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Solvent-Free DABCO-Mediated [3 + 2] Cycloadditions of Donor−Acceptor Cyclopropanes with Aldehydes: Strategy for Synthesis of Fully Substituted Furans

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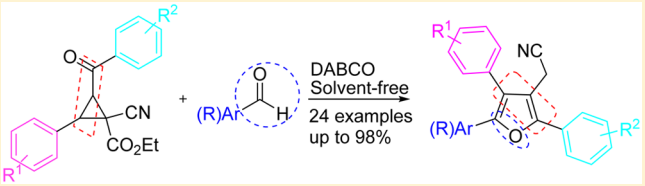
Supporting Information

ABSTRACT: DABCO-mediated [3 + 2] cycloadditions of donor−acceptor cyclopropanes with aldehydes under solvent-free conditions have been developed for the preparation of fully substituted furans which are a wide range of structurally interesting and pharmacologically significant compounds. The reaction appears to be general for a variety of 1-cyanocyclopropane-1-carboxylates and aldehydes and tolerates the presence of aromatic moieties with electron-withdrawing and electron-donating substituents.



Furans are an important class of five-membered heterocycles because of their diverse and potent biological properties in many pharmaceutical and natural products.[1] Polysubstituted furans have also frequently been employed as basic building blocks in synthetic chemistry[2] and as great potential skeletons in materials science.[3] Typical methods for the synthesis of furans deal with the approaches based on both the Feist−Bénary cyclocondensation and the Paal−Knorr cyclocondensation.[4] Although cyclocondensation of single precursors represents established access to furans, they usually rely on the intramolecular cyclization of complex acyclic precursors which may need tedious multistep synthesis and purification; hence, these protocols are unsuitable for the rapid generation of a library of polysubstituted furans. Due to the frequent occurrence of polysubstituted furans in natural products, pharmaceuticals, biochemicals, and other functional molecules as well as their utility as synthetic intermediates, the development of efficient methods for the synthesis of polysubstituted furans attracted substantial interest from synthetic chemists.[5] For example, an enormous increase of efficient approaches to substituted furans included the functionalization of existing furans such as transition-metal-catalyzed direct arylation of furans via C−H activation,[6] transition-metal-catalyzed cyclocondensations of alkynyl, allenyl, or cyclopropyl ketones or other derivatives,[7] and the [3 + 2] cycloaddition of two simple starting materials.[8] Additionally, many multicomponent reactions also have gained a great deal of attention for the synthesis of polysubstituted furans.[9] The exploration of new methods for the synthesis of polysubstituted furans still continues to attract the interest of chemists. Herein, we disclose a novel method to construct fully substituted furans through an efficient and regioselective DABCO-mediated [3 + 2] cycloaddition of donor−acceptor cyclopropanes with aldehydes under solvent-free conditions.

In the past decades, a massive increase of interest in cycloaddition reactions of donor−acceptor cyclopropanes has occurred;[10] thus, these reactions became an enormously active and inventive field of various carbo- and heterocyclic syntheses because they often take place in a regioselective manner as well as under very mild reaction conditions. Because of their high π character and intrinsic ring strain, donor−acceptor cyclopropanes undergo various types of ring-opening reactions under the influence of a variety of conditions which can easily give an especially 1,3-dipolar intermediate that affords formal [3 + 2]-cycloaddition with dipoles such as alkenes, aldehydes, ketones, imines, enol ethers, isocyanates, diazenes, pyrazolines, azomethine imine ylides, acetylenes, nitriles, and nitrones leading to five-membered cyclic scaffolds.[11] In particular, [3 + 2] cycloadditions of D−A cyclopropanes with aldehydes demonstrated the simplicity and high efficiency of this type of chemistry in the construction of valuable substituted furans[12] (Scheme 1, eq 1). Besides the commonly used 2-substituted cyclopropane 1,1-diesters, the variation on the structures of cyclopropane 1,1-diesters has been studied recently. Some 2,2-disubstituted cyclopropane 1,1-diesters and 2,3-disubstituted cyclopropane 1,1-diesters have been examined in this type of reaction (Scheme 1, eqs 2 and 3).[12a,b,e,f] Among them, the different stereochemical 2,3-disubstituted cyclopropane 1,1-diesters were used in the [3 + 2] cycloadditions with aldehydes for the stereoselective synthesis of otherwise difficult to obtain fully substituted furans. As a novel type of donor−acceptor cyclopropane, similar to 2-aroyl-3-arylcyclopropane 1,1-diesters introduced by Yang and co-workers,[12e,f] we used 2-aroyl-3-aryl-1-cyanocyclopropane-1-carboxylates as a precursor of 1,3-dipolar intermediate for novel cycloaddition reactions which have recently proved to be a versatile building block in the synthesis of many important aromatic compounds and aromatic heterocycles.[13] We recently discovered the [4 + 1] cycloaddition of 1-cyanocyclopropane-1-carboxylates with water to

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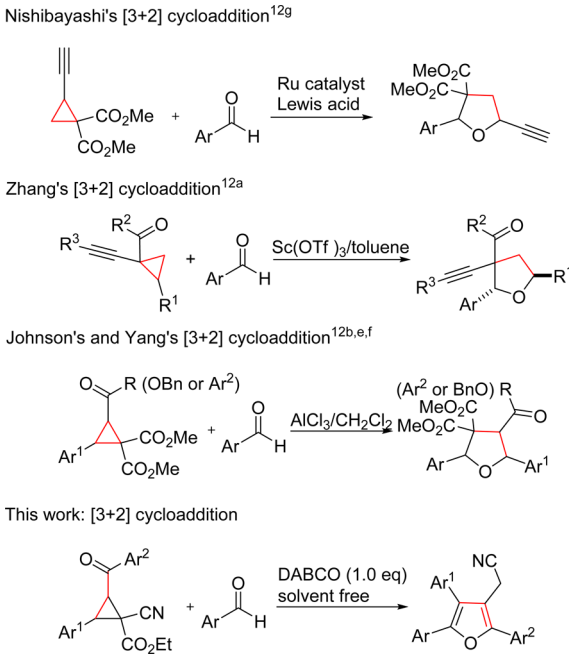
Scheme 1. Two Different Types of Cycloaddition Reactions of Donor–Acceptor Cyclopropanes with Aldehydes



afford functionalized 2-aminofuran frameworks, which involves the sequential ring-opening/intramolecular cyclization reaction.[13e] In our recent research on the intramolecular [3 + 2] cycloaddition reactions of D–A cyclopropane with carbonyls, we found that under catalysis by Lewis base or Brönsted acid an intermolecular [3 + 2] cycloaddition took place in which the D–A cyclopropane with carbonyls acted as C3 synthons from two carbons of cyclopropane and a carbonyl.[13c,d]

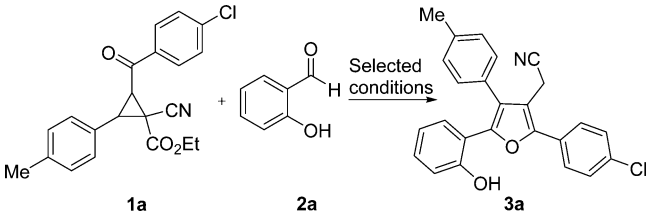
To the best of our knowledge, no example using [3 + 2] cycloaddition reactions of cyclopropane 1,1-diester or 1-cyanocyclopropane-1-carboxylate with aldehydes to directly afford fully substituted furans was reported in which two carbons came from the skeleton of cyclopropane and the other carbon was from its side chain α-carbonyl. Based on our studies on the reactivity of 2-aroyl-3-aryl-1-cyanocyclopropane-1-carboxylates, we envisioned that the reaction of 2-aroyl-3-aryl-1-cyanocyclopropane-1-carboxylates with substituted aldehydes may offer an efficient approach to furan skeletons via [3 + 2] cycloadditions and aromatization (Scheme 1, eq 4).

We commenced our studies by exploring the reaction between ethyl 2-(4-chlorobenzoyl)-1-cyano-3-(*p*-tolyl)cyclopropane-1-carboxylate (**1a**), which was readily prepared from ethyl 2-cyano-3-(*p*-tolyl)acrylate and 1-(2-(4-chlorophenyl)-2-oxoethyl)pyridin-1-ium bromide,[14] and 2-hydroxybenzaldehyde (**2a**). Table 1 summarizes the results.

Our initial experiments focused on the identification of an appropriate basic agent and solvent. The reaction of **1a** (1.0 equiv) and **2a** (2.0 equiv) in the presence of DABCO (1,4-diazabicyclooctane) (2.0 equiv) was performed in toluene at 110 °C (Table 1, entry 1). The cycloaddition product **3a** was isolated in less than 5% yield. The structure of the compound **3a** was characterized by ^{1}H NMR, ^{13}C NMR, and HRMS measurements. Compound **3a** was further confirmed by X-ray crystallographic analysis (see Figure S1).[15]

Our previous results showed the ring opening of 1-cyanocyclopropane-1-carboxylates occurred easily at about 110 °C.[13] Next, different solvents (DMF and dioxane) were

Table 1. Optimization of Reaction Conditions in the Synthesis of 3a



1a **2a** **3a**

entry	1a/2a (mol)	base (equiv)	solvent	T (°C)	time (h)	yield[a] (%)
1	1:2	DABCO (2.0)	$C_6H_5CH_3$	110	24	<5
2	1:2	DABCO (2.0)	1,4-dioxane	110	24	0
3	1:2	DABCO (2.0)	DMF	110	24	0
4	1:6	DABCO (1.0)		60	24	0
5	1:6	DABCO (2.0)		110	9	95
6	1:6	NaOH (2.0)		110	9	0
7	1:6	K_2CO_3 (2.0)		110	9	0
8	1:6	DBU (2.0)		110	9	31
9	1:6	Et_3N (2.0)		110	9	<5
10	1:6	piperidine (2.0)		110	9	<5
11	1:6	DABCO (1.5)		110	9	95
12	1:6	DABCO (1.0)		110	9	94
13	1:6	DABCO (0.75)		110	9	88
14	1:6	DABCO (0.5)		110	9	74
15	1:6	DABCO (1.0)		100	9	96
16	1:6	DABCO (1.0)		80	16	73
17	1:4	DABCO (1.0)		100	9	86

[a]Isolated yields.

investigated for the improvement of the title reaction; as a result, product **3a** was not isolated (Table 1, entries 2 and 3). These results suggested that the intermediate anion from 1-cyanocyclopropane-1-carboxylates by ring opening might be solvated to attack the carbonyl of benzaldehyde. Thus, when the ratio of the aldehyde **2a** was raised, the reaction was carried out at 60 °C under solvent free conditions, the product **3a** was also not obtained (Table 1, entry 4). To our surprise, under the promotion of DABCO (2.0 equiv), raising the reaction temperature to 110 °C obviously improved the yield of the product **3a** 6 equiv of the aldehyde **2a** was used (Table 1, entry 5). Other bases such as NaOH, K_2CO_3, DBU, Et_3N, and piperidine were also screened: DBU, Et_3N, and piperidine were not as effective, and DABCO, NaOH, and K_2CO_3 did not work at all (Table 1, entries 6–10). We found that the reaction proceeded smoothly at 110 °C under the promotion of DABCO (2.0 equiv) with a better regioselectivity. This condition was selected as optimal for further research. Subsequently, reducing the amount of DABCO from 2.0 to 1.5 equiv and 1.0 equiv all gave the expected furan products in excellent yields (Table 1, entries 11 and 12); further varying the loading amount of DABCO led to inferior results (Table 1,

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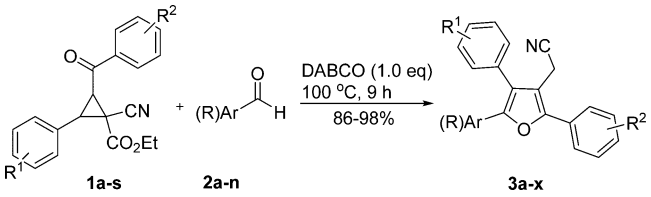
entries 13 and 14). With the aim of yield optimization, we turned our attention to the reaction temperature; decreasing the reaction temperature to 100 °C led to improvements in the yield of **3a** (96%) (Table 1, entry 15). Further decreasing the reaction temperature to 80 °C led to an inferior yield even with a much longer reaction time (Table 1, entry 16). While screening the ratio of the aldehyde **2a**, we found that reducing the amount of the aldehyde **2a** from 6.0 equiv to 4.0 equiv gave a lower yield of **3a** (Table 1, entry 17). To summarize, the optimal reaction conditions were selected as 1 equiv of 1-cyanocyclopropane-1-carboxylates, 6 equiv of aldehydes, and 1 equiv of DABCO at 100 °C for 9 h.

Under the optimized conditions, we further used a range of substituted aldehydes **2a−n** with various 1-cyanocyclopropane-1-carboxylates **1a−s** for the synthesis of 2-(2,4,5-trisubstituted furan-3-yl)acetonitriles via the [3 + 2] cycloaddition reaction. The results are summarized in Table 2. Both electron-deficient

Table 2. Synthesis of 2-(2,4,5-Trisubstituted furan-3-yl)acetonitriles[a]



1a-s **2a-n** **3a-x**

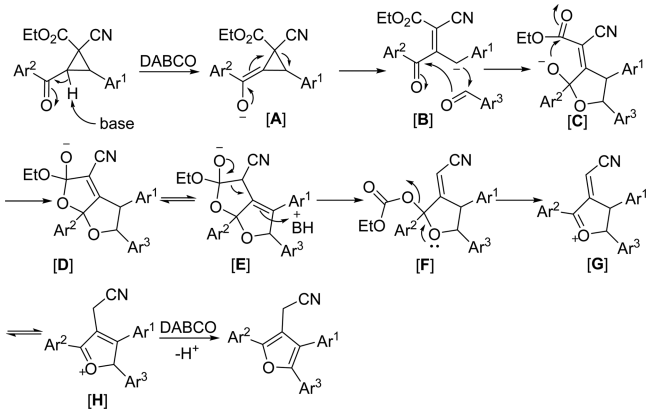
entry	R^1	R^2	Ar(R)	product	yield[b] (%)
1	*p*-Me	*p*-Cl	*o*-HOC_6H_4	**3a**	96
2	*p*-Cl	*p*-Cl	*o*-HOC_6H_4	**3b**	97
3	*p*-I	*p*-Br	*o*-HOC_6H_4	**3c**	95
4	*p*-Br	*p*-Br	*o*-HOC_6H_4	**3d**	96
5	*p*-Cl	*p*-MeO	*o*-HOC_6H_4	**3e**	86
6	*p*-Br	H	*o*-HOC_6H_4	**3f**	95
7	*p*-CO_2Me	H	*o*-HOC_6H_4	**3g**	94
8	3,4-OCH_2CH_2O	H	*o*-HOC_6H_4	**3h**	92
9	*m*-Br	*p*-Br	*o*-HOC_6H_4	**3i**	93
10	*o*-Me	H	*o*-HOC_6H_4	**3j**	97
11	*o*-Br	H	*o*-HOC_6H_4	**3k**	94
12	*p*-Me	H	*o*-ClC_6H_4	**3l**	93
13	*p*-Me	H	*o*-MeC_6H_4	**3m**	94
14	*m*-Br	H	*p*-ClC_6H_4	**3n**	95
15	*m*-Br	H	*p*-MeC_6H_4	**3o**	98
16	*o*-Cl	*p*-MeO	*m*-ClC_6H_4	**3p**	94
17	*p*-Cl	H	*m*-MeC_6H_4	**3q**	97
18	*m*-CH_3	H	thiophen-3-	**3r**	89
19	*m*-CH_3	*p*-MeO	C_6H_5	**3s**	92
20	*p*-Br	*p*-MeO	*p*-$MeOC_6H_4$	**3t**	93
21	*p*-Br	*p*-Cl	*o*-$MeOC_6H_4$	**3u**	92
22	*p*-Br	*p*-Cl	*p*-IC_6H_4	**3v**	88
23	*p*-Br	*p*-MeO	C_2H_5	**3w**	91
24	*p*-Br	*p*-MeO	*n*-C_3H_7	**3x**	89

[a]Reaction conditions: 1-cyanocyclopropane-1-carboxylates **1a−s** (2 mmol), substituted aldehydes **2a−n** (12 mmol), DABCO (224 mg, 2 mmol), 100 °C, 9 h. [b]Isolated yield.

and electron-rich aromatic groups were similarly viable, affording the products in good to excellent yields (86−98%). Substrates bearing methyl, chloro, bromo, iodo, and ethoxycarbonyl at the 2-, 3-, or 4-position of the aryl displayed similar reactivity, but substrates bearing an alkoxy of the aryl showed slightly lower activities to furnish the products in good yields (Table 2, entries 5, 8, and16). The results in Table 2 also showed that the electron-withdrawing or electron-donating groups attached to the benzaldehyde moiety did not have a significant influence on the [3 + 2] cycloaddition reaction. The structures of **3d** and **3m** are shown in Figures S2 and S3 (see the Supporting Information).[15] X-ray crystallographic analysis further determined that products **3d** and **3m** possess three aryls and cyanomethyl contiguous substituents at C(2), C(4), C(5), and C(3) of furan skeleton. On the basis of spectroscopic evidence the structure of compound **3a−x** was identified as 2-(2,4,5-trisubstituted furan-3-yl) acetonitriles.

On the basis of these results, we proposed a possible mechanism for the title reaction (Scheme 2). The key steps

Scheme 2. Tentative Reaction Mechanism



involved the generation of a benzyl anion via the carbonyl αH-elimination of 1-cyanocyclopropane-1-carboxylates. First, in the presence of base DABCO, the carbonyl αH-elimination of 1-cyanocyclopropane-1-carboxylates occurred, following the keto−enol tautomerism of α carboanion of the carbonyl gave enol anion **A**.[13a,16,17] Then the ring opening of methylenecyclopropane enol anion **A** formed a benzyl anion (**B**). The cycloaddition of **B** with a carboanion to the carbonyl of benzaldehyde afforded the tetrahydrofuran intermediate **C**. Next, the intramolecular nucleophilic addition of anion **C** to the carbonyl group of the ester formed the bicyclic 3-cyanotetrahydrofuro[2,3-*b*]furan-2-olate intermediate **D** again; in the presence of base DABCO, hydrogen 1,3-shift afforded a conjugated styrene intermediate **E**. The tetrahydrofuro[2,3-*b*]furan-2-olate intermediate **E** was transformed to the 3-(cyanomethylene)tetrahydrofuran-2-yl ethyl carbonate intermediate **F**. Next, removal of ethyl carbonate[18] yielded the 4-(cyanomethylene)-3,4-dihydro-2*H*-furan-1-ium intermediate **G**, and the following intermediate **G** was transformed to the 4-(cyanomethyl)-2*H*-furan-1-ium intermediate **H** via 1,3-shift hydrogen. The fully substituted furans were finally obtained through the deprotonation of the 4-(cyanomethyl)-2*H*-furan-1-ium intermediate **H** driven by the formation of a conjugated furan system.

In conclusion, we have developed an efficient DABCO-mediated [3 + 2] cycloaddition of donor−acceptor cyclopropanes with aldehydes under solvent-free conditions for the preparation of fully substituted furans which are a wide range of structurally interesting and pharmacologically significant compounds. This reaction involves a highly efficient multiple domino sequence consisting of ring opening of donor−acceptor cyclopropanes, regioselective intermolecular nucleo-

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philic addition, intramolecular *O*-nucleophilic addition. and aromatization as key unit steps. The reaction appears to be general for a variety of 1-cyanocyclopropane-1-carboxylates and aldehydes and tolerates the presence of aromatic moieties with electron-withdrawing and electron-donating substituents.

EXPERIMENTAL SECTION

All melting points were determined in a Mel-Tem capillary melting point apparatus and are uncorrected. IR spectra were recorded on an FT-IR instrument at normal temperature with a KBr pellet formed by grinding the sample with KBr (IR grade). The ^{1}H NMR (400 or 600 MHz) and ^{13}C NMR (100 or 150 MHz) spectra are recorded with TMS as internal reference in DMSO-d_6 or $CDCl_3$ solutions. Chemical shifts, δ (in ppm), are reported relative to TMS δ (^{1}H) 0.0, δ (^{13}C) 0.0, which was used as the inner reference with multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet). The *J* values are given in hertz. Only discrete or characteristic signals for the ^{1}H NMR are reported. High-resolution mass spectra were obtained on a UHR-TOF mass spectrometer. Flash chromatography was performed on silica gel (230−400 mesh) eluting with ethyl acetate−hexanes mixture. All reactions were monitored by thin-layer chromatography (TLC). All reagents and solvents were purchased from commercial sources and purified commonly before used. All starting cyclopropane derivatives were prepared according to reported methods.[14]

General Procedure for Preparation of 2-(2,4,5-Trisubstituted furan-3-yl) Acetonitriles 3a−x. The standard procedure for the synthesis of 2-(2,4,5-trisubstitutedfuran-3-yl)acetonitriles via [3 + 2] reaction between substituted ethyl 2-aroyl-3-aryl-1-cyanocyclopropane-1-carboxylates and aldehydes follows. To the mixture of 2-aroyl-3-aryl-1-cyanocyclopropane-1-carboxylates **1a−s** (2 mmol) and substituted aldehydes (12 mmol) was added DABCO (224 mg, 2 mmol) at 100 °C. The resulting mixture was stirred at 100 °C for 9 h, and the completion of the reaction was confirmed by TLC (hexanes/EtOAc 8/1). Subsequently, the excess substituted aldehydes were removed by steam distillation and were recovered, and the residue was extracted with dichloromethane (15 mL × 2). The organic phase was washed with water (10 mL) and brine (15 mL) and dried over anhydrous sodium sulfate. After removal of dichloromethane, the crude product was purified by flash chromatography (silica gel, EtOAc/hexanes, 1/15) to give the desirable products **3a−x**.

*2-(2-(4-Chlorophenyl)-5-(2-hydroxyphenyl)-4-(p-tolyl)furan-3-yl)-acetonitrile (**3a**):* white solid, 760 mg, 95%; mp 255.7−256.4 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3382, 3030, 2949, 2918, 2256, 1583, 1487, 1447, 1353, 1290, 1259, 1201, 1118, 1085, 1011, 955, 825, 752; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.64 (s, 1H), 7.72 (d, *J* = 8.4 Hz, 2H), 7.61 (d, *J* = 8.4 Hz, 2H), 7.20 (dd, *J* = 8.4 and 8.4 Hz, 3H), 7.16 (dd, *J* = 7.8 and 7.8 Hz, 3H), 6.86 (d, *J* = 8.4 Hz, 1H), 6.75 (dd, *J* = 7.2 and 7.2 Hz, 1H), 3.89 (s, 2H), 2.32 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.6, 147.8, 147.6, 136.6, 132.7, 130.9, 129.3, 129.1, 129.0, 128.8, 128.4, 127.4, 125.0, 118.7, 118.0, 116.9, 111.9, 20.8, 13.4; HRMS (ESI) calcd for $C_{25}H_{18}ClNNaO_2$ [(M + Na)$^+$] 422.0918, found 422.0916.

*2-(2,4-Bis(4-chlorophenyl)-5-(2-hydroxyphenyl)furan-3-yl)-acetonitrile (**3b**):* yellow solid, 813 mg, 97%; mp 249.7−250.9 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3019, 2941, 2908, 1581, 1477, 1440, 1351, 1276, 1243, 1189, 1111, 1075, 1011, 985, 834, 753; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.65 (s, 1H), 7.74 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 8.4 Hz, 2H), 7.47 (dd, *J* = 7.8 and 7.8 Hz, 2H), 7.28 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 7.8 Hz, 1H), 7.21 (dd, *J* = 7.8 and 7.8 Hz, 1H), 6.86 (d, *J* = 7.8 Hz, 1H), 6.80 (dd, *J* = 7.8 and 7.8 Hz, 1H), 3.95 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.4, 148.1, 147.8, 132.9, 132.2, 131.0, 130.8, 130.7, 130.5, 129.1, 128.7, 128.3, 127.6, 124.0, 118.9, 117.9, 116.6, 116.2, 111.8, 13.3; HRMS (ESI) calcd for $C_{24}H_{15}Cl_2NNaO_2$ [(M + Na)$^+$] 442.0372, found 442.0367.

*2-(2-(4-Bromophenyl)-5-(2-hydroxyphenyl)-4-(4-iodophenyl)-furan-3-yl)acetonitrile (**3c**):* yellow solid, 1054 mg, 95%; mp 249.7−250.9 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3375, 3065, 2949, 2259, 1730, 1627, 1585, 1484, 1446, 1352, 1074, 1007, 825, 764, 505, 476; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.62 (s, 1H), 7.73 (d, *J* = 3.2 Hz, 2H), 7.71 (d, *J* = 4.0 Hz, 2H), 7.63 (d, *J* = 8.4 Hz, 2H), 7.21 (d, *J* = 8.0 Hz, 1H), 7.17 (d, *J* = 7.6 Hz, 1H), 7.03 (dd, *J* = 8.0 and 8.0 Hz, 2H), 6.82 (d, *J* = 8.0 Hz, 1H), 6.77 (dd, *J* = 7.2 and 7.2 Hz, 1H), 3.90 (s, 2H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 155.8, 148.6, 148.2, 137.9, 132.5, 132.1, 131.7, 131.2, 130.9, 129.1, 128.3, 124.6, 121.9, 119.3, 118.3, 117.0, 116.6, 112.2, 94.3, 13.8; HRMS (ESI) calcd for $C_{24}H_{15}BrINNaO_2$ [(M + Na)$^+$] 577.9223, found 577.9212.

*2-(2,4-Bis(4-bromophenyl)-5-(2-hydroxyphenyl)furan-3-yl)-acetonitrile (**3d**):* white solid, 977 mg, 96%; mp 251.7−252.2 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3015, 2949, 2918, 1590, 1474, 1446, 1331, 1264, 1222, 1193, 1101, 1045, 1001, 987, 854, 793; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.69 (s, 1H), 7.75 (d, *J* = 7.2 Hz, 2H), 7.67 (d, *J* = 7.8 Hz, 2H), 7.60 (d, *J* = 7.2 Hz, 2H), 7.27 (d, *J* = 6.6 Hz, 1H), 7.22 (d, *J* = 7.2 Hz, 3H), 6.87 (d, *J* = 7.2 Hz, 1H), 6.81 (dd, *J* = 6.6 and 6.6 Hz, 1H), 3.96 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.4, 148.1, 147.8, 132.0, 131.6, 131.4, 131.1, 130.8, 130.5, 128.6, 127.8, 124.0, 121.5, 120.8, 118.9, 117.9, 116.6, 116.2, 111.8, 13.4; HRMS (ESI) calcd for $C_{24}H_{15}Br_2NNaO_2$ [(M + Na)$^+$] 531.9300, found 531.9337.

*2-(4-(4-Chlorophenyl)-5-(2-hydroxyphenyl)-2-(4-methoxyphenyl)furan-3-yl)acetonitrile (**3e**):* white solid, 714 mg, 86%; mp 235.3−236.1 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3379, 3027, 2948, 2921, 2264, 1587, 1486, 1457, 1333, 1256, 1201, 1108, 1005, 953, 827, 749; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.53 (d, *J* = 7.8 Hz, 4H), 7.19 (d, *J* = 8.4 Hz, 2H), 7.14 (dd, *J* = 7.8 and 7.8 Hz, 1H), 6.99 (d, *J* = 8.4 Hz, 3H), 6.89 (d, *J* = 7.8 Hz, 1H), 6.71 (dd, *J* = 7.8 and 7.8 Hz, 1H), 6.43 (s, 1H), 3.81 (s, 3H), 3.44 (s, 2H); ^{13}C NMR ($CDCl_3$, 150 MHz) δ 159.3, 152.4, 149.9, 145.5, 131.7, 130.3, 129.4, 129.3, 127.7, 126.9, 123.1, 121.8, 120.6, 119.5, 116.4, 116.3, 114.6, 113.7, 109.3, 54.4, 13.1; HRMS (ESI) calcd for $C_{25}H_{18}ClNNaO_3$ [(M + Na)$^+$] 438.0900, found 438.0911.

*2-(4-(4-Bromophenyl)-5-(2-hydroxyphenyl)-2-phenylfuran-3-yl)-acetonitrile (**3f**):* white solid, 815 mg, 95%; mp 144.9−145.4 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3081, 2965, 2258, 1742, 1611, 1564, 1490, 1442, 1355, 1244, 1000, 842, 767, 511, 496; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.70 (s, 1H), 7.72 (d, *J* = 7.8 Hz, 2H), 7.57−7.53 (m, 3H), 7.48 (s, 1H), 7.45 (dd, *J* = 7.2 and 7.2 Hz, 1H), 7.37 (dd, *J* = 7.8 and 7.8 Hz, 1H), 7.27 (d, *J* = 7.8 Hz, 2H), 7.22 (dd, *J* = 7.8 and 7.8 Hz, 1H), 6.87 (d, *J* = 7.8 Hz, 1H), 6.82 (dd, *J* = 7.8 and 7.8 Hz, 1H), 3.94 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.4, 149.3, 147.7, 134.7, 131.4, 130.9, 130.7, 130.5, 130.2, 129.4, 129.1, 128.4, 128.2, 126.0, 123.6, 121.7, 118.9, 118.1, 116.6, 116.1, 111.0, 13.5; HRMS (ESI) calcd for $C_{24}H_{16}BrNNaO_2$ [(M + Na)$^+$] 452.0257, found 452.0254.

*Methyl 4-(4-(cyanomethyl)-2-(2-hydroxyphenyl)-5-phenylfuran-3-yl)benzoate (**3g**):* yellow solid, 769 mg, 94%; mp 198.1−198.8 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3423, 2920, 2852, 2252, 1721, 1611, 1445, 1279, 1104, 1021, 958, 758, 698, 588; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.64 (s, 1H), 7.97 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 7.8 Hz, 2H), 7.57 (dd, *J* = 7.8 and 7.8 Hz, 2H), 7.45 (dd, *J* = 7.8 and 7.8 Hz, 1H), 7.42 (d, *J* = 8.4 Hz, 2H), 7.27 (dd, *J* = 7.8 and 1.8 Hz, 1H), 7.21 (td, *J* = 7.8 and 1.8 Hz, 1H), 6.85 (d, *J* = 7.8 Hz, 1H), 6.80 (dd, *J* = 7.2 and 7.2 Hz, 1H), 3.97 (s, 2H), 3.86 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 166.0, 155.3, 149.4, 147.8, 137.5, 130.8, 130.5, 129.4, 129.3, 129.1, 128.4, 128.3, 126.0, 124.0, 118.9, 118.0, 116.6, 116.2, 111.0, 52.1, 13.5; HRMS (ESI) calcd for $C_{26}H_{19}NNaO_4$ [(M + Na)$^+$] 432.1206, found 432.1202.

*2-(4-(2,3-Dihydrobenzo[b][1,4]dioxin-6-yl)-5-(2-hydroxyphenyl)-2-phenylfuran-3-yl)acetonitrile (**3h**):* pink solid, 753 mg, 92%; mp 129.2−130.0 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3062, 2926, 2842, 2217, 1717, 1605, 1512, 1452, 1258, 1213, 1180, 1125, 1025, 833, 758, 532; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.60 (s, 1H), 7.66 (d, *J* = 7.6 Hz, 2H), 7.51 (dd, *J* = 7.6 and 7.6 Hz, 2H), 7.39 (dd, *J* = 7.6 and 7.6 Hz, 1H), 7.16 (dd, *J* = 7.6 and 7.6 Hz, 2H), 6.85 (d, *J* = 4.8 Hz, 1H), 6.83 (d, *J* = 4.8 Hz, 1H), 6.74 (dd, *J* = 7.6 and 7.6 Hz, 2H), 6.68 (dd, *J* = 8.0 and 2.0 Hz, 1H), 4.21 (s, 4H), 3.83 (s, 2H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 156.2, 149.3, 147.6, 143.7, 143.3, 131.5, 130.7, 130.1, 129.5, 128.6, 126.2, 125.3, 125.0, 122.6, 119.2, 118.7, 118.1, 117.7, 117.6, 116.6, 111.7, 64.5, 64.4, 14.0; HRMS (ESI) calcd for $C_{26}H_{20}NO_4$ [(M + H)$^+$] 410.1387, found 410.1380.

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*2-(4-(3-Bromophenyl)-2-(4-bromophenyl)-5-(2-hydroxyphenyl)-furan-3-yl)acetonitrile (**3i**):* white solid, 947 mg, 93%; mp 251.7−252.2 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3019, 2951, 2910, 1587, 1479, 1421, 1338, 1244, 1202, 1173, 1101, 1041, 1001, 957, 853, 792; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.74 (s, 1H), 7.76 (d, J = 7.8 Hz, 2H), 7.68 (d, J = 8.4 Hz, 2H), 7.54 (d, J = 7.8 Hz, 1H), 7.50 (s, 1H), 7.37 (dd, J = 7.8 and 7.8 Hz, 1H), 7.29 (d, J = 6.0 Hz, 2H), 7.23 (dd, J = 7.8 and 7.8 Hz, 1H), 6.90 (d, J = 8.4 Hz, 1H), 6.82 (dd, J = 7.8 and 7.8 Hz, 1H), 3.97 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.4, 148.2, 148.0, 134.6, 132.0, 131.5, 130.8, 130.7, 130.6, 130.3, 128.6, 128.2, 127.8, 123.8, 121.6, 118.9, 117.9, 116.5, 116.2, 111.8, 13.4; HRMS (ESI) calcd for $C_{24}H_{15}Br_2NNaO_2$ [(M + Na)$^+$] 531.9300, found 531.9337.

*2-(5-(2-Hydroxyphenyl)-2-phenyl-4-(o-tolyl)furan-3-yl)-acetonitrile (**3j**):* yellow solid, 708 mg, 97%; mp 110.7−111.5 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3409, 3012, 2958, 2910, 1557, 1467, 1441, 1368, 1256, 1200, 1187, 1163, 1072, 1003, 951, 857, 789; ^{1}H NMR (600 MHz, DMSO-d_6) δ 9.66 (s, 1H), 7.72 (d, J = 7.2 Hz, 2H), 7.56 (dd, J = 7.2 and 7.2 Hz, 2H), 7.43 (dd, J = 7.2 and 7.2 Hz, 1H), 7.28 (dd, J = 7.2 and 7.2 Hz, 1H), 7.19 (dd, J = 7.2 and 7.2 Hz, 1H), 7.16 (dd, J = 9.6 and 9.6 Hz, 2H), 7.13 (s, 1H), 7.05 (d, J = 7.8 Hz, 1H), 6.88 (d, J = 7.8 Hz, 1H), 6.76 (dd, J = 7.8 and 7.8 Hz, 1H), 3.88 (s, 2H), 2.29 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 155.7, 148.9, 147.3, 137.6, 131.9, 131.0, 130.2, 129.7, 129.6, 129.0, 128.5, 128.2, 128.1, 126.3, 125.8, 125.0, 118.7, 118.2, 117.1, 116.1, 111.2, 21.0, 13.5; HRMS (ESI) calcd for $C_{25}H_{19}NNaO_2$ [(M + Na)$^+$] 388.1308, found 388.1297.

*2-(4-(2-Bromophenyl)-5-(2-hydroxyphenyl)-2-phenylfuran-3-yl)-acetonitrile (**3k**):* yellow solid, 807 mg, 94%; mp 176.3−177.0 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3085, 2971, 2259, 1731, 1623, 1556, 1489, 1451, 1350, 1259, 1002, 849, 765, 513, 488; ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.68 (s, 1H), 7.68 (d, J = 7.6 Hz, 2H), 7.55−7.48 (m, 3H), 7.44 (dd, J = 1.6 and 2.0 Hz,, 1H), 7.41 (dd, J = 7.2 and 7.2 Hz, 1H), 7.33 (dd, J = 7.6 and 7.6 Hz, 1H), 7.25 (dd, J = 1.2 and 2.0 Hz,, 1H), 7.23 (dd, J = 1.6 and 1.6 Hz,, 1H), 7.19 (td, J = 1.2 and 7.2 Hz, 1H), 6.82 (d, J = 8.0 Hz, 1H), 6.78 (dd, J = 7.2 and 7.2 Hz, 1H), 3.91 (s, 2H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 155.9, 149.7, 148.1, 135.2, 131.9, 131.3, 131.1, 131.0, 130.6, 129.9, 129.5, 128.8, 128.6, 126.4, 124.1, 122.2, 119.3, 118.5, 117.1, 116.6, 111.5, 13.9; HRMS (ESI) calcd for $C_{24}H_{16}BrNNaO_2$ [(M + Na)$^+$] 452.0257, found 452.0251.

*2-(5-(2-Chlorophenyl)-2-phenyl-4-(p-tolyl)furan-3-yl)acetonitrile (**3l**):* white solid, 713 mg, 93%; mp 129.8−131.7 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3423, 3032, 2919, 2250, 1607, 1566, 1515, 1464, 1434, 1178, 1109, 1051, 955, 917, 823, 762, 693, 541, 483; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.75 (d, J = 7.2 Hz, 2H), 7.58 (dd, J = 7.8 and 7.8 Hz, 2H), 7.55 (d, J = 7.8 Hz, 1H), 7.46 (dd, J = 7.8 and 7.8 Hz, 1H), 7.43 (dd, J = 7.2 and 7.2 Hz, 2H), 7.34 (dd, J = 7.2 and 7.2 Hz, 1H), 7.23 (d, J = 7.2 Hz, 2H), 7.15 (d, J = 7.8 Hz, 2H), 3.94 (s, 2H), 2.32 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 150.0, 146.2, 137.2, 132.8, 132.3, 130.8, 130.1, 129.6, 129.2, 129.1, 129.0, 128.8, 128.6, 127.9, 127.2, 126.4, 126.0, 118.0, 111.3, 20.8, 13.4; HRMS (ESI) calcd for $C_{25}H_{18}ClNNaO$ [(M + Na)$^+$] 406.0969, found 406.0958.

*2-(2-Phenyl-5-(o-tolyl)-4-(p-tolyl)furan-3-yl)acetonitrile (**3m**):* white solid, 683 mg, 94%; mp 147.0−148.1 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3427, 3055, 3025, 2988, 2922, 2246, 1623, 1575, 1485, 1448, 1402, 1292, 1117, 1032, 955, 820, 765, 698, 512, 451; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.74 (d, J = 7.2 Hz, 2H), 7.57 (dd, J = 7.8 and 7.8 Hz, 2H), 7.45 (dd, J = 7.8 and 7.8 Hz, 1H), 7.27 (dd, J = 5.4 and 5.4 Hz, 2H), 7.23 (dd, J = 6.6 and 6.6 Hz, 3H), 7.15 (dd, J = 8.4 and 8.4 Hz, 3H), 3.92 (s, 2H), 2.32 (s, 3H), 2.18 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 149.4, 149.0, 137.0, 136.7, 130.7, 130.2, 129.6, 129.4, 129.3, 129.2, 129.1, 128.8, 128.4, 128.3, 125.8, 125.7, 125.2, 118.1, 111.3, 20.7, 20.1, 13.5; HRMS (ESI) calcd for $C_{26}H_{21}NNaO$ [(M + Na)$^+$] 386.1515, found 386.1507.

*2-(4-(3-Bromophenyl)-5-(4-chlorophenyl)-2-phenylfuran-3-yl)-acetonitrile (**3n**):* yellow solid, 849 mg, 95%; mp 163.7−164.8 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3423, 3062, 2894, 2245, 1596, 1556, 1491, 1406, 1095, 1009, 829, 797, 758, 689, 488, 450; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.81 (d, J = 7.8 Hz, 2H), 7.73 (d, J = 8.4 Hz, 1H), 7.64 (s, 1H), 7.59 (dd, J = 7.8 and 7.8 Hz, 2H), 7.52 (dd, J = 7.8 and 7.8 Hz, 1H), 7.48 (dd, J = 7.2 and 7.2 Hz, 1H), 7.45−7.42 (m, 5H), 3.86 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 149.3, 146.8, 133.5, 132.8, 132.2, 131.5, 131.4, 129.1, 129.0, 128.9, 128.7, 128.1, 127.0, 126.1, 123.5, 122.5, 117.7, 112.8, 13.1; HRMS (ESI) calcd for $C_{24}H_{15}BrClNNaO$ [(M + Na)$^+$] 469.9900, found 469.9894.

*2-(4-(3-Bromophenyl)-2-phenyl-5-(p-tolyl)furan-3-yl)acetonitrile (**3o**):* yellow solid, 837 mg, 98%; mp 134.5−135.0 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3427, 3082, 2905, 2265, 1599, 1565, 1481, 1400, 1195, 1002, 853, 787, 683, 481, 457; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.79 (d, J = 7.8 Hz, 2H), 7.70 (d, J = 9.0 Hz, 1H), 7.61 (s, 1H), 7.58 (dd, J = 7.2 and 7.2 Hz, 2H), 7.51 (dd, J = 7.8 and 7.8 Hz, 1H), 7.46 (dd, J = 7.2 and 7.2 Hz, 1H), 7.41 (d, J = 7.2 Hz, 1H), 7.32 (d, J = 8.4 Hz, 2H), 7.17 (d, J = 7.8 Hz, 2H), 3.84 (s, 2H), 2.28 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 148.7, 148.1, 137.9, 135.2, 134.0, 132.3, 131.4, 131.3, 131.0, 129.3, 129.1, 129.0, 128.5, 126.6, 126.0, 125.4, 123.6, 122.3, 122.2, 117.8, 112.6, 20.8, 13.2; HRMS (ESI) calcd for $C_{25}H_{18}BrNNaO$ [(M + Na)$^+$] 450.0448, found 450.0459.

*2-(4-(2-Chlorophenyl)-5-(3-chlorophenyl)-2-(4-methoxyphenyl)-furan-3-yl)acetonitrile (**3p**):* yellow solid, 814 mg, 94%; mp 109.3−110.8 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3071, 2911, 2267, 1589, 1566, 1474, 1406, 1295, 1015, 873, 797, 686, 484, 452; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.82 (d, J = 9.0 Hz, 2H), 7.74 (dd, J = 7.8 and 0.6 Hz, 1H), 7.61 (td, J = 7.8 and 1.8 Hz, 1H), 7.56 (td, J = 7.2 and 1.2 Hz, 1H), 7.52 (dd, J = 7.2 and 1.8 Hz, 1H), 7.37−7.32 (m, 3H), 7.26 (d, J = 7.8 Hz, 1H), 7.16 (d, J = 9.0 Hz, 2H), 3.86 (s, 3H), 3.79 (d, J = 18.0 Hz, 1H), 3.71 (d, J = 18.0 Hz, 1H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 159.6, 149.7, 145.4, 133.7, 133.6, 132.3, 131.5, 131.0, 130.7, 130.1, 130.0, 128.2, 127.7, 127.6, 123.7, 122.7, 122.6, 121.4, 117.3, 114.6, 111.6, 55.3, 13.0; HRMS (ESI) calcd for $C_{25}H_{17}Cl_2NNaO_2$ [(M + Na)$^+$] 456.0529, found 456.0517.

*2-(4-(4-Chlorophenyl)-2-phenyl-5-(m-tolyl)furan-3-yl)acetonitrile (**3q**):* yellow solid, 743 mg, 97%; mp 151.7−152.5 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3401, 3074, 2917, 2252, 1597, 1564, 1465, 1401, 1294, 1005, 893, 754, 689, 496, 455; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.81 (d, J = 7.8 Hz, 2H), 7.61 (d, J = 8.4 Hz, 2H), 7.58 (dd, J = 7.8 and 7.8 Hz, 2H), 7.47 (dd, J = 7.8 and 7.8 Hz, 1H), 7.43 (d, J = 7.8 Hz, 2H), 7.36 (s, 1H), 7.21 (dd, J = 7.8 and 7.8 Hz, 1H), 7.12−7.11 (m, 2H), 3.84 (s, 2H), 2.26 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 148.9, 147.9, 138.0, 133.2, 131.7, 130.4, 129.3, 129.1, 128.8, 128.6, 128.5, 126.0, 125.9, 123.1, 122.6, 117.7, 112.7, 21.0, 13.1; HRMS (ESI) calcd for $C_{25}H_{19}ClNO$ [(M + H)$^+$] 384.1150, found 384.1144.

*2-(2-Phenyl-5-(thiophene-3-yl)-4-(m-tolyl)furan-3-yl)acetonitrile (**3r**):* yellow solid, 596 mg, 89%; mp 132.0−132.9 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3103, 2911, 2379, 2352, 2317, 1707, 1518, 1406, 1290, 1212, 1138, 1094, 1046, 924, 789, 693, 617, 544, 461; ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.76 (d, J = 8.9 Hz, 2H), 7.57 (dd, J = 2.8 and 1.2 Hz, 2H), 7.55 (d, J = 7.6 Hz, 1H), 7.53 (d, J = 8.4 Hz, 1H),7.51 (dd, J = 3.2 and 2.0 Hz, 1H), 7.42 (dd, J = 7.6 and 7.6 Hz, 1H), 7.29 (d, J = 7.6 Hz, 1H), 7.20 (s, 1H), 7.17 (d, J = 7.6 Hz, 1H), 6.90 (dd, J = 5.2 and 1.2 Hz, 1H), 3.76 (s, 2H), 2.35 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 149.2, 145.9, 139.0, 131.6, 131.5, 130.7, 129.8, 129.2, 129.1, 129.0, 128.3, 127.2, 126.1, 125.7, 125.1, 123.6, 120.7, 117.6, 111.9, 21.4, 14.0; HRMS (ESI) calcd for $C_{23}H_{17}NNaOS$ [(M + Na)$^+$] 378.0929, found 378.0926.

*2-(2-(4-Methoxyphenyl)-5-phenyl-4-(m-tolyl)furan-3-yl)-acetonitrile (**3s**):* yellow solid, 698 mg, 92%; mp 130.9−131.6 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3044, 2958, 2864, 1605, 1501, 1415, 1303, 1253, 1175, 1107, 1030, 831, 801, 767, 697, 615, 505; ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.70 (d, J = 8.4 Hz, 2H), 7.41−7.38 (m, 3H), 7.30−7.26 (m, 3H), 7.22 (d, J = 7.8 Hz, 1H), 7.18 (s, 1H),7.14 (d, J = 7.8 Hz, 1H), 7.09 (d, J = 8.8 Hz, 2H), 3.81 (s, 3H), 3.70 (s, 2H), 2.33 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 159.7, 149.9, 147.5, 139.0, 132.1, 130.6, 130.4, 129.2, 129.0, 128.4, 127.7, 127.4, 127.1, 125.3, 124.5, 122.6, 117.8, 114.5, 111.0, 55.4, 21.5, 14.0; HRMS (ESI) calcd for $C_{26}H_{21}NNaO_2$ [(M + Na)$^+$] 402.1470, found 402.1474.

*2-(4-(4-Bromophenyl)-2,5-bis(4-methoxyphenyl)furan-3-yl)-acetonitrile (**3t**):* yellow solid, 882 mg, 93%; mp 122.9−123.7 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3129, 2894, 2833, 2353, 2315, 1734, 1508, 1301, 1251, 1179, 1073, 1030, 950, 832, 603, 466; ^{1}H NMR (400

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MHz, DMSO-d_6) δ 7.69 (d, J = 6.8 Hz, 4H), 7.39 (dd, J = 7.6 and 6.0 Hz, 2H), 7.28 (dd, J = 7.2 and 6.0 Hz, 2H), 7.02 (s, d, J = 8.0 Hz, 2H), 6.80 (d, J = 8.0 Hz, 2H), 3.87 (s, 3H), 3.78 (s, 3H), 3.42 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 159.7, 159.4, 149.0, 147.7, 132.7, 132.4, 132.2, 131.5, 127.9, 127.3, 122.5, 122.2, 121.9, 118.3, 115.0, 114.7, 111.3, 55.7, 55.6, 13.5; HRMS (ESI) calcd for $C_{26}H_{20}BrNNaO_3$ [(M + Na)$^+$] 496.0524, found 496.0529.

*2-(4-(4-Bromophenyl)-2-(4-chlorophenyl)-5-(2-methoxyphenyl)-furan-3-yl) acetonitrile (**3u**):* yellow solid, 881 mg, 92%; mp 161.7−162.9 °C(EA/PE); IR (KBr, cm^{-1}) ν = 3072, 2941, 2842, 2253, 1912, 1731, 1576, 1486, 1436, 1384, 1274, 1181, 1119, 1084, 1014, 829, 783, 754, 527, 497; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.75 (d, J = 8.4 Hz, 2H), 7.62 (d, J = 8.4 Hz, 2H), 7.61 (d, J = 7.8 Hz, 2H), 7.44 (d, J = 7.2 Hz, 1H), 7.39 (dd, J = 8.4 and 7.2 Hz, 1H), 7.17 (d, J = 8.4 Hz, 2H), 7.02 (d, J = 8.4 Hz, 1H), 7.00 (dd, J = 8.4 and 7.8 Hz, 1H), 3.95 (s, 2H), 3.43 (s, 3H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 156.3, 148.3, 146.9, 133.0, 131.6, 131.5, 130.9, 130.8, 130.5, 129.1, 128.1, 127.7, 124.5, 120.8, 120.5, 118.2, 117.9, 117.5, 111.9, 54.8, 13.3; HRMS (ESI) calcd for $C_{25}H_{18}BrClNO_2$ [(M + H)$^+$] 478.0209, found 478.0191.

*2-(4-(4-Bromophenyl)-2-(4-chlorophenyl)-5-(4-iodophenyl)furan-3-yl)acetonitrile (**3v**):* yellow solid, 1011 mg, 88%; mp 218.7−219.6 °C (EA/PE); IR (KBr, cm^{-1}) ν = 2977, 2889, 2317, 1649, 1528, 1486, 1417, 1384, 1233, 1186, 1145, 1092, 1009, 949, 913, 826, 751, 689, 536, 494, 463; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.82 (d, J = 9.0 Hz, 2H), 7.75 (d, J = 8.4 Hz, 2H), 7.73 (d, J = 9.0 Hz, 2H), 7.64 (d, J = 8.4 Hz, 2H), 7.35 (d, J = 8.4 Hz, 2H), 7.21 (d, J = 8.4 Hz, 2H), 3.86 (s, 2H); ^{13}C NMR (DMSO-d_6, 150 MHz) δ 148.2, 147.1, 137.6, 133.3, 132.4, 131.9, 130.2, 129.2, 128.7, 127.8, 127.7, 127.2, 124.0, 122.1, 117.5, 113.5, 94.9, 13.0; HRMS (ESI) calcd for $C_{24}H_{15}BrClINO$ [(M + H)$^+$] 573.9015, found 573.9012.

*2-(4-(4-Bromophenyl)-5-ethyl-2-(4-methoxyphenyl)furan-3-yl)-acetonitrile (**3w**):* white solid, 721 mg, 91%; mp 114.1−114.9 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3209, 2816, 1702, 1607, 1509, 1403, 1288, 1250, 1072, 907, 830, 613, 540, 465; ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.66 (d, J = 8.4 Hz, 2H), 7.53 (d, J = 8.8 Hz, 2H), 7.30 (d, J = 8.4 Hz, 2H), 7.06 (d, J = 8.8 Hz, 2H), 3.79 (s, 3H), 3.78 (s, 2H), 2.61 (q, J = 7.2 Hz, 2H), 1.16 (t, J = 7.6 Hz, 3H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 159.1, 152.3, 148.3, 131.8, 131.4, 130.8, 127.3, 122.1, 121.3, 120.9, 118.1, 114.5, 108.7, 55.3, 19.4, 13.2, 12.8; HRMS (ESI) calcd for $C_{21}H_{18}BrNNaO_2$ [(M + Na)$^+$] 418.0419, found 418.0416.

*2-(4-(4-Bromophenyl)-2-(4-methoxyphenyl)-5-propylfuran-3-yl)-acetonitrile (**3x**):* white solid, 730 mg, 89%; mp 72.3−72.9 °C (EA/PE); IR (KBr, cm^{-1}) ν = 3320, 2959, 2901, 2832, 1729, 1507, 1292, 1251, 1178, 1073, 1038, 988, 921, 830, 588, 498, 465; ^{1}H NMR (600 MHz, DMSO-d_6) δ 7.70 (d, J = 8.4 Hz, 2H), 7.57 (d, J = 8.4 Hz, 2H), 7.32 (d, J = 7.8 Hz, 2H), 7.10 (d, J = 8.4 Hz, 2H), 3.83 (s, 3H), 3.80 (s, 2H), 2.61 (t, J = 7.2 Hz, 2H), 1.63 (q, J = 7.2 Hz, 2H), 0.88 (t, J = 7.2 Hz, 3H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 159.6, 151.7, 148.8, 132.3, 131.9, 131.3, 127.8, 122.6, 122.5, 121.4, 118.6, 115.0, 109.1, 55.7, 28.2, 21.8, 14.1, 13.7; HRMS (ESI) calcd for $C_{22}H_{20}BrNNaO_2$ [(M + Na)$^+$] 432.0575, found 432.0572.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b01259.

^{1}H NMR and ^{13}C NMR Spectra of all the products (PDF)

X-ray data for **3a** (CIF)

X-ray data for **3d** (CIF)

X-ray data for **3m** (CIF)

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Notes

The authors declare no competing financial interest.

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(15) Crystallographic data for 2-(2,4,5-triarylfuran-3-yl)acetonitriles **3a**, **3d**, and **3m** have been deposited with the Cambridge Crystallographic Data Centre with deposition nos. CCDC 1432694, 1432854, and 1472825. These data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax (+44) 1223 336033, e-mail: deposit@ccdc.cam.ac.uk].
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(18) The title reaction was carried out under the optimized reaction conditions for 9 h, and the reaction mixture was tested by GC−mass spectrometry to afford a stronger ion peak, 91.0 (m/z), which corresponded to the mass of the molecular ion (M + 1) for compound ethyl carbonate (Figure S4, see the Supporting Information).

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