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Transition-metal-free C-C σ-Bonds Activation of α-Aryl Ketones and Subsequent Zn-catalyzed Intramolecular Cyclization: Synthesis of Tetrasubstituted Furans

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A highly atom-economical protocol for the synthesis of tetrasubstituted furans has been developed. This process is realized through the tandem reactions of Cs_2CO_3 promoted C-C σ-bonds activation of α-aryl ketones followed by Zn-catalyzed intramolecular cyclization. This represents the first example for the preparation of tetrasubstituted furans through rearrangement of molecular skeletons and subsequent transformations. Mild reaction conditions and readily accessible starting material make the protocol attractive in organic synthesis.

Introduction

Highly substituted furans are of great importance because they exhibit a wide range of biological activities and appear as key structural units in many natural products, pharmaceuticals, and agrochemicals[1], examples include two sesquiterpenoids (**I** and **II**)[1e] and dimethylfuroguaiacin (**III**)[1f] (Figure 1). Moreover, they are versatile building blocks in synthetic organic chemistry.[2] Many synthetic routes for their preparation have been developed, such as direct functionalization of furan rings,[3] the Paal-Knorr synthesis from 1,4-dicarbonyl compounds,[4] the Feist- Bénary synthesis,[5] and transition-metal-catalyzed cycloisomerization of alkynyl or allenyl ketones.[6] However, literature reports for the syntheses of tetrasubstituted furans are relatively rare.[7] Polysubstituted furans were synthesized through Iron-catalyzed C-H/C-H coupling of activated carbonyl methylenes with S, S-functionalized olefins (Scheme 1, a).[7c] Ag-catalyzed coupling of two (sp^3)C –H groups afforded tetrasubstituted furans (Scheme 1, b).[7h] DBU-mediated tandem Michael addition/ cycloisomerization of keto-methylenes and enynes also gave tetrasubstituted furans.[7f] Although these methods are

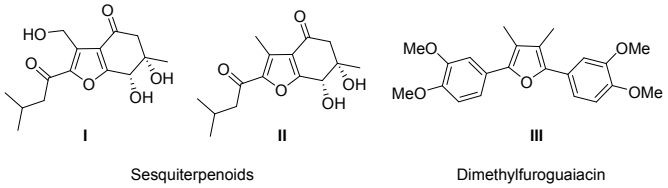
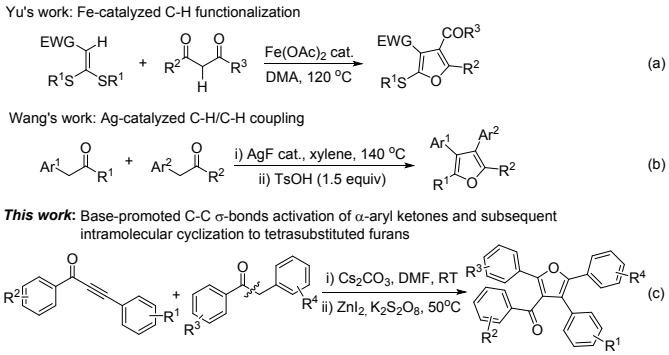


Figure 1 Some naturally occurring compounds containing substituted furans.



Scheme 1 synthesis of tetrasubstituted furans using keto-methylenes.

effective, more diverse and atom-economical procedures are strongly demanded for highly functionalized furans. In this context, processes initiated from the C-C σ-bonds activation toward tetrasubstituted furans would be very attractive, because it can reorganize the molecular skeleton and form two carbon-carbon bonds simultaneously without any byproducts.[8] As a continuation of our interest in the C-H and C-C σ-bonds activation chemistry, we report herein the one-pot procedure of Cs_2CO_3 mediated C-C bond insertion of alkynones into α–aryl ketones and subsequent Zn-catalyzed intramolecular cyclization (Scheme 1, c).[9a] The reaction produces the corresponding tetrasubstituted furans in good yields with easily accessible starting materials. This is the first example for the synthesis of tetrasubstituted furans through transition-metal-free carbon-carbon σ-bonds cleavage of unstrained molecules, as far as our knowledge.

Results and discussion

We initially conducted the reactions of 1,3-diphenylprop-2-yn-1-one (**1a**) with 1,2-diphenylethanone (**2a**) (1.0 equiv) in

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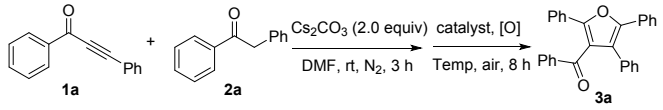
the presence of Cs_2CO_3 (2.0 equiv) in DMF under N_2 at room temperature. After the C-C bond cleavage product was formed as monitored by TLC, several reaction parameters were screened in order to achieve subsequent further transformations, the results are depicted in Table 1. When ZnI_2 (20 mol %) was added and the reaction temperature was increased to 50 °C, no new product was observed (entry 1). Interestingly, when $K_2S_2O_8$ (2.0 equiv) was employed, the corresponding tetrasubstituted furan **3a** was formed in 78% yield (entry 2). A higher temperature of 80 °C gave the same result as that of 50 °C (entry 3). A lower reaction temperature (30 °C) resulted in only 31% yield of **3a** (entry 4). It is worth to note that the subsequent reaction could also occur in the absence of ZnI_2 to give a low yield of the desired product (entry 5). Reducing the catalyst loading of ZnI_2 to 10 mol % achieved **3a** in 67% yield (entry 6). 50 mol % of catalyst loading gave almost the same outcome as that of 20 mol % (entry 7 vs entry 2). Then, the amount of $K_2S_2O_8$ was tested. Decreasing or increasing the amount of $K_2S_2O_8$ made lower yields of the desired furan (entries 8, 9). Next, other metal salts were screened. It was found that CuI, $FeCl_3$, $ZnCl_2$ and $Zn(OTf)_2$ could also catalyze the reaction, however, the yields of **3a** were in the range of 37-64% (entries 10-13). Lastly, different oxidants were tested. $(NH_4)_2S_2O_8$ and *tert*-butyl hydroperoxide (TBHP) afforded the desired **3a** in 55% and 26% yields, respectively (entries 14, 15). Whereas, di-*tert*-butyl peroxide (DTBP) and H_2O_2 are not effective for this reaction.

Table 1 Screening of the reaction conditions for the synthesis of **3a**



entry	cat.	[O] (equiv)	temp (°C)	yield (%)[a]
1	ZnI_2 (20 mol%)	–	50	NP
2	**ZnI_2 (20 mol%)**	**$K_2S_2O_8$ [2]**	**50**	**78%**
3	ZnI_2 (20 mol%)	$K_2S_2O_8$ [2]	80	78%
4	ZnI_2 (20 mol%)	$K_2S_2O_8$ [2]	30	31%
5	–	$K_2S_2O_8$ [2]	50	39%
6	ZnI_2 (10 mol%)	$K_2S_2O_8$ [2]	50	67%
7	ZnI_2 (50 mol%)	$K_2S_2O_8$ [2]	50	77%
8	ZnI_2 (20 mol%)	$K_2S_2O_8$ [1]	50	54%
9	ZnI_2 (20 mol%)	$K_2S_2O_8$ [3]	50	63%
10	CuI (20 mol%)	$K_2S_2O_8$ [2]	50	64%
11	$FeCl_3$ (20 mol%)	$K_2S_2O_8$ [2]	50	50%
12	$ZnCl_2$ (20 mol%)	$K_2S_2O_8$ [2]	50	38%
13	$Zn(OTf)_2$ (20 mol%)	$K_2S_2O_8$ [2]	50	37%
14	ZnI_2 (20 mol%)	$(NH_4)_2S_2O_8$ [2]	50	55%
15	ZnI_2 (20 mol%)	TBHP [2]	50	26%
16	ZnI_2 (20 mol%)	DTBP [2]	50	NP
17	ZnI_2 (20 mol%)	H_2O_2 [2]	50	trace

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.2 mmol), Cs_2CO_3 (0.4 mmol), DMF (2.0 mL), 50 °C, isolated yields. NP = No Product.

Encouraged by the above results, we next examined the substrate scope toward the synthesis of diverse tetrasubstituted furans by varying substituents on alkynones under the conditions shown in Table 1, entry 2. The results are depicted in Figure 2. First, we investigated the effect of different substituents (R^1) of the aryl rings on the triple bond. It was found that both electron-withdrawing and electron-donating groups on the aryl ring underwent the reaction smoothly to afford the desired substituted furans in good to high yields (Figure 2, **3a**-**3g**). With electron-withdrawing groups on the *para*-position of the aryl ring such as *p*-CN and *p*-Cl, the corresponding products **3b** or **3c** were obtained in 59% and 81% yields, respectively. With electron-donating groups on the aryl ring such as *p*-Me or *p*-OMe, the desired tetrasubstituted furans were also produced in high yields (**3d**, **3e**). A methyl group on the *ortho*-position of the aryl ring afforded the target compound **3f** in a yield of 69%. A *meta*-chloro substituted aryl ring produced the desired furan **3g** in 73% yield. Next, the R^2 substituents of the aryl ring on the carbonyl carbon were explored (Figure 2, **3h**-**3l**). It was worth noting when substituents on the carbonyl carbon of substrates **1** and **2** were different, two isomers would be obtained. With an electron-withdrawing group on the *para*-position of the aryl ring such as *p*-F, two isomerized products **3h** and **3h'** were obtained in a combined yield of 76% with a ratio of 4:3. The results indicated that there was competitively enolization between two carbonyl group of the C-C cleavage intermediate. Other electron-withdrawing groups such as *p*-Cl and *p*-Br were tolerable to the reaction conditions, affording (**3i**, **3i'**) and (**3j**, **3j'**) as two isomers in high yields. Substrates bearing electron-donating groups such as *p*-Me and *p*-OMe cyclized readily under the standard reaction conditions to afford the corresponding tetrasubstituted furans (**3k**, **3k'**) and (**3l**, **3l'**) in 83% and 52% yields, respectively.

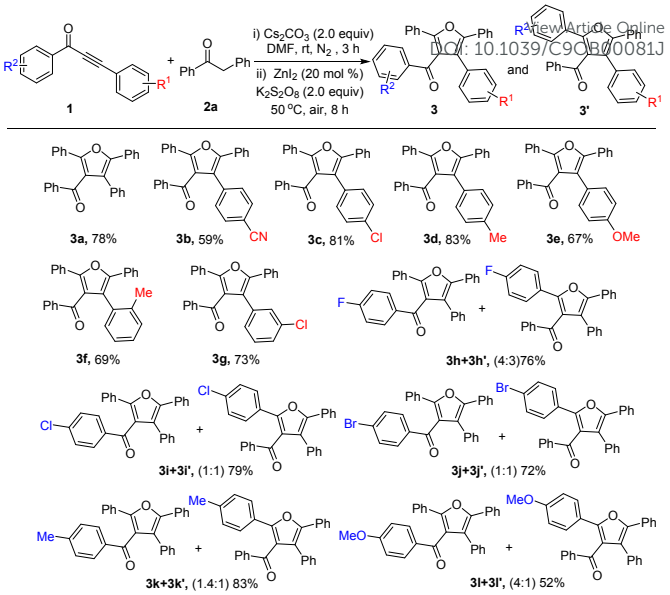


Figure 2 The scope of alkynone **1** for the synthesis of furan **3**. Reaction conditions: **1** (0.2 mmol), **2a** (0.2 mmol), Cs_2CO_3 (0.4 mmol), DMF (2.0 mL), ZnI_2 (0.04 mmol), $K_2S_2O_8$ (0.4 mmol), isolated yields.

To investigate whether our synthetic strategy is effective for alkyl-substituted alkynones, we next introduced *tert*-butyl and ethyl groups on the carbonyl side of the alkynone **1**. Interestingly, the desired tetrasubstituted furans (**3m**, **3m'**) and (**3n**, **3n'**) were obtained as well in good yields of 61% and 63% as two isomers, respectively (Figure 3, a). However, when the alkyne terminus was an *n*-butyl, only complex reaction mixture was observed in the first step reaction (Figure 3, b).

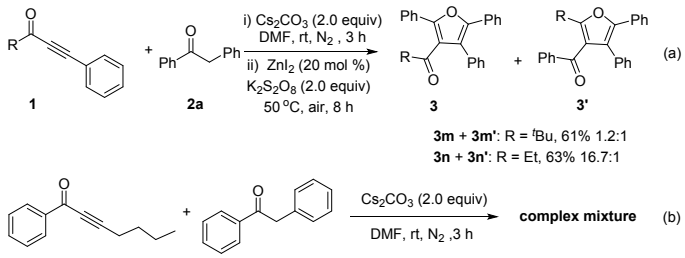


Figure 3 Synthesis of furans using alkyl substituted alkynones.

The scope of the α-aryl ketone **2** was also examined (Figure 4). In order to synthesize only one isomer, we tried to keep R^2 and R^3 as the same groups. For R^4 substituent, both electron-withdrawing and -donating groups on the aryl ring readily delivered the corresponding furans in good yields (**3o**-**3s**). A variety of functional groups such as nitro (**3o**), fluoro (**3p**), chloro (**3q**), bromo (**3r**), and methyl (**3s**) were tolerated well. The structure of **3q** was confirmed by comparing with the reported compound.[7a] For R^3 substituent, again, both electron-withdrawing and -donating character of the substituents on the aryl ring, such as *p*-Cl, *p*-Br, *p*-Me and *p*-OMe were well tolerated (**3t**-**3w**), providing the products in 51-82% yields. Interestingly, when R^3 as *p*-Br was employed to react with 1,3-diphenylprop-2-yn-1-one (**1a**), the corresponding **3j** and **3j'** were formed in a combined yield of 71%. We can find a similar result from Figure 2 for the preparation of **3j** and **3j'**. In that case, the desired substituted furans were produced from the reaction of 1-(4-bromophenyl)-3-phenylprop-2-yn-1-one with 1,2-diphenylethanone (**2a**). Moreover, bicyclic substituent smoothly underwent to this reaction, offering the desired furan **3x** in 51% yield, demonstrating the synthetic potential for the construction of complex organic molecules by this

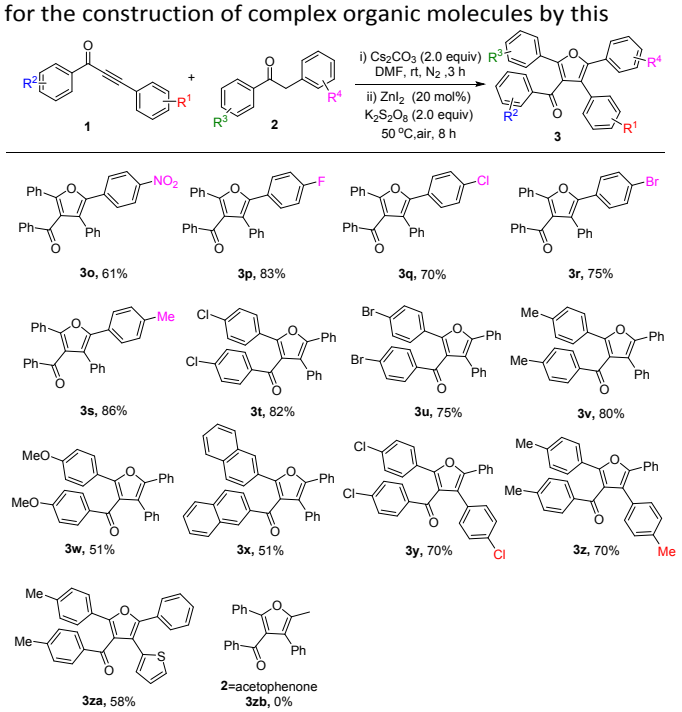
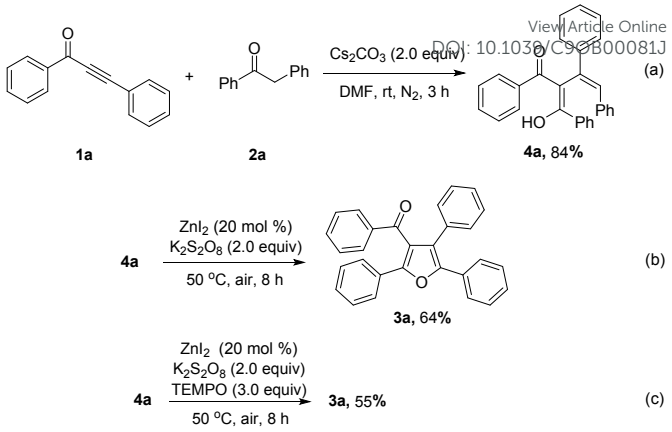


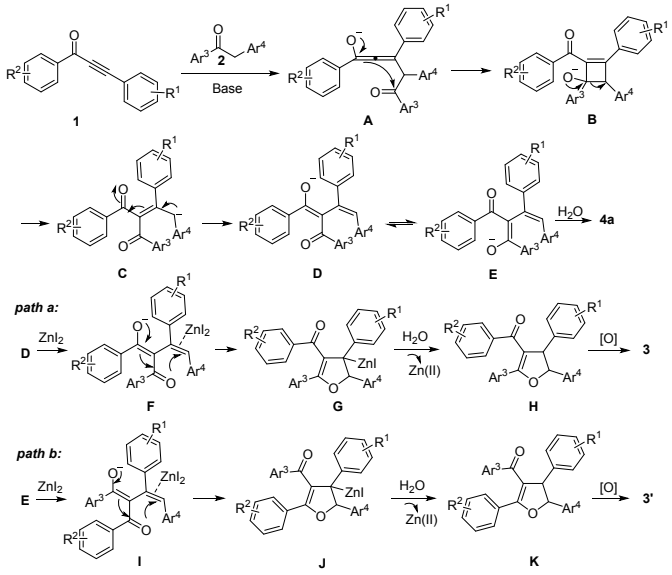
Figure 4 The scope of α-aryl ketone **2**. Reaction conditions: **1** (0.2 mmol), **2** (0.2 mmol), Cs_2CO_3 (0.4 mmol), DMF (2.0 mL), ZnI_2 (0.04 mmol), $K_2S_2O_8$ (0.4 mmol), isolated yields.



Scheme 2 Control experiments.

method. When R^1 substituent of substrate **1** with *p*-Cl or *p*-Me groups were used, the corresponding furans (**3y**, **3z**) were obtained both in 70% yield. With a 2-thienyl group in the alkyne side, the corresponding furan **3za** was also produced in 58% yield. However, when acetophenone was used, since the first step of the reaction cannot occur, the target product **3zb** cannot be obtained. To demonstrate the practical utility of this methodology, the gram scale reaction was conducted for the synthesis of **3a**, and the desired product **3a** was obtained in 73% (1.47 g) yield.

In order to clarify the reaction mechanism, we carried out the following control experiments (Scheme 2). First, the reaction of **1a** with **2a** was performed under the optimized reaction conditions for the first step. An intermediate **4a** was obtained in 84% yield after 3 h (Scheme 2, a). Treatment of **4a** with the general reaction conditions for the second step of our system, the desired furan **3a** was formed in 64% isolated yield within 8 h (Scheme 2, b). The result implicates that **4a** is the reaction intermediate for the formation of **3a** in the one-pot reaction. When the reaction was carried out with the addition of a radical scavenger TEMPO (3.0 equiv), a 55% yield of **3a** was obtained as well (Scheme 2, c). This indicates that a racical reaction pathway may not be involved in the reaction process.



Scheme 3 A plausible reaction mechanism.

Based on the above observation and our previous reports,[9] a plausible reaction mechanism is depicted in Scheme 3. In the presence of a base, **1** is attacked by α-aryl ketone **2** to give an intermediate **A**, which undergoes an intramolecular nucleophilic addition/ring-opening to give a formal alkyne insertion product **C**. Tautermerization of **C** leads to the formation of **D** or **E**, which delivers intermediate **4a** after hydrolysis. There are two possible pathways to achieve the final products **3** and **3'**. In path a, coordination of the double bond of **D** to ZnI_2 affords **F**. Nucleophilic attack of the carbonyl O atom to the activated double bond gives **G**. Hydrolysis of **G** followed by oxidative aromatization offers furan **3**. In path b, coordination of the double bond of **E** to ZnI_2 produces **I**. Nucleophilic attack of the carbonyl O atom to a double bond gives **J.** Hydrolysis of **J** followed by aromatization affords furan **3'**.

Conclusions

In summary, we have developed a one-pot procedure for the atom-economical synthesis of tetrasubstituted furans from α-aryl ketones and alkynones under mild conditions. This reaction proceeds through the base-promoted cleavage of a unstrained C-C single bond of ketones followed by the subsequent Zn-catalyzed intramolecular cyclization.

Experimental

General Information.

All reactions were performed in flame-dried glassware under an atmosphere of dry nitrogen, unless otherwise noted. Anhydrous DMF were prepared by distillation from CaH_2. Unless noted, all commercial reagents were used without further purification. Reactions were monitored by thin layer chromatography. Preparation of ynones and diaryl ketones were using reported methods.[9a-9j, 10] Purification of reaction products was carried out by flash chromatography on silica gel (200~300 mesh). ^1H NMR spectra were recorded at 400 MHz, ^{13}C NMR spectra were recorded at 100 MHz, and in $CDCl_3$ (containing 0.03% TMS) solutions. ^1H NMR spectra was recorded with tetramethylsilane (δ= 0.00 ppm) as internal reference; ^{13}C NMR spectra was recorded with $CDCl_3$(δ= 77.00 ppm) as internal reference. High-resolution mass spectra were performed on a mass spectrometer with a TOF (for EI or ESI) or FT-ICR (for MALDI) analyzer.

Typical Procedure for the Synthesis of 1

To a solution of alkyne (12 mmol) in anhydrous THF (30 mL), n-BuLi (2.5M, 10 mmol, 4 mL) was added at -78 °C. The resulting mixture was stirred at -78 °C for 1 hour, then the aldehyde (10 mmol) was added and the reaction temperature was raised to room temperature till aldehyde disappeared by TLC analysis. The resulting mixture was quenched with a saturated solution of NH_4Cl and extracted with ethyl acetate (20 mL × 3). The combined organic layers were washed with brine and dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. Purification by column chromatography with petroleum ether/ethyl acetate = 5/1-10:1 as the eluent afforded the substituted alkynol.

To a solution of substituted alkynol (10 mmol) in DMSO (20 mL) in round-bottom flask, IBX (12 mmol, 3.36 g) was added at room temperature. The reaction was stirred in air until the full conversion of substituted alkynol monitored by thin-layer chromatography. The resulting mixture was quenched with water (20 mL) and filtered. Then the filtrate was extracted with ethyl acetate (20 mL × 3). The organic layers was combined, washed with brine, dried over anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. Purification by column chromatography with petroleum ether/ethyl acetate = 10/1-20:1 as the eluent afforded the acetylenic ketones.

4,4-dimethyl-1-phenylpent-1-yn-3-one and **1-phenylpent-1-yn-3-one** were synthesized according to the references 10a and 10b, respectively.

Typical Procedure for the Synthesis of 2.[9a]

To a Schlenk tube with a magnetic stirring bar were charged the respective nitrile (1.0 mmol), arylboronic acid (2.0 mmol), $Pd(OAc)_2$ (5 mol %, 11.2 mg), bpy (10 mol%, 15.6 mg), TFA (10 equiv, 0.74 ml), THF (5 mL), and H_2O (1 mL) under N_2 atmosphere. The reaction mixture was stirred at 80 °C for 36 h. After cooling to r.t., the mixture was poured into EtOAc (5 mL), which was washed with sat. aq $NaHCO_3$ (2 × 10 mL) and then brine (1 × 10 mL). After extracting the aqueous layer with EtOAc (3 × 10 mL), the combined organic layers were dried over anhydrous Na_2SO_4, and evaporated under vacuum. Purification by column chromatography with petroleum ether/ethyl acetate = 5/1-10:1 as the eluent afforded the alkyl aryl ketones **2**.

Typical Procedure for the Synthesis of 3

In a schlenk tube, acetylenic ketone **1a** (0.2 mmol, 40.2 mg), 2-phenylacetophenone **2a** (0.2 mmol, 39.2 mg), Cs_2CO_3 (0.4 mmol, 130.3 mg) and DMF (2.0 mL) were stirred at room temperature under N_2. After 3 h, then ZnI_2 (0.04 mmol, 12.8 mg) and $K_2S_2O_8$ (0.4 mmol, 108.1 mg) were added. After the completion of the addition, the reaction mixture was allowed to react at 50 °C for 8 h. Then, the reaction mixture was cooled to room temperature and was treated with H_2O, then extracted with EA and dried over anhydrous Na_2SO_4. After removal of the EA, the residue was purified by chromatography on basic silica gel (PE: EA = 30: 1) to afford **3a** (yellow solid, 62.5 mg, 78%).

Phenyl(2,4,5-triphenylfuran-3-yl)methanone (3a). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 78%, 62.5 mg, m.p. 185-187 °C. ^1H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 8.0 Hz, 2H), 7.63 (d, *J* = 7.6 Hz, 2H), 7.54 (d, *J* = 7.6 Hz, 2H), 7.42-7.37 (m, 1H), 7.35-7.15 (m, 13H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.0, 151.3, 148.4, 137.7, 133.6, 132.4, 130.4, 130.0, 129.8, 128.8, 128.7, 128.6, 128.1, 127.9, 126.5, 126.2, 124.3,

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124.0. HRMS (ESI) calcd for $C_{29}H_{20}NaO_2$ [M+Na]$^+$: 423.1356; found: 423.1361.

4-(4-Benzoyl-2,5-diphenylfuran-3-yl)benzonitrile (3b). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 59%, 50.5 mg, m.p. 134-136 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.60 (d, *J* = 7.2 Hz, 2H), 7.53 (d, *J* = 8.0 Hz, 2H), 7.49-7.42 (m, 3H), 7.41-7.37 (m, 2H), 7.36-7.25 (m, 8H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 152.4, 149.3, 137.7, 137.4, 134.0, 132.6, 130.8, 130.0, 129.6, 129.3, 129.1, 128.9, 128.8, 128.8, 126.8, 126.6, 123.1, 122.5, 118.8, 111.5. HRMS (ESI) calcd for $C_{30}H_{19}NNaO_2$ [M+Na]$^+$: 448.1308; found: 448.1323.

(4-(4-Chlorophenyl)-2,5-diphenylfuran-3-yl)(phenyl)methanone (3c). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 81%, 70.2 mg, mp 137-139 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 7.6 Hz, 2H), 7.60 (d, *J* = 7.2 Hz, 2H), 7.52 (d, *J* = 6.4 Hz, 2H), 7.45-7.41 (m, 1H), 7.32-7.25 (m, 7H), 7.25-7.17 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 151.6, 148.7, 137.5, 133.9, 133.8, 131.4, 130.9, 130.1, 130.0, 129.6, 129.1, 128.8, 128.7, 128.4, 126.6, 126.3, 123.7, 123.1. HRMS (ESI) calcd for $C_{29}H_{19}ClNaO_2$ [M+Na]+: 457.0966; found: 457.0972.

(2,5-Diphenyl-4-(p-tolyl)furan-3-yl)(phenyl)methanone (3d). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 83%, 69.2 mg, m.p. 148-150 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 8.0 Hz, 2H), 7.61 (d, *J* = 7.6 Hz, 2H), 7.56 (d, *J* = 7.6 Hz, 2H), 7.45-7.38 (m, 1H), 7.33-7.21 (m, 8H), 7.15 (d, *J* = 8.0 Hz, 2H), 7.03 (d, *J* = 8.0 Hz, 2H), 2.28 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.1, 151.0, 148.4, 137.7, 137.6, 133.6, 130.5, 130.1, 129.8, 129.5, 129.2, 128.8, 128.7, 128.6, 128.0, 126.5, 126.2, 124.4, 124.1, 21.0. HRMS (ESI) calcd for $C_{30}H_{22}NaO_2$ [M+Na]$^+$: 437.1512; found: 437.1516.

(4-(4-Methoxyphenyl)-2,5-diphenylfuran-3-yl)(phenyl)methanone (3e). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 67%, 57.8 mg, m.p. 104-106 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 8.0 Hz, 2H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.56 (d, *J* = 7.6 Hz, 2H), 7.45-7.39 (m, 1H), 7.34-7.23 (m, 8H), 7.19 (d, *J* = 8.4 Hz, 2H), 6.77 (d, *J* = 8.4 Hz, 2H), 3.75 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.2, 159.4, 151.0, 148.3, 137.7, 133.6, 131.2, 130.5, 130.0, 129.8, 128.8, 128.7, 128.6, 128.0, 126.4, 126.1, 124.4, 124.1, 124.0, 114.2, 55.0. HRMS (ESI) calcd for $C_{30}H_{22}NaO_3$ [M+Na]$^+$: 453.1461; found: 453.1467.

(2,5-diphenyl-4-(o-tolyl)furan-3-yl)(phenyl)methanone (3f). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 69%, 57.5 mg, m.p. 163-165 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, *J* = 7.6 Hz, 2H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.45 (d, *J* = 7.6 Hz, 2H), 7.42-7.36 (m, 1H), 7.32-7.13 (m, 11H), 7.12-7.05 (m, 1H), 2.15 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.5, 151.4, 148.2, 137.6, 137.4, 133.4, 131.8, 130.7, 130.6, 130.4, 129.8, 129.7, 128.8, 128.7, 128.7, 128.4, 128.4, 127.9, 126.7, 126.1, 125.0, 124.3, 123.5, 19.8. HRMS (ESI) calcd for $C_{30}H_{22}NaO_2$ [M+Na]$^+$: 437.1512; found: 437.1515.

(4-(3-chlorophenyl)-2,5-diphenylfuran-3-yl)(phenyl)methanone (3g). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 73%, 63.3 mg, m.p. 136-138 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.52 (d, *J* = 7.2 Hz, 2H), 7.44-7.39 (m, 1H), 7.33-7.23 (m, 9H), 7.19-7.13 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.5, 151.7, 148.8, 137.6, 134.5, 134.3, 133.7, 130.1, 130.0, 129.9, 129.5, 128.9, 128.8, 128.6, 128.4, 128.1, 126.6, 126.3, 123.6, 122.8. HRMS (ESI) calcd for $C_{29}H_{19}ClNaO_2$ [M+Na]$^+$: 457.0966; found: 457.0964.

(4-Fluorophenyl)(2,4,5-triphenylfuran-3-yl)methanone and (2-(4-fluorophenyl)-4,5-diphenylfuran-3-yl)(phenyl)methanone (3h+3h'). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 76%, 63.5 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 4: 3 isomer. Major isomer: δ 7.89-7.78 (m, 2H), 7.66-7.60 (m, 2H), 7.57-7.50 (m, 2H), 7.46-7.36 (m, 1H), 7.32-7.20 (m, 10H), 6.95-6.88 (m, 2H); minor isomer: δ 7.12-6.96 (m, 2H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 192.3, 167.5, 164.9, 164.3, 161.8, 151.3, 150.6, 148.5, 148.4, 137.6, 134.1, 134.1, 133.7, 133.3, 132.7, 132.6, 132.3, 130.3, 130.0, 130.0, 129.7, 128.8, 128.8, 128.7, 128.6, 128.5, 128.5, 128.2, 128.0, 127.9, 126.5, 126.2, 124.3, 124.2, 123.8, 123.7, 116.0, 115.8, 115.8, 115.6. HRMS (ESI) calcd for $C_{29}H_{19}FNaO_2$ [M+Na]$^+$: 441.1261; found: 441.1266.

(4-Chlorophenyl)(2,4,5-triphenylfuran-3-yl)methanone and (2-(4-chlorophenyl)-4,5-diphenylfuran-3-yl)(phenyl)methanone (3i+3i'). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 79%, 68.3 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 1: 1 isomer. Isomer 1: δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.64-7.51 (m, 4H), 7.46-7.36 (m, 1H), 7.30-7.20 (m, 12H); isomer 2: δ 7.76 (d, *J* = 8.0 Hz, 2H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 192.6, 151.4, 150.0, 148.7, 148.6, 140.1, 137.5, 136.0, 134.6, 133.8, 132.2, 132.1, 131.3, 130.2, 130.2, 130.0, 129.6, 129.1, 128.9, 128.9, 128.8, 128.7, 128.6, 128.3, 128.2, 128.0, 127.9, 127.6, 126.5, 126.3, 126.2, 124.4, 124.1, 123.5. HRMS (ESI) calcd for $C_{29}H_{19}ClNaO_2$ [M+Na]$^+$: 457.0966; found: 457.0967.

(4-Bromophenyl)(2,4,5-triphenylfuran-3-yl)methanone and (2-(4-bromophenyl)-4,5-diphenylfuran-3-yl)(phenyl)methanone (3j+3j'). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 72%, 68.9 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 1: 1 isomer. Isomer 1: δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.55-7.38 (m, 5H), 7.32-7.20 (m, 10H); isomer 2: δ 7.69 (d, *J* = 8.4 Hz, 2H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 192.8, 151.5, 150.0, 148.7, 148.6, 137.5, 136.4, 133.8, 132.2, 132.1, 132.0, 131.9, 131.4, 130.2, 130.2, 130.0, 129.6, 128.9, 128.8, 128.7, 128.7, 128.3, 128.2, 128.0, 128.0, 127.8, 126.5, 126.3, 126.2, 124.5, 124.4, 124.2, 123.5, 122.8. HRMS (ESI) calcd for $C_{29}H_{19}BrNaO_2$ [M+Na]+: 501.0461; found: 501.0461.

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P-tolyl(2,4,5-triphenylfuran-3-yl)methanone and (4,5-diphenyl-2-(p-tolyl)furan-3-yl)(phenyl)methanone (3k+3k'). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 83%, 69.0 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 1.4: 1 isomer. Major isomer: δ 7.76 (d, *J* = 7.6 Hz, 2H), 7.64-7.50 (m, 4H), 7.45-7.35 (m, 1H), 7.30-7.20 (m, 10H), 7.13-7.03 (m, 2H), 2.30 (s, 3H); minor isomer: δ 7.83 (d, *J* = 7.6 Hz, 2H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.1, 193.7, 151.6, 150.6, 148.4, 148.1, 144.7, 138.8, 137.8, 135.2, 133.5, 132.5, 132.4, 130.5, 130.2, 130.0, 130.0, 130.0, 129.8, 129.5, 129.4, 128.8, 128.8, 128.7, 128.5, 128.1, 128.0, 127.8, 127.8, 127.0, 126.5, 126.3, 126.2, 126.2, 124.3, 124.3, 124.2, 123.4, 21.4, 21.0. HRMS (ESI) calcd for $C_{30}H_{22}NaO_2$ $[M+Na]^+$: 437.1512; found: 437.1513.

(4-Methoxyphenyl)(2,4,5-triphenylfuran-3-yl)methanone and (2-(4-methoxyphenyl)-4,5-diphenylfuran-3-yl)(phenyl)methanone (3l+3l'). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 10:1); yield: 52%, 44.8 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 4: 1 isomer. Major isomer: δ 7.84 (d, *J* = 8.8 Hz, 2H), 7.63 (d, *J* = 7.6 Hz, 2H),7.54 (d, *J* = 7.2 Hz, 2H), 7.33-7.20 (m, 11H), 6.76 (d, *J* = 8.4 Hz, 2H), 3.78 (s, 3H); minor isomer: δ 7.42-7.37 (m, 1H), 6.82 (d, *J* = 8.8 Hz, 2H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.5, 164.2, 150.4, 148.3, 133.4, 132.5, 130.8, 130.5, 130.0, 130.0, 130.0, 129.9, 128.8, 128.8, 128.7, 128.7, 128.5, 128.5, 128.2, 128.0, 127.9, 127.9, 127.8, 126.2, 126.1, 124.3, 124.2, 114.2, 113.8, 55.3, 55.1. HRMS (ESI) calcd for $C_{30}H_{22}NaO_3$: $[M+Na]^+$: 453.1461 found: 453.1467.

2,2-dimethyl-1-(2,4,5-triphenylfuran-3-yl)propan-1-one and (2-(tert-butyl)-4,5-diphenylfuran-3-yl)(phenyl)methanone (3m+3m'). white solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 50:1); yield: 61%, 46.6 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 1.2: 1 isomer. Major isomer: δ 7.78 (d, *J* = 7.6 Hz, 2H), 7.53 (d, *J* = 6.8 Hz, 2H), 7.45-7.11 (m, 11H), 1.36 (s, 9H); minor isomer: δ 7.65 (d, *J* = 8.0 Hz, 2H), 0.82 (s, 9H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 212.7, 195.4, 159.8, 148.2, 147.6, 146.0, 138.6, 133.4, 133.2, 132.8, 130.8, 130.8, 130.5, 130.3, 129.9, 129.0, 128.9, 128.6, 128.6, 128.5, 128.4, 128.1, 128.0, 127.5, 127.5, 126.2, 126.0, 125.8, 125.2, 123.0, 122.6, 122.0, 45.7, 34.1, 29.2, 26.5. HRMS (ESI) calcd for $C_{27}H_{24}NaO_2$: $[M+Na]^+$: 403.1669 found: 403.1669.

1-(2,4,5-triphenylfuran-3-yl)propan-1-one and (2-ethyl-4,5-diphenylfuran-3-yl)(phenyl)methanone (3n+3n'). yellow oil, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 50:1); yield: 63%, 44.6 mg. ^{1}H NMR (400 MHz, $CDCl_3$) Obtained as 16.7: 1 isomer. Major isomer: δ 7.71 (d, *J* = 7.6 Hz, 2H), 7.45 (d, *J* = 7.2 Hz, 2H),7.54-7.36 (m, 1H), 7.29-7.12 (m, 10H), 2.75 (q, *J* = 7.6 Hz, 2H), 1.31 (t, 3H); minor isomer: δ 7.98 (d, *J* = 7.6 Hz, 2H), 2.31 (q, *J* = 7.6 Hz, 2H), 0.94 (t, 3H); other peaks are overlapped with the other isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.1, 159.9, 147.5, 138.7, 135.1, 132.9, 132.8, 130.6, 130.1, 129.6, 129.2, 129.2, 128.8, 128.5, 128.5, 128.2, 127.7, 127.4, 127.2, 126.1, 123.3, 122.5, 20.9, 12.3. HRMS (ESI) calcd for $C_{25}H_{20}NaO_2$: $[M+Na]^+$: 375.1356 found: 375.1354.

(5-(4-Nitrophenyl)-2,4-diphenylfuran-3-yl)(phenyl)methanone (3o). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 61%, 54.5 mg, m.p. 157-159 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.8 Hz, 2H), 7.82 (d, *J* = 7.6 Hz, 2H), 7.72-7.60 (m, 4H) , 7.45-7.40 (m, 1H), 7.35-7.23 (m, 10H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 152.8, 146.8, 146.0, 137.3, 136.3, 133.9, 131.4, 129.9, 129.7, 129.4, 129.2, 129.1, 128.9, 128.7, 128.0, 126.7, 126.0, 124.5, 124.1. HRMS (ESI) calcd for $C_{29}H_{19}NNaO_4$ $[M+Na]^+$: 468.1206; found: 468.1207.

(5-(4-Fluorophenyl)-2,4-diphenylfuran-3-yl)(phenyl)methanone (3p). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 83%, 69.3 mg, m.p. 150-152 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 7.6 Hz, 2H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.54-7.47 (m, 2H) , 7.43-7.38 (m, 1H), 7.32-7.21 (m, 10H), 7.02-6.94 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 162.7 (*J* = 248.6 Hz), 151.3, 147.6, 137.6, 133.6, 132.2, 130.0, 130.0, 129.7, 128.9, 128.8, 128.7, 128.6, 128.1 (*J* = 8.1 Hz), 128.0, 126.6 (*J* = 3.3 Hz), 126.5, 124.0, 123.9, 115.7 (*J* = 21.8 Hz). HRMS (ESI) calcd for $C_{29}H_{19}FNaO_2$ $[M+Na]^+$: 441.1261; found: 441.1264.

(5-(4-Chlorophenyl)-2,4-diphenylfuran-3-yl)(phenyl)methanone (3q). white solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 70%, 60.9 mg, m.p. 178-180 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 7.6 Hz, 2H), 7.62 (d, *J* = 7.2 Hz, 2H), 7.46 (d, *J* = 8.4 Hz, 2H), 7.42-7.37 (m, 1H), 7.35-7.14 (m, 12H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 151.5, 147.4, 137.6, 133.9, 133.7, 132.0, 130.0, 129.9, 129.6, 128.9, 128.9, 128.8, 128.8, 128.6, 128.1, 127.4, 126.5, 124.8, 124.0. HRMS (ESI) calcd for $C_{29}H_{19}ClNaO_2$ $[M+Na]^+$: 457.0966; found: 457.0970 .

(5-(4-Bromophenyl)-2,4-diphenylfuran-3-yl)(phenyl)methanone (3r). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 75%, 72.0 mg, m.p. 164-166 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.62 (d, *J* = 7.2 Hz, 2H), 7.42-7.36 (m, 5H), 7.30-7.21 (m, 10H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 151.5, 147.4, 137.5, 133.7, 132.0, 131.9, 130.0, 129.9, 129.5, 129.2, 128.9, 128.8, 128.8, 128.6, 128.1, 127.6, 126.5, 124.9, 124.0, 122.0. HRMS (ESI) calcd for $C_{29}H_{19}BrNaO_2$ $[M+Na]^+$: 501.0461; found: 501.0466.

(2,4-Diphenyl-5-(p-tolyl)furan-3-yl)(phenyl)methanone (3s). yellow solid, obtained in 11 h and purified by chromatographyon silica gel (petroleum ether/ethyl acetate = 30:1); yield: 86%, 71.3 mg, m.p. 140-142 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, *J* = 7.6 Hz, 2H), 7.63 (d, *J* = 7.2 Hz, 2H), 7.45-7.36 (m, 3H) , 7.31-7.18 (m, 10H), 7.10 (d, *J* = 8.0 Hz, 2H), 2.33 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.1, 151.0, 148.7, 138.1, 137.7, 133.6, 132.5, 130.0, 129.8, 129.4, 128.8, 128.7, 128.6, 128.5, 127.7, 127.6, 126.5, 126.2, 123.9, 123.7, 21.0. HRMS (ESI) calcd for $C_{30}H_{22}NaO_2$ $[M+Na]^+$: 437.1512; found: 437.1516.

(4-Chlorophenyl)(2-(4-chlorophenyl)-4,5-diphenylfuran-3-yl)methanone (3t). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 82%, 76.9 mg, m.p. 147-149 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8.4 Hz, 2H), 7.58 (d, *J* = 8.4 Hz, 2H), 7.52 (d, *J* = 7.2 Hz, 2H), 7.32-7.18 (m, 12H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.5, 150.2, 148.8, 140.3, 135.8, 134.8, 132.0, 131.3, 130.0, 129.9, 129.2, 129.0, 128.9, 128.7, 128.4, 128.1, 127.6, 126.3, 124.2, 123.9. HRMS (ESI) calcd for $C_{29}H_{18}Cl_2NaO_2$ $[M+Na]^+$: 491.0576; found: 491.0577.

(4-Bromophenyl)(2-(4-bromophenyl)-4,5-diphenylfuran-3-yl)methanone (3u). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 75%, 83.2 mg, m.p. 193-195 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.0 Hz, 2H), 7.54-7.40 (m, 8H), 7.32-7.20 (m, 8H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.7, 150.2, 148.9, 136.2, 132.1, 132.0, 131.9, 131.4, 130.0, 129.9, 129.2, 128.9, 128.8, 128.5, 128.4, 128.1, 127.8, 126.3, 124.2, 124.0, 123.0. HRMS (ESI) calcd for $C_{29}H_{18}Br_2NaO_2$ $[M+Na]^+$: 578.9566; found: 578.9577.

(4,5-Diphenyl-2-(p-tolyl)furan-3-yl)(p-tolyl)methanone (3v). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 80%, 68.6 mg, m.p. 168-170 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8.0 Hz, 2H), 7.55-7.47 (m, 4H), 7.30-7.18 (m, 8H), 7.12-7.03 (m, 4H), 2.29 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 151.0, 148.0, 144.6, 138.6, 135.3, 132.5, 130.5, 130.2, 130.0, 129.5, 129.3, 128.7, 128.6, 127.9, 127.8, 127.1, 126.3, 126.2, 124.3, 123.5, 21.4, 21.0. HRMS (ESI) calcd for $C_{31}H_{24}NaO_2$ $[M+Na]^+$: 451.1669; found: 451.1678.

(4-Methoxyphenyl)(2-(4-methoxyphenyl)-4,5-diphenylfuran-3-yl)methanone (3w). yellow oil, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 10:1); yield: 51%, 46.6 mg. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 8.8 Hz, 2H), 7.58 (d, *J* = 8.4 Hz, 2H), 7.52 (d, *J* = 7.6 Hz, 2H), 7.29-7.20 (m, 8H), 6.82 (d, *J* = 8.4 Hz, 2H), 6.75 (d, *J* = 8.8 Hz, 2H), 3.77 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.6, 164.1, 160.0, 150.9, 147.7, 132.6, 132.5, 130.9, 130.6, 130.0, 128.7, 128.6, 127.9, 127.8, 127.8, 126.1, 124.3, 122.8, 122.7, 114.2, 113.8, 55.3, 55.1. HRMS (ESI) calcd for $C_{31}H_{24}NaO_4$ $[M+Na]^+$: 483.1567; found: 483.1572.

Naphthalen-2-yl(2-(naphthalen-2-yl)-4,5-diphenylfuran-3-yl)methanone (3x). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 51%, 51.1 mg, m.p. 136-138 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (s, 1H), 8.20 (s,1H), 8.01 (d, *J* = 8.4 Hz, 2H), 7.80-7.68 (m, 7H), 7.63 (d, *J* = 7.6 Hz, 2H), 7.53-7.47 (m, 1H), 7.42-7.15 (m, 11H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.0, 151.0, 148.7, 136.0, 135.2, 133.4, 133.2, 132.9, 132.6, 132.4, 130.4, 130.0, 129.9, 128.8, 128.8, 128.7, 128.6, 128.6, 128.2, 127.9, 127.9, 127.8, 127.2, 126.8, 126.7, 126.7, 126.3, 125.6, 124.7, 124.7, 124.6, 123.8. HRMS (ESI) calcd for $C_{37}H_{24}NaO_2$ $[M+Na]^+$: 523.1669; found: 523.1681.

(2,4-Bis(4-chlorophenyl)-5-phenylfuran-3-yl)(4-chlorophenyl)methanone (3y). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 70%, 70.7 mg, m.p. 145-147 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.0 Hz, 2H), 7.56-7.46 (m, 4H), 7.35-7.16 (m, 11H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.2, 150.4, 149.2, 140.6, 135.7, 135.0, 134.2, 131.3, 130.5, 129.7, 129.3, 129.2, 128.9, 128.7, 127.9, 127.7, 126.4, 123.6, 123.0. HRMS (ESI) calcd for $C_{29}H_{17}Cl_3NaO_2$ $[M+Na]^+$: 525.0186; found: 525.0200.

(5-Phenyl-2,4-di-p-tolylfuran-3-yl)(p-tolyl)methanone (3z). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 70%, 62.3 mg, m.p. 64-66 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, *J* = 7.6 Hz, 2H), 7.55 (d, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 8.0 Hz, 2H), 7.30-7.22 (m, 3H), 7.18-7.00 (m, 8H), 2.3-2.2 (m, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.8, 150.8, 147.9, 144.6, 138.5, 137.5, 135.3, 130.7, 130.2, 129.8, 129.5, 129.5, 129.4, 128.6, 127.8, 127.1, 126.3, 126.1, 124.3, 123.6, 21.4, 21.0, 21.0. HRMS (ESI) calcd for $C_{32}H_{26}NaO_2$ $[M+Na]^+$: 465.1825; found: 465.1828.

(5-phenyl-4-(thiophen-2-yl)-2-(p-tolyl)furan-3-yl)(p-tolyl)methanone (3za). yellow solid, obtained in 11 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 30:1); yield: 58%, 50.4 mg, m.p. 177-179 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 6.8 Hz, 2H), 7.50 (d, *J* = 8.4 Hz, 2H), 7.35-7.26 (m, 3H), 7.23-7.18 (m, 1H), 7.14-7.06 (m, 4H), 6.97-6.92 (m, 1H), 6.92-6.87 (m, 1H), 2.33 (S, 3H), 2.30 (S, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 150.8, 149.4, 144.8, 138.8, 135.2, 132.6, 130.2, 130.1, 129.5, 129.4, 128.7, 128.6, 128.3, 127.5, 126.9, 126.7, 126.4, 126.2, 123.8, 116.8, 21.5, 21.0. HRMS (ESI) calcd for $C_{29}H_{22}NaO_2S$ $[M+Na]^+$: 457.1233; found: 457.1239.

Typical Procedure for the Synthesis of 4a.

In a schlenk tube acetyenic ketone **1a** (0.2 mmol, 41.2 mg), Cs_2CO_3 (0.4 mmol, 130.3 mg), DMF (3.0 mL) and 2-phenylacetophenone **2a** (0.2 mmol, 39.2 mg) was stirred at room temperature under N_2. After the reaction was completed as monitored by thin-layer chromatography, the reaction mixture was then quenched by water, and the water layers were extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. Purification by chromatography on silica gel (petroleum ether/ethyl acetate = 20/1) afforded desired compound **4a** (yellow solid, 67.6 mg, 84%).

(2Z,3Z)-2-(hydroxy(phenyl)methylene)-1,3,4-triphenylbut-3-en-1-one (4a). yellow solid, obtained in 3.0 h and purified by chromatography on silica gel (petroleum ether/ethyl acetate = 20:1); yield: 84%, 67.6 mg, m.p. 156-158 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.94 (s, 1H), 7.44-7.32 (m, 6H), 7.25-7.05 (m, 14H), 6.64 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7, 143.0, 137.8, 137.2, 137.0, 132.3, 130.6, 128.7, 128.5, 128.5, 127.7, 127.6, 127.5, 127.2, 127.0, 110.7. HRMS (ESI) calcd for $C_{29}H_{22}NaO_2$ $[M+Na]^+$: 425.1512; found: 425.1505.

Gram Scales.

In a schlenk tube, acetyenic ketone **1a** (5.0 mmol, 1031.2 mg), 2-phenylacetophenone **2a** (5.0 mmol, 981.2 mg), Cs_2CO_3 (10.0 mmol, 3258.2 mg) and DMF (50 mL) were stirred at room temperature under N_2. After 3 h, then ZnI_2 (1.0 mmol, 319.2mg)

and $K_2S_2O_8$ (10.0 mmol, 2703.2 mg) were added. After the completion of the addition, the reaction mixture was allowed to react at 50 °C for 8 h. Then, the reaction mixture was cooled to room temperature and was treated with H_2O, then extracted with EA and dried over anhydrous Na_2SO_4. After removal of the EA, the residue was purified by chromatography on basic silica gel (PE: EA = 30: 1) to afford **3a** (yellow solid, 1469.3 mg, 73%).

Conflicts of interest

There are no conflicts to declare.

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