (C), 44.7 (CH_2), 36.8 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}BrO_2Na$ $[M + Na]^+$, 429.0461; found, 429.0456.

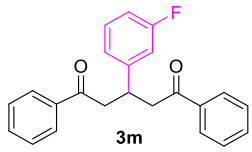
*3-(3-Chlorophenyl)-1,5-diphenylpentane-1,5-dione (**3l**).*[23]



3l

Colorless syrup (181.5 mg, 70% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93−7.91 (m, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.43 (t, J = 7.9 Hz, 4H, ArH), 7.26 (br s, 1H, ArH), 7.19−7.17 (m, 2H, ArH), 7.15−7.13 (m, 1H, ArH), 4.05 (p, J = 7.0 Hz, 1H, CH), 3.47 (dd, J = 6.8, 16.9 Hz, 2H, CH_2), 3.32 (dd, J = 7.1, 16.8 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.2 (CO), 146.2 (C), 136.9 (C), 134.5 (C), 133.4 (CH), 130.0 (CH), 128.8 (CH), 128.2 (CH), 127.7 (CH), 127.0 (CH), 126.1 (CH), 44.7 (CH_2), 36.8 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}ClO_2Na$ $[M + Na]^+$, 385.0966; found, 385.0958.

*3-(3-Fluorophenyl)-1,5-diphenylpentane-1,5-dione (**3m**).*

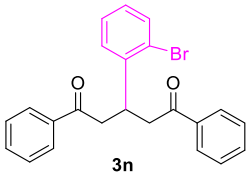


3m

Colorless syrup (201.1 mg, 72% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.94−7.91 (m, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.45−7.42 (m, 4H, ArH), 7.24−7.19 (m, 1H, ArH), 7.06 (d, J = 7.7 Hz, 1H, ArH), 6.98 (dt, J = 2.2, 10.1 Hz, 1H, ArH), 6.87−6.83 (m, 1H, ArH), 4.07 (p, J = 7.0 Hz, 1H, CH), 3.46 (dd, J = 6.8, 16.9 Hz, 2H, CH_2), 3.33 (dd, J = 7.2, 16.9 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.3 (CO), 164.0 (C), 162.1 (C), 146.7 (C), 146.6 (C), 136.9 (C), 133.3 (CH), 130.2 (CH), 130.2 (CH), 128.8 (CH), 128.2 (CH), 123.4 (CH), 123.4 (CH), 114.6 (CH), 114.4 (CH), 113.8 (CH), 113.6 (CH), 44.8 (CH_2), 36.9 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}FO_2Na$ $[M + Na]^+$, 369.1261; found, 369.1253.

https://dx.doi.org/10.1021/acsomega.0c05328
ACS Omega 2021, 6, 7296−7311

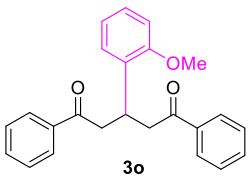
*3-(2-Bromophenyl)-1,5-diphenylpentane-1,5-dione (**3n**).*[23]



3n

White solid (186.9 mg, 85% yield); mp 120−122 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.95 (dd, J = 1.2, 8.5 Hz, 4H, ArH), 7.55−7.51 (m, 3H, ArH), 7.42 (t, J = 7.9 Hz, 4H, ArH), 7.31 (dd, J = 1.5, 7.8 Hz, 1H, ArH), 7.23−7.20 (m, 1H ArH), 7.04−7.01 (m, 1H ArH), 4.52 (p, J = 6.9 Hz, 1H, CH), 3.51 (dd, J = 7.2, 16.9 Hz, 2H, CH_2), 3.42 (dd, J = 6.7, 16.9 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.5 (CO), 142.6 (C), 136.9 (C), 133.5 (CH), 133.3 (CH), 128.7 (CH), 128.3 (CH), 128.2 (CH), 127.8 (CH), 124.6 (C), 43.3 (CH_2), 36.4 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{19}BrO_2Na$ $[M + Na]^+$, 429.0461; found, 429.0455.

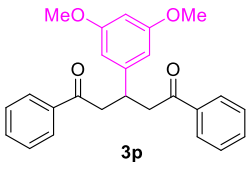
*3-(2-Methoxyphenyl)-1,5-diphenylpentane-1,5-dione (**3o**).*[23]



3o

White solid (236.6 mg, 90% yield); mp 116−1118 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.97 (dd, J = 1.3, 8.4 Hz, 4H, ArH), 7.54−7.50 (m, 2H, ArH), 7.42 (t, J = 7.9 Hz, 4H, ArH), 7.20 (dd, J = 1.4, 7.5 Hz, 1H, ArH), 7.15 (td, J = 1.6, 8.2 Hz, 1H, ArH), 6.87−6.81 (m, 2H, ArH), (4.33 (p, J = 7.0 Hz, 1H, CH), 3.76 (s, 3H, OCH_3), 3.48 (dd, J = 7.2, 16.5 Hz, 2H, CH_2), 3.42 (dd, J = 6.9, 16.4 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 199.4 (CO), 157.2 (C), 137.2 (C), 133.0 (CH), 131.5 (C), 128.6 (CH), 128.3 (CH), 127.8 (CH), 120.8 (CH), 111.0 (CH), 55.3 (OCH_3), 43.2 (CH_2), 33.0 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{22}O_3Na$ $[M + Na]^+$, 381.1461; found, 381.1454.

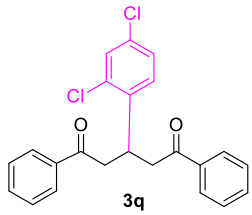
*3-(3,3-Dimethoxyphenyl)-1,5-diphenylpentane-1,5-dione (**3p**).*



3p

Colorless syrup (217.2 mg, 93% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93 (dd, J = 1.3, 7.1 Hz, 4H, ArH), 7.55−7.51 (m, 2H, ArH), 7.42 (t, J = 8.0 Hz, 4H, ArH), 6.41 (d, J = 2.2 Hz, 2H, ArH), 6.26 (t, J = 2.2 Hz, 1H, ArH), 4.00 (p, J = 7.0 Hz, 1H, CH), 3.72 (s, 6H, OCH_3), 3.42 (dd, J = 7.1, 16.7 Hz, 2H, CH_2), 3.32 (dd, J = 7.0, 16.7 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.7 (CO), 161.0 (C), 146.5 (C), 137.1 (C), 133.2 (CH), 128.7 (CH), 128.3 (CH), 105.8 (CH), 98.5 (CH), 55.4 (OCH_3), 44.9 (CH_2), 37.5 (CH); HRMS (ESI) m/z: calcd for $C_{25}H_{24}O_4Na$ $[M + Na]^+$, 411.1567; found, 411.1563.

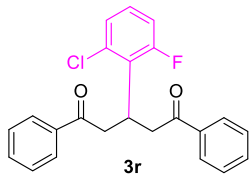
*3-(2,4-Dichlorophenyl)-1,5-diphenylpentane-1,5-dione (**3q**).*[23]



3q

White solid (201.2 mg, 81% yield); mp 115−117 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.94 (dd, J = 1.3, 8.5 Hz, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.43 (t, J = 7.9 Hz, 4H, ArH), 7.35 (d, J = 2.2 Hz, 1H, ArH), 7.27 (d, J = 8.4 Hz, 1H, ArH), 7.15 (dd, J = 2.1, 8.4 Hz, 1H, ArH), 4.47 (p, J = 6.9 Hz, 1H, CH), 3.51 (dd, J = 7.0, 17.0 Hz, 2H, CH_2), 3.41 (dd, J = 6.8, 17.0 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.2 (CO), 139.6 (C), 136.8 (C), 134.5 (C), 133.4 (CH), 132.9 (C), 129.9 (CH), 129.5 (CH), 128.8 (CH), 128.3 (CH), 127.4 (CH), 42.9 (CH_2), 33.6 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{18}Cl_2O_2Na$ $[M + Na]^+$, 419.0576; found, 419.0572.

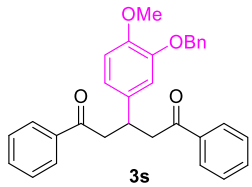
*3-(2-Chloro-6-fluorophenyl)-1,5-diphenylpentane-1,5-dione (**3r**).* Colorless syrup (190.0 mg, 79% yield); ^{1}H NMR



3r

(500 MHz, $CDCl_3$): δ (ppm) 7.96 (dd, J = 1.4, 8.5 Hz, 4H, ArH), 7.55−7.52 (m, 2H, ArH), 7.44−7.41 (m, 4H, ArH), 7.14 (d, J = 8.0 Hz, 1H, ArH), 7.10−7.06 (m, 1H, ArH), 6.93−6.89 (m, 1H, ArH), 4.70 (p, J = 7.2 Hz, 1H, CH), 3.61 (dd, J = 7.1, 16.9 Hz, 2H, CH_2), 3.49 (dd, J = 7.2, 16.9 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.4 (CO), 163.2 (C), 161.3 (C), 136.8 (C), 133.3 (CH), 129.1 (C), 129.0 (C), 128.7 (CH), 128.5 (CH), 128.4 (CH), 128.3 (CH), 126.1 (CH), 126.1 (CH), 115.0 (CH), 114.8 (CH), 42.1 (CH_2), 42.1 (CH_2), 31.4 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{18}ClFO_2Na$ $[M + Na]^+$, 403.0872; found, 403.0863.

*3-(3-Benzyloxy-4-methoxyphenyl)-1,5-diphenylpentane-1,5-dione (**3s**).*



3s

Colorless syrup (152.7 mg, 80% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.89 (dd, J = 0.8, 8.2 Hz, 4H, ArH), 7.53 (t, J = 7.3 Hz, 2H, ArH), 7.44−7.37 (m, 6H, ArH), 7.30 (t, J = 7.3 Hz, 2H, ArH), 7.25−7.22 (m, 1H, ArH), 6.81 (d, J = 8.3 Hz, 1H, ArH), 6.78−6.76 (m, 2H, ArH), 5.06 (s, 2H, OCH_2), 3.94 (p, J = 6.9 Hz, 1H, CH), 3.81 (s, 3H, OCH_3), 3.37 (dd, J = 6.9, 16.5 Hz, 2H, CH_2), 3.22 (dd, J = 6.9, 16.5 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.8 (CO), 148.6 (C), 148.1 (C), 137.4 (C), 137.1 (C), 136.4 (C), 133.2 (CH), 128.7 (CH), 128.6 (CH), 128.3 (CH), 127.9 (CH), 127.6 (CH), 120.3 (CH), 114.3 (CH), 112.1 (CH), 71.3 (OCH_2), 56.1

https://dx.doi.org/10.1021/acsomega.0c05328
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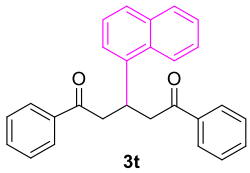
(OCH_3), 45.1 (CH_2), 36.9 (CH); HRMS (ESI) m/z: calcd for $C_{31}H_{28}O_4Na$ $[M + Na]^+$, 487.1880; found, 487.1876.

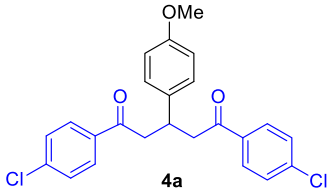
*3-(Naphthalen-1-yl)-1,5-diphenylpentane-1,5-dione (**3t**).*[67]



3t

White solid (206.8 mg, 85% yield); mp 124−126 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.20 (d, J = 8.4 Hz, 1H, ArH), 7.92 (dd, J = 1.2, 8.3 Hz, 4H, ArH), 7.83 (d, J = 7.8 Hz, 1H, ArH), 7.70 (d, J = 8.2 Hz, 1H, ArH), 7.53−7.36 (m, 10H, ArH), 5.01 (p, J = 6.7 Hz, 1H, CH), 3.62 (dd, J = 7.3, 16.9 Hz, 2H, CH_2), 3.52 (dd, J = 6.3, 16.9 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.8 (CO), 140.2 (C), 137.1 (C), 134.3 (C), 133.2 (CH), 131.4 (C), 129.1 (CH), 128.7 (CH), 128.3 (CH), 127.3 (CH), 126.4 (CH), 125.7 (CH), 125.5 (CH), 123.3 (CH), 44.6 (CH_2), 31.3 (CH); HRMS (ESI) m/z: calcd for $C_{27}H_{22}O_2Na$ $[M + Na]^+$, 401.1512; found, 401.1510.

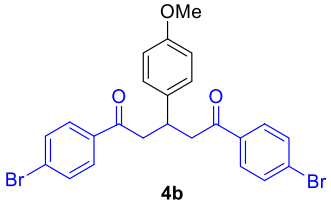
*1,5-Bis(4-chlorophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4a**).*[15]



4a

Colorless syrup (310.6 mg, 99% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.86 (d, J = 8.6 Hz, 4H, ArH), 7.39 (d, J = 8.7 Hz, 4H, ArH), 7.14 (d, J = 8.6 Hz, 2H, ArH), 6.78 (d, J = 8.7 Hz, 2H, ArH), 3.94 (p, J = 7.0 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.41 (dd, J = 7.0, 16.6 Hz, 2H, CH_2), 3.24 (dd, J = 7.0, 16.5 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 197.6 (CO), 158.5 (C), 139.7 (C), 135.5 (C), 135.3 (C), 129.7 (CH), 129.1 (CH), 128.5 (CH), 114.2 (CH), 55.3 (OCH_3), 45.2 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{20}Cl_2O_3Na$ $[M + Na]^+$, 449.0682; found, 449.0685.

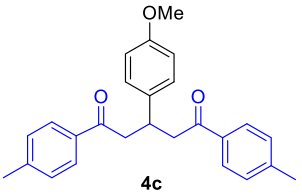
*1,5-Bis(4-bromophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4b**).*



4b

Colorless syrup (316.8 mg, 84% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.78 (d, J = 8.5 Hz, 4H, ArH), 7.56 (d, J = 8.4 Hz, 4H, ArH), 7.14 (d, J = 8.6 Hz, 2H, ArH), 6.78 (d, J = 8.7 Hz, 2H, ArH), 3.94 (p, J = 7.1 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.40 (dd, J = 7.0, 16.5 Hz, 2H, CH_2), 3.23 (dd, J = 7.1, 16.5 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 197.8 (CO), 158.5 (C), 135.7 (C), 135.4 (C), 132.1 (C), 129.8 (CH), 128.5 (CH), 114.2 (CH), 55.3 (OCH_3), 45.2 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{20}Br_2O_3Na$ $[M + Na]^+$, 536.9671; found, 536.9670.

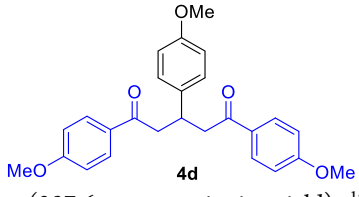
*3-(4-Methoxyphenyl)-1,5-bis(4-methylphenyl)pentane-1,5-dione (**4c**).*



4c

Colorless syrup (257.8 mg, 91% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.83 (d, J = 8.2 Hz, 4H, ArH), 7.21 (d, J = 8.0 Hz, 4H, ArH), 7.16 (d, J = 8.6 Hz, 2H, ArH), 6.78 (d, J = 8.7 Hz, 2H, ArH), 3.98 (p, J = 7.0 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.40 (dd, J = 7.0, 16.4 Hz, 2H, CH_2), 3.25 (dd, J = 7.2, 16.3 Hz, 2H, CH_2), 2.38 (s, 6H, CH_3); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.6 (CO), 158.3 (C), 143.9 (C), 136.1 (C), 134.6 (C), 129.4 (CH), 128.5 (CH), 128.4 (CH), 114.1 (CH), 55.3 (OCH_3), 45.2 (CH_2), 36.8 (CH), 21.8 (CH_3); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_3Na$ $[M + Na]^+$, 409.1774; found, 409.1769.

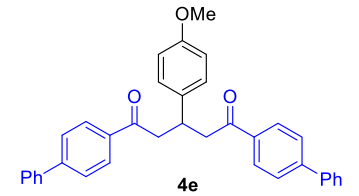
*1,3,5-Tris(4-methoxyphenyl)pentane-1,5-dione (**4d**).*[31]



4d

Colorless syrup (307.6 mg, quantitative yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.93−7.90 (m, 4H, ArH), 7.17−7.15 (m, 2H, ArH), 6.91−6.88 (m, 4H, ArH), 6.79−6.76 (m, 2H, ArH), 3.96 (p, J = 7.0 Hz, 1H, CH), 3.84 (s, 6H, OCH_3), 3.73 (s, 3H, OCH_3), 3.38 (dd, J = 7.0, 16.2 Hz, 2H, CH_2), 3.21 (dd, J = 7.3, 16.2 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 197.5 (CO), 163.6 (C), 158.3 (C), 136.1 (C), 130.6 (CH), 130.2 (C), 128.5 (CH), 114.1 (CH), 113.8 (CH), 55.6 (OCH_3), 55.3 (OCH_3), 45.1 (CH_2), 37.1 (CH); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_5Na$ $[M + Na]^+$, 441.1673; found, 441.1664.

*3-(4-Methoxyphenyl)-1,5-bis(4-phenylphenyl)pentane-1,5-dione (**4e**).*



4e

White solid (303.0 mg, 81% yield); mp 178−180 °C; 1H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.02 (d, J = 8.4 Hz, 4H, ArH), 7.66 (d, J = 8.4 Hz, 4H, ArH), 7.61 (dd, J = 1.2, 8.5 Hz, 4H, ArH), 7.45 (t, J = 7.3 Hz, 4H, ArH), 7.40−7.37 (m, 2H, ArH), 7.22 (d, J = 8.6 Hz, 2H, ArH), 6.82 (d, J = 8.6 Hz, 2H, ArH), 4.06 (p, J = 7.0 Hz, 1H, CH), 3.75 (s, 3H, OCH_3), 3.50 (dd, J = 7.0, 16.4 Hz, 2H, CH_2), 3.34 (dd, J = 7.1, 16.4 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 198.5 (CO), 158.4 (C), 145.9 (C), 140.0 (C), 135.9 (C), 135.8 (C), 129.1 (CH), 128.9 (CH),

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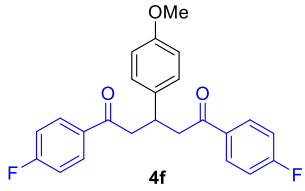
128.6 (CH), 128.3 (CH), 127.4 (CH), 127.4 (CH), 114.2 (CH), 55.3 (OCH_3), 45.4 (CH_2), 36.9 (CH); HRMS (ESI) *m/z*: calcd for $C_{36}H_{30}O_3Na$ $[M + Na]^+$, 533.2087; found, 533.2078.

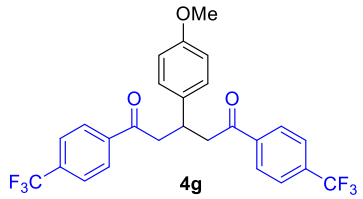
*1,5-Bis(4-fluorophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4f**).*[32]



4f

Colorless syrup (195.9 mg, 68% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.97−7.94 (m, 4H, ArH), 7.16−7.13 (m, 2H, ArH), 7.11−7.07 (m, 4H, ArH), 6.80−6.77 (m, 2H, ArH), 3.95 (p, *J* = 7.0 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.42 (dd, *J* = 7.0, 16.5 Hz, 2H, CH_2), 3.24 (dd, *J* = 7.1, 16.5 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 197.3 (CO), 166.9 (C), 164.9 (C), 158.5 (C), 135.6 (C), 133.5 (C), 133.4 (C), 131.0 (CH), 130.9 (CH), 128.5 (CH), 115.9 (CH), 115.7 (CH), 114.2 (CH), 55.3 (OCH_3), 45.2 (CH_2), 36.7 (CH); HRMS (ESI) *m/z*: calcd for $C_{24}H_{20}F_2O_3Na$ $[M + Na]^+$, 417.1273; found, 417.1266.

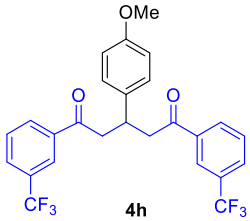
*1,5-Bis(4-trifluoromethylphenyl)-3-(4-methoxyphenyl)-pentane-1,5-dione (**4g**).*



4g

Colorless syrup (118.0 mg, 33% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.02 (d, *J* = 8.1 Hz, 4H, ArH), 7.69 (d, *J* = 8.2 Hz, 4H, ArH), 7.15 (d, *J* = 8.3 Hz, 2H, ArH), 6.80 (d, *J* = 8.2 Hz, 2H, ArH), 3.98 (p, *J* = 6.9 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.48 (dd, *J* = 7.0, 16.7 Hz, 2H, CH_2), 3.31 (dd, *J* = 6.9, 16.7 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 197.9 (CO), 158.6 (C), 139.6 (C), 135.2 (C), 135.0 (C), 134.7 (C), 134.5 (C), 134.2 (C), 128.8 (CH), 128.6 (CH), 128.5 (CH), 127.0 (C), 125.9 (CH), 125.8 (CH), 125.8 (CH), 124.8 (C), 122.6 (C), 120.5 (C), 114.3 (CH), 55.4 (OCH_3), 45.4 (CH_2), 36.5 (CH); HRMS (ESI) *m/z*: calcd for $C_{26}H_{21}F_6O_3$ $[M + H]^+$, 495.1394; found, 495.1395.

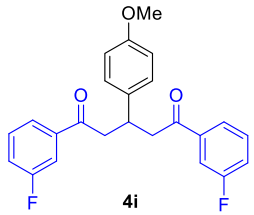
*1,5-Bis(3-trifluoromethylphenyl)-3-(4-methoxyphenyl)-pentane-1,5-dione (**4h**).*



4h

Colorless syrup (116.2 mg, 32% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.15−8.11 (m, 4H, ArH), 7.79 (d, *J* = 7.7 Hz, 2H, ArH), 7.56 (t, *J* = 7.9 Hz, 2H, ArH), 7.18 (d, *J* = 8.6 Hz, 2H, ArH), 6.80 (d, *J* = 8.6 Hz, 2H, ArH), 4.00 (p, *J* = 6.8 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.48 (dd, *J* = 6.9, 16.8 Hz, 2H, CH_2), 3.34 (dd, *J* = 7.0, 16.8 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 197.4 (CO), 158.6 (C), 137.5 (C), 135.3 (C), 131.5 (C), 131.4 (CH), 131.3 (C), 129.7 (CH), 129.7 (CH), 129.5 (CH), 128.5 (CH), 125.2 (CH), 125.1 (CH), 124.9 (CH), 122.7 (CH), 114.3 (CH), 55.4 (OCH_3), 45.2 (CH_2), 36.4 (CH); HRMS (ESI) *m/z*: calcd for $C_{26}H_{21}F_6O_3$ $[M^+]$, 494.1321; found, 494.1317.

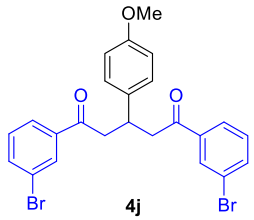
*1,5-Bis(3-fluorophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4i**).*



4i

White solid (136.9 mg, 47% yield); mp 111−114 °C; ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.71 (d, *J* = 8.0 Hz, 2H, ArH), 7.59 (d, *J* = 9.5 Hz, 2H, ArH), 7.43−7.39 (m, 2H, ArH), 7.25−7.21 (m, 2H, ArH), 7.16 (d, *J* = 8.6 Hz, 2H, ArH), 6.80 (d, *J* = 8.6 Hz, 2H, ArH), 3.97 (p, *J* = 7.0 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.42 (dd, *J* = 6.9, 16.7 Hz, 2H, CH_2), 3.27 (dd, *J* = 7.0, 16.6 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 197.5 (CO), 164.0 (C), 162.0 (C), 158.5 (C), 139.1 (C), 139.1 (C), 135.5 (C), 130.5 (CH), 130.4 (CH), 128.5 (CH), 124.1 (CH), 124.0 (CH), 120.4 (CH), 120.2 (CH), 115.1 (CH), 114.9 (CH), 114.2 (CH), 55.4 (OCH_3), 45.3 (CH_2), 36.5 (CH); HRMS (ESI) *m/z*: calcd for $C_{24}H_{20}F_2O_3Na$ $[M + Na]^+$, 417.1273; found, 417.1274.

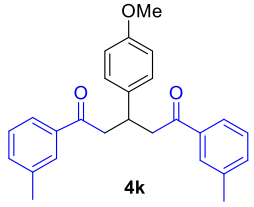
*1,5-Bis(3-bromophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4j**).*



4j

White solid (167.0 mg, 44% yield); mp 115−117 °C; ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.02 (t, *J* = 1.7 Hz, 2H, ArH), 7.84 (dt, *J* = 1.0, 7.9 Hz, 2H, ArH), 7.66−7.64 (m, 2H, ArH), 7.30 (t, *J* = 7.9 Hz, 2H, ArH), 7.17−7.14 (m, 2H, ArH), 6.80−6.79 (m, 2H, ArH), 3.96 (p, *J* = 6.9 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.40 (dd, *J* = 6.9, 16.6 Hz, 2H, CH_2), 3.26 (dd, *J* = 7.1, 16.7 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 197.4 (CO), 158.5 (C), 138.7 (C), 136.1 (CH), 135.4 (C), 131.3 (CH), 130.3 (CH), 128.5 (CH), 126.8 (CH), 123.1 (C), 114.2 (CH), 55.4 (OCH_3), 45.2 (CH_2), 36.4 (CH); HRMS (ESI) *m/z*: calcd for $C_{24}H_{20}Br_2O_3Na$ $[M + Na]^+$, 536.9671; found, 536.9667.

*3-(4-Methoxyphenyl)-1,5-bis(3-methylphenyl)pentane-1,5-dione (**4k**).*



4k

Colorless syrup (263.0 mg, 93% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.73−7.72 (m, 4H, ArH), 7.34−7.29 (m, 4H,

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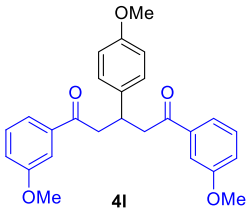
ArH), 7.19−7.17 (m, 2H, ArH), 6.81−6.78 (m, 2H, ArH), 3.99 (p, J = 7.1 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.42 (dd, J = 6.9, 16.5 Hz, 2H, CH_2), 3.28 (dd, J = 7.1, 16.4 Hz, 2H, CH_2), 2.37 (s, 6H, CH_3); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 199.1 (CO), 158.3 (C), 138.5 (C), 137.1 (C), 136.1 (C), 133.9 (CH), 128.8 (CH), 128.6 (CH), 128.5 (CH), 125.5 (CH), 114.1 (CH), 55.3 (OCH_3), 45.3 (CH_2), 36.6 (CH), 21.5 (CH_3); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_3Na$ $[M + Na]^+$, 409.1774; found, 409.1773.

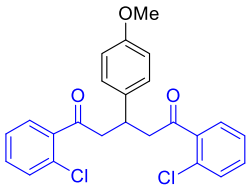
*3-(4-Methoxyphenyl)-1,5-bis(3-methoxyphenyl)pentane-1,5-dione (**4l**).*



4l

White solid (287.3 mg, 94% yield); mp 84−87 °C; ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.52 (d, J = 7.7 Hz, 2H, ArH), 7.45−7.44 (m, 2H, ArH), 7.33 (t, J = 8.1 Hz, 2H, ArH), 7.18−7.15 (m, 2H, ArH), 7.08−7.06 (m, 2H, ArH), 6.80−6.78 (m, 2H, ArH), 3.99 (p, J = 7.1 Hz, 1H, CH), 3.82 (s, 6H, OCH_3), 3.73 (s, 3H, OCH_3), 3.42 (dd, J = 6.9, 16.6 Hz, 2H, CH_2), 3.26 (dd, J = 7.2, 16.5 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 198.7 (CO), 160.0 (C), 158.4 (C), 138.4 (C), 135.9 (C), 129.7 (CH), 128.5 (CH), 121.0 (CH), 119.9 (CH), 114.1 (CH), 112.4 (CH), 55.6 (OCH_3), 55.3 (OCH_3), 45.4 (CH_2), 36.8 (CH); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_5Na$ $[M + Na]^+$, 441.1673; found, 441.1665.

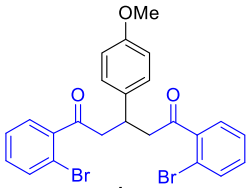
*1,5-Bis(2-chlorophenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4m**).*



4m

Colorless syrup (236.1 mg, 75% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.35−7.30 (m, 4H, ArH), 7.25−7.21 (m, 4H, ArH), 7.10−7.08 (m, 2H, ArH), 6.77−6.75 (m, 2H, ArH), 3.88 (p, J = 7.3 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.39 (dd, J = 6.7, 16.9 Hz, 2H, CH_2), 3.28 (dd, J = 7.9, 16.8 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 201.9 (CO), 158.4 (C), 139.5 (C), 134.9 (C), 131.7 (CH), 130.9 (C), 130.5 (CH), 129.0 (CH), 128.7 (CH), 127.0 (CH), 114.0 (CH), 55.4 (OCH_3), 49.3 (CH_2), 36.7 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{20}Cl_2O_3Na$ $[M + Na]^+$, 449.0682; found, 449.0686.

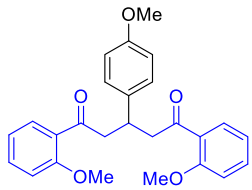
*3-(4-Methoxyphenyl)-1,5-bis(2-bromophenyl)pentane-1,5-dione (**4n**).*



4n

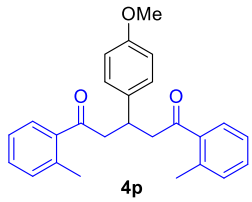
Colorless syrup (324.2 mg, 86% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.53 (dd, J = 1.0, 7.8 Hz, 2H, ArH), 7.28−7.21 (m, 4H, ArH), 7.16 (dd, J = 1.9, 7.4 Hz, 2H, ArH), 7.11−7.09 (m, 2H, ArH), 6.78−6.75 (m, 2H, ArH), 3.88 (p, J = 7.3 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.40 (dd, J = 6.7, 17.0 Hz, 2H, CH_2), 3.25 (dd, J = 7.9, 17.0 Hz, 2H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 202.6 (CO), 158.5 (C), 141.7 (C), 134.8 (C), 133.7 (CH), 131.6 (CH), 128.8 (CH), 128.6 (CH), 127.5 (CH), 118.7 (C), 114.1 (CH), 55.4 (OCH_3), 48.9 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{20}Br_2O_3Na$ $[M + Na]^+$, 536.9671; found, 536.9674.

*3-(4-Methoxyphenyl)-1,5-bis(2-methoxyphenyl)pentane-1,5-dione (**4o**).* White solid (245.8 mg, 80% yield); mp 102−104 °C; ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.45 (dd, J = 1.5, 7.6 Hz, 2H, ArH), 7.41−7.37 (m, 2H, ArH), 7.08 (d, J = 8.7 Hz, 2H, ArH), 6.92−6.89 (m, 4H, ArH), 6.74 (d, J = 8.7 Hz, 2H, ArH), 3.86 (p, J = 7.1 Hz, 1H, CH), 3.83 (s, 6H, OCH_3), 3.73 (s, 3H, OCH_3), 3.36−3.27 (m, 4H, CH_2); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 201.5 (CO), 158.3 (C), 158.0 (C), 136.7 (C), 133.3 (CH), 130.4 (CH), 128.8 (CH), 128.7 (CH), 120.7 (CH), 113.7 (CH), 111.5 (CH), 55.6 (OCH_3), 55.3 (OCH_3), 50.4 (CH_2), 36.8 (CH); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_5Na$ $[M + Na]^+$, 441.1673; found, 441.1672.



4o

*3-(4-Methoxyphenyl)-1,5-bis-(2-methylphenyl)pentane-1,5-dione (**4p**).*



4p

Colorless syrup (261.1 mg, 92% yield); ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.54 (dd, J = 1.1, 7.7 Hz, 2H, ArH), 7.32 (td, J = 1.3,15.0 Hz, 2H, ArH), 7.22−7.19 (m, 2H, ArH), 7.18−7.17 (m, 2H, ArH), 7.09−7.06 (m, 2H, ArH), 6.78−6.75 (m, 2H, ArH), 3.87 (p, J = 7.3 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.34 (dd, J = 7.4, 16.4 Hz, 2H, CH_2), 3.18 (dd, J = 7.8, 16.4 Hz, 2H, CH_2), 2.23 (s, 6H, CH_3); $^{13}C\{H\}$ NMR (125 MHz, $CDCl_3$): δ (ppm) 203.2 (CO), 158.4 (C), 138.2 (C), 138.1 (C), 135.5 (C), 132.0 (CH), 131.3 (CH), 128.7 (CH), 128.4 (CH), 125.7 (CH), 114.1 (CH), 55.4 (OCH_3), 48.3 (CH_2), 37.1 (CH), 21.0 (CH_3); HRMS (ESI) m/z: calcd for $C_{26}H_{26}O_3Na$ $[M + Na]^+$, 409.1774; found, 409.1770.

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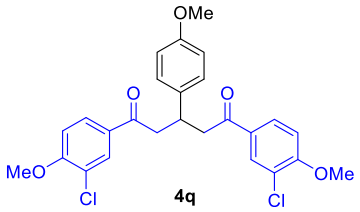
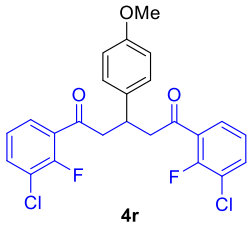
*1,5-Bis-(3-chloro-4-methoxyphenyl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4q**).*



4q

Colorless syrup (336.6 mg, 94% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.95 (d, J = 2.1 Hz, 2H, ArH), 7.86 (dd, J = 2.1, 8.6 Hz, 2H, ArH), 7.15 (d, J = 8.7, 2H, ArH), 6.92 (d, J = 8.6 Hz, 2H, ArH), 6.78 (d, J = 8.6, 2H, ArH), 3.96−3.90 (overlap, 7H, CH, OCH_3), 3.73 (s, 6H, OCH_3), 3.73 (s, 3H, OCH_3), 3.37 (dd, J = 7.0, 16.4 Hz, 2H, CH_2), 3.19 (dd, J = 7.1, 16.4 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 196.5 (CO), 158.8 (C), 158.3 (C), 135.6 (C), 130.6 (CH), 130.5 (C), 128.8 (CH), 128.4 (CH), 122.9 (C), 114.1 (CH), 111.3 (CH), 55.5 (OCH_3), 55.3 (OCH_3), 44.9 (CH_2), 36.8 (CH); HRMS (ESI) m/z: calcd for $C_{26}H_{24}O_5Cl_2Na$ [M + Na]$^+$, 509.0893; found, 509.0899.

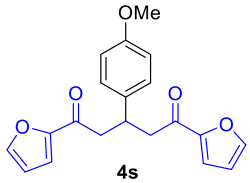
*1,5-Bis-(3-chloro-2-fluorophenyl)-3-(4-methoxyphenyl)-pentane-1,5-dione (**4r**).*



4r

White solid (134.5 mg, 40% yield); mp 124−126 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.58 (t, J = 6.4 Hz, 2H, ArH), 7.53 (t, J = 6.8 Hz, 2H, ArH), 7.16 (d, J = 8.5 Hz, 2H, ArH), 7.11 (t, J = 8.0 Hz, 2H, ArH), 6.78 (d, J = 8.5 Hz, 2H, ArH), 3.98 (p, J = 6.9 Hz, 1H, CH), 3.74 (s, 3H, OCH_3), 3.36 (dd, J = 2.5, 6.9 Hz, 4H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 196.1 (CO), 196.1 (CO), 158.4 (C), 158.3 (C), 156.3 (C), 135.6 (C), 134.8 (CH), 129.1 (CH), 128.6 (CH), 127.4 (C), 127.3 (C), 124.9 (CH), 124.9 (CH), 122.5 (C), 122.4 (C), 114.1 (CH), 55.3 (OCH_3), 50.0 (CH_2), 50.0 (CH_2), 35.7 (CH); HRMS (ESI) m/z: calcd for $C_{24}H_{18}Cl_2O_3F_2Na$ [M + Na]$^+$, 485.0493; found, 485.0487.

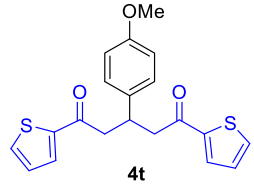
*1,5-Di(furan-2-yl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4s**).*[68]



4s

White solid (97.5 mg, 40% yield); mp 108−110 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.51 (s, 2H, ArH), 7.18−7.15 (m, 4H, ArH), 6.77 (d, J = 8.6 Hz, 2H, ArH), 6.47 (dd, J = 1.6, 3.5 Hz, 2H, ArH), 3.95 (p, J = 7.2 Hz, 1H, CH), 3.72 (s, 3H, OCH_3), 3.26−3.13 (overlap, 4H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 187.7 (CO), 158.4 (CO), 152.9 (C), 146.5 (CH), 135.4 (C), 128.5 (CH), 117.4 (CH), 114.1 (CH), 112.3 (C), 55.3 (OCH_3), 44.8 (CH_2), 36.6 (CH); HRMS (ESI) m/z: calcd for $C_{20}H_{18}O_5Na$ [M + Na]$^+$, 361.1046; found, 361.1039.

*1,5-Di(thiophen-2-yl)-3-(4-methoxyphenyl)pentane-1,5-dione (**4t**).*

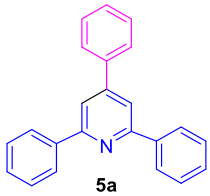


4t

Colorless syrup (217.9 mg, 80% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.73 (dd, J = 1.0, 3.8 Hz, 2H, ArH), 7.58 (dd, J = 1.0, 4.9 Hz, 2H, ArH), 7.19−7.17 (m, 2H, ArH), 7.08 (dd, J = 3.9, 4.8 Hz, 2H, ArH), 6.80−6.77 (m, 2H, ArH), 4.00 (p, J = 7.1 Hz, 1H, CH), 3.73 (s, 3H, OCH_3), 3.38 (dd, J = 7.0, 15.9 Hz, 2H, CH_2), 3.22 (dd, J = 7.3, 15.9 Hz, 2H, CH_2); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 191.6 (CO), 158.4 (CO), 144.4 (C), 135.3 (C), 133.8 (CH), 132.3 (CH), 128.5 (CH), 128.3 (CH), 114.2 (CH), 55.3 (OCH_3), 45.7 (CH_2), 37.4 (CH); HRMS (ESI) m/z: calcd for $C_{20}H_{18}O_3S_2Na$ [M + Na]$^+$, 393.0590; found, 393.0587.

General Procedure for the Synthesis of 2,4,6-Triayl Pyridine Derivatives (5a−e).[53,55,56,63] The representative 1,3,5-triayl-1,5-dione (**3** and **4**) (0.186 mmol, 1 equiv) was dissolved in EtOH (1.5 mL). To this, a stirred solution of ammonium acetate (1.93 mmol, 10.4 equiv) was added and the reaction mixture was refluxed at 80 °C for 4−10 h depending on the reactivity of the types of 1,5-diketones. Upon cooling to rt, the EtOH was removed by rotary vacuum, dissolved in ethyl acetate, and neutralized with water. The desired product was extracted from the aqueous phases with ethyl acetate and then washed three times with water. The combined organic phases were washed with saturated brine solution. Next, the organic layers were separated and dried over anhydrous $MgSO_4$, filtered, and concentrated in rotary vacuum to give the crude products. Purification of the crude products by flash column chromatography using 1 to 5% ethyl acetate in hexane afforded the corresponding pure and known 2,4,6-triayl pyridine derivatives **5a**,[55,56,64] **5b**,[53] **5c**,[56,63] **5d**,[56] and **5e**.[63]

*2,4,6-Triphenylpyridine (**5a**).*[55,56]



5a

White solid (37.4 mg, 71% yield); mp 135−138 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.21 (d, J = 7.4 Hz, 4H, ArH), 7.89 (s, 2H, ArH), 7.75 (d, J = 7.3 Hz, 2H, ArH), 7.54−7.43 (m, 9H, ArH); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 157.7 (C), 150.3 (C), 139.7 (C), 139.2 (C), 129.3 (CH), 129.2 (CH), 129.1 (CH), 128.9 (CH), 127.3 (CH), 127.3 (CH), 117.3 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{16}N$ [M + H]$^+$, 308.1434; found, 308.1426.

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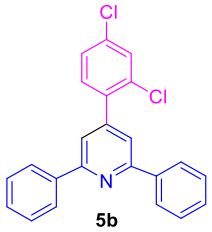
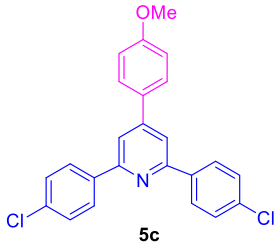
*4-(2,4-Dichlorophenyl)-2,6-diphenylpyridine (**5b**).*[55]



5b

Colorless paste (39.8 mg, 68% yield); ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.17−8.15 (m, 4H, ArH), 7.72 (s, 2H, ArH), 7.56 (t, J = 1.2 Hz, 1H, ArH), 7.51−7.48 (m, 4H, ArH), 7.45−7.41 (m, 2H, ArH), 7.37 (d, J = 1.2 Hz, 2H, ArH); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 157.2 (C), 147.7 (C), 139.4 (C), 137.2 (C), 135.2 (C), 133.3 (C), 131.8 (CH), 130.3 (CH), 129.4 (CH), 128.9 (CH), 127.7 (CH), 127.3 (CH), 119.4 (CH); HRMS (ESI) m/z: calcd for $C_{23}H_{16}NCl_2$ $[M + H]^+$, 376.0654; found, 376.0652.

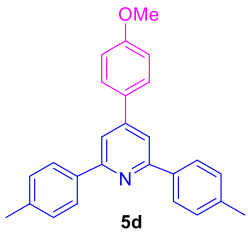
*2,6-Bis(4-chlorophenyl)-4-(4-methoxyphenyl)pyridine (**5c**).*[56]



5c

White solid (55.1 mg, 73% yield); mp 181−183 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.11−8.08 (m, 4H, ArH), 7.78 (s, 2H, ArH), 7.67−7.64 (m, 2H, ArH), 7.47−7.44 (m, 4H, ArH), 7.04−7.02 (m, 2H, ArH), 3.88 (s, 3H, OCH_3); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 160.8 (C), 156.4 (C), 150.1 (C), 138.0 (C), 135.3 (C), 131.0 (CH), 129.1 (CH), 128.5 (CH), 128.4 (CH), 116.7 (CH), 114.7 (CH), 55.6 (OCH_3); HRMS (ESI) m/z: calcd for $C_{24}H_{18}NOCl_2$ $[M + H]^+$, 406.0760; found, 406.0753.

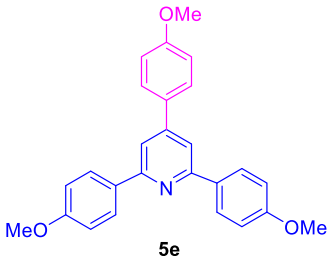
*2,6-Bis(4-methylphenyl)-4-(4-methoxyphenyl)pyridine (**5d**).*[56]



5d

White solid (51.5 mg, 72% yield); mp157−158 °C; ^{1}H NMR (500 MHz, $CDCl_3$): (ppm) 8.10 (d, J = 8.1 Hz, 4H, ArH), 7.80 (s, 2H, ArH), 7.70−7.67 (m, 2H, ArH), 7.31 (d, J = 8.0 Hz, 4H, ArH), 7.05−7.02 (m, 2H, ArH), 3.87 (s, 3H, OCH_3), 2.43 (s, 6H, CH_3); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 160.5 (C), 157.5 (C), 149.6 (C), 139.0 (C), 137.2 (C), 131.6 (C), 129.5 (CH), 128.4 (CH), 127.1 (CH), 116.1 (CH), 114.6 (CH), 55.5 (OCH_3), 21.4 (CH_3); HRMS (ESI) m/z: calcd for $C_{26}H_{24}NO$ $[M + H]^+$, 366.18524; found, 366.18492.

*2,6-Bis(4-methoxyphenyl)-4-(4-methoxyphenyl)pyridine (**5e**).*[55,56]



5e

White solid (43.0 mg, 61% yield); mp 135−137 °C; ^{1}H NMR (500 MHz, $CDCl_3$): (ppm) 8.15−8.12 (m, 4H, ArH), 7.72 (s, 2H, ArH), 7.69−7.66 (m, 2H, ArH), 7.03−7.00 (m, 6H, ArH), 3.87 (s, 9H, OCH_3); ^{13}C{H} NMR (125 MHz, $CDCl_3$): δ (ppm) 160.6 (C), 160.5 (C), 157.0 (C), 149.6 (C), 132.6 (C), 131.7 (C), 128.5 (CH), 128.4 (CH), 115.4 (CH), 114.6 (CH), 114.1 (CH), 55.6 (OCH_3), 55.5 (OCH_3); HRMS (ESI) m/z: calcd for $C_{26}H_{24}NO_3$ $[M + H]^+$, 398.1751; found, 398.1750.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.0c05328.

Detailed experimental procedures and spectroscopic data for all compounds (PDF)

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Notes

The authors declare no competing financial interest.

CCDC 2031225, 2031234, 2031242, 2031245, and 2031246 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif or by emailing data_request@ccdc.cam.ac.uk, or by containing The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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