Coupling-Isomerization-Stetter and Coupling-Isomerization-Stetter–Paal–Knorr Sequences – A Multicomponent Approach to Furans and Pyrroles

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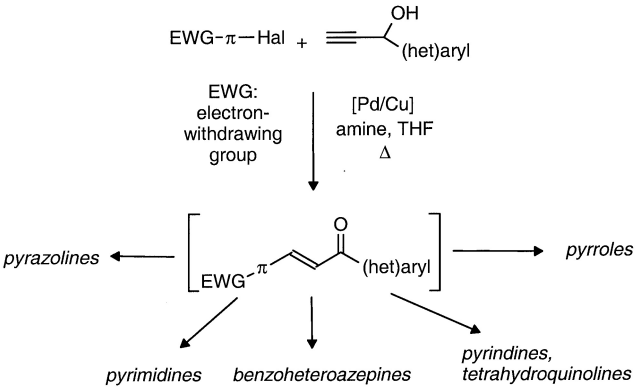
Abstract: 2,3,5-Trisubstituted furans **6** and 1,2,3,5-tetrasubstituted pyrroles **8** can be synthesized in good yields in a one-pot three-step three- or four-component process by a coupling-isomerization-Stetter–Paal–Knorr sequence of an electron-poor (hetero)aryl halide **1**, a terminal propargyl alcohol **2**, an aldehyde **3**, and, in the case of pyrroles, a primary amine **7**. All novel furans and pyrroles exhibit a strong blue fluorescence with considerable Stokes shifts.

Key words: catalysis, cross-couplings, diketones, furans, pyrroles

Introduction

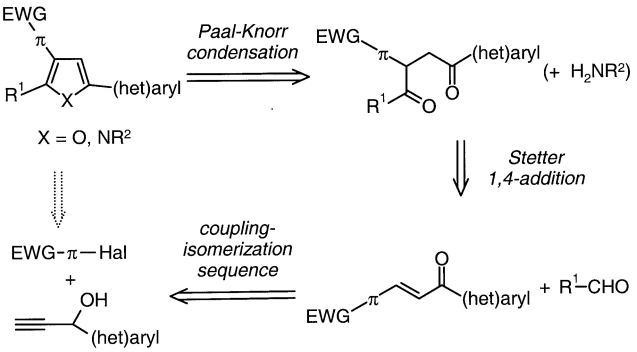
Sequential one-pot multicomponent processes have a considerable and steadily increasing academic, economic and ecological interest since they address very fundamental principles of synthetic efficiency and reaction design.[1,2] In addition, the prospect of extending one-pot reactions into combinatorial and solid phase syntheses[1c,3] opens manifold opportunities for developing novel lead structures of pharmaceuticals, catalysts and even novel molecule-based materials. Recently, based upon a palladium-copper-catalyzed domino coupling-isomerization (CI) sequence of electron-poor halogen substituted π-systems and 1-(hetero)aryl prop-2-yn-1-ols furnishing 1,3-di(hetero)aryl enones (i.e. chalcones)[4] and considering the mild reaction conditions, quite a number of generic structures of pharmaceutically relevant heterocyclic classes can be readily accessed. Therefore, we have recently introduced a very efficient entry to three-component one-pot syntheses of pyrazolines,[4] pyrimidines,[5] and 1,5-benzoheteroazepines[6] and four-component one-pot syntheses of pyrroles,[7] pyrindines, and tetrahydroquinolines[8] (Scheme 1).

Among numerous heterocycles, furans and pyrroles have always been the most prominent ones since they constitute important classes of natural products,[9] synthetic pharmaceuticals,[6,9c] and of electrically conducting materials such as polypyrroles.[10] In particular, 2,3,5-trisubstituted furans and 1,2,3,5-tetrasubstituted pyrroles are highly biologically active and have proven to display antibacterial,[11] antiviral (also anti-HIV-1),[12] anti-inflammatory[13] and antioxidant[14] activity as well as inhibition of cytokine-mediated diseases.[15]



Scheme 1 One-pot syntheses of pyrazolines, pyrimidines, benzoheteroazepines, pyrroles, pyrindines, and tetrahydroquinolines based upon a coupling-isomerization sequence.

Thus, applying our concept of coupling-isomerization reaction towards the synthesis of furans and pyrroles, it can be readily deduced that 2,3,5-trisubstituted furans and 1,2,3,5-tetrasubstituted pyrroles should be accessible by combining a Stetter reaction, furnishing the 1,4-diketones,[16] and a subsequent Paal–Knorr cyclocondensation (Scheme 2).[9a,b,d] Here, we report on synthetic studies of the CIR-Stetter access to 1,4-diketones, and on CI-Stetter–Paal–Knorr sequences to furans and pyrroles, as well as their absorption and emission properties.



Scheme 2 Retrosynthetic concept for a three-component furan and four-component pyrrole synthesis.

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CI-Stetter Sequence to 1,4-Diketones

First, we had to test the compatibility of the Stetter addition of (hetero)aromatic and aliphatic aldehydes with regard to the CIR formed chalcone functionality. Thus, upon reacting electron-poor (hetero)aryl halides **1**, (hetero)aryl propynols **2**, and after some reaction time, aldehydes **3**, in the presence of a thiazolium salt **4** under the conditions of the Sonogashira coupling in a boiling mixture of triethylamine and a solvent or neat triethylamine, beige to yellow 1,2,4-trisubstituted 1,4-diketones **5** were obtained in 34–88% yield (Scheme 3, Table 1).

The structures of the 1,4-diketones **5** were unambiguously assigned by ^{1}H, ^{13}C and NOESY NMR experiments. As a consequence of the Michael addition of aldehydes to the transient enone functionality, three distinct aliphatic proton resonances, a methine and two diastereotopic methylene protons, appear most characteristically in the ^{1}H spectra as splitting patterns (doublets of doublets) of ABM spin systems. Therefore, due to the characteristic geminal and vicinal coupling constants (^{2}J = 17.7–18.1 Hz, ^{3}J = 3.7–5.1 Hz, ^{3}J = 9.1–10.1 Hz), the signals at δ 3.13–3.39 and δ 3.98–4.21 can be assigned to the diastereotopic methylene protons. Conformational analyses applying the Karplus correlation of coupling constants and dihedral angles suggests that a thermodynamically favored staggered orientation minimizing the *gauche* interactions of the bulky EWG-π- and (hetero)aryl-substituents is strongly populated in solution. Furthermore, the appearance of vicinal coupling constants (^{3}J = 3.7–5.1 Hz, ^{3}J = 9.1–10.1 Hz) for the signals at δ 4.41–5.32 completes the assignment of the methine resonances. In this series of 1,4-diketones, compound **5k** is the only one bearing an additional center of chirality. Therefore, the formation of a mixture of diastereomers could be expected. The diastereomeric ratio of 1:1 indicates the absence of any 1,4-facial diastereoselection in the course of the Stetter reaction. Furthermore, the resonances of the (hetero)aromatic and aliphatic protons can be detected with expected chemical shifts.

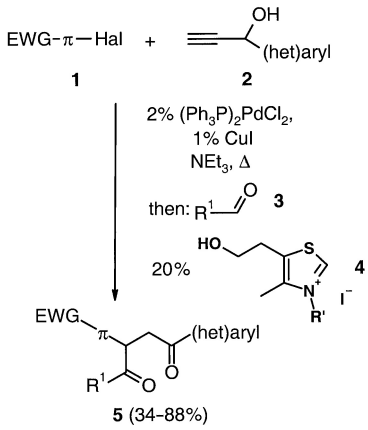
Most revealing, in the carbon NMR spectra, two quaternary carbonyl resonances are found between δ 184.9–198.0 for alkyl (hetero)aryl ketones and/or δ 207.6–212.4 for dialkyl ketones. The methine and methylene carbon nuclei resulting from the Stetter reaction appear at δ 46.9–53.6 and δ 40.5–44.1, respectively. Another strong spectroscopic support of the 1,4-dicarbonyl functionality can be derived from the mass spectra, revealing that an α-cleav-

Biographical Sketches

from left to right: Thomas J. J. Müller, Roland U. Braun

Roland U. Braun was born in Würzburg, Germany, in 1974 and studied chemistry at the Ludwig-Maximilians-Universität München from 1994 to 2000. He obtained his Diploma in 2000 under the supervision of Prof. H. Mayr and completed his Ph.D. in 2004 at the Ruprecht-Karls-Universität Heidelberg with Prof. T. J. J. Müller on synthetic and mechanistic investigations of the coupling-isomerization reaction and the development of novel multicomponent syntheses of heterocycles. His research interests encompass synthetic heterocyclic chemistry and transition metal catalysis.

Thomas J. J. Müller was born in Würzburg, Germany, in 1964 and studied chemistry at the Ludwig-Maximilians-Universität München (LMU) from 1984 to 1989. He obtained his Diploma in 1989 and completed his Ph.D. in 1992 with Prof. R. Gompper on novel cyanine systems as models for optical switches and molecular metals. After a post-doctoral stay with Prof. B. M. Trost at Stanford University (USA) in 1993 and 1994 working on ruthenium-catalyzed Alder–Ene reactions, he returned to Germany. In 1994, as a Liebig scholar, he began his independent research at the Technical University Darmstadt, moved to LMU as a DFG scholar in 1997, to obtain his habilitation and was appointed to Privatdozent in 2000. In 1999/2000 he was acting professor at the University of Stuttgart. In 2002 he became a professor of organic chemistry at the Ruprecht-Karls-Universität Heidelberg. His research interests encompass synthetic heterocyclic chemistry, its implication for developing novel tailor-made chromophores, nanometer-sized redox active molecules, and the design of novel multicomponent reactions.



Scheme 3 CI-Stetter sequence to 1,4-diketones **5**

age of the carbonyl fragments is by far the most important initial fragmentation step. In the IR spectra, typical CO-valence vibrations of (hetero)aryl ketones are found between 1673 and 1683 cm^{-1}. In the case of aliphatic ketones (**5i**, **5j**, **5k**, and **5l**) two significant carbonyl vibrations are detected at 1705–1716 and 1676–1685 cm^{-1}.

The applicability of this one-pot CI-Stetter sequence to the synthesis of 1,4-diketones **5** is fairly broad, and occurs under mild conditions and with excellent chemoselectivity. Conceptually, this sequence is highly intriguing since two catalytic processes, the CIR and the Stetter reaction, are highly compatible and can be sequentially performed in the same reaction medium. In particular, the scope of the Stetter reaction in this sequence encompasses electron-poor to electron-rich aromatic aldehydes (entries 1–8), aliphatic aldehydes (entries 9–12), and even polar functional groups (entry 12) are compatible with the conditions of the CI-Stetter sequence. In agreement with the Stetter reaction,[16] 3,4-dimethyl-5-(2-hydroxyethyl) thiazolium iodide (**4a**) is the catalyst of choice for aromatic aldehydes, whereas 3-benzyl-4-methyl-5-(2- hydroxyethyl) thiazolium chloride (**4b**) is used for the addition of aliphatic aldehydes to enones.

Table 1 Coupling-Isomerization-Stetter Synthesis of 1,4-Diketones **5**

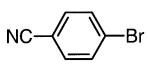
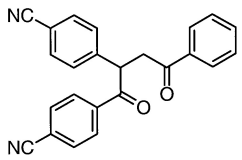
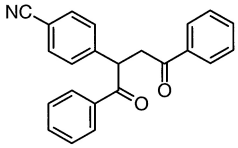
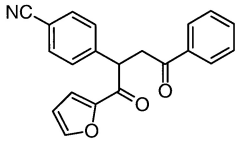
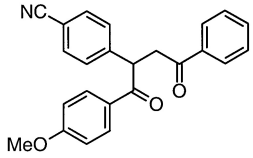
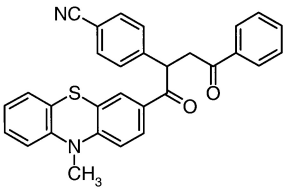
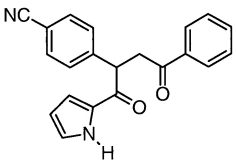
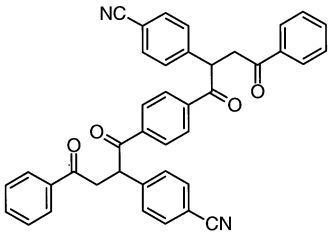
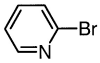
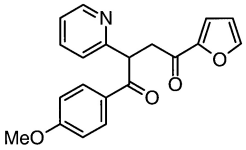
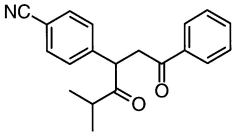
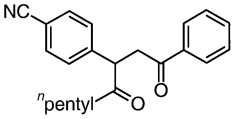
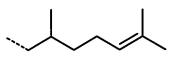
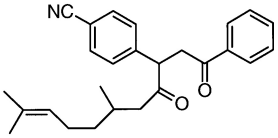
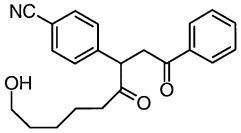
Entry	(Hetero)aryl Halide **1**	Propargyl Alcohol **2**	Aldehyde **3**	Thiazolium Salt **4**	1,4-Diketone **5** (Yield)
1	 **1a**	(het)aryl = Ph (**2a**)	R^1 = *p*-NCC_6H_4 (**3a**)	R′ = CH_3 (**4a**)	 **5a** (88%)
2[a]	**1a**	**2a**	R^1 = Ph (**3b**)	**4a**	 **5b** (84%)
3	**1a**	**2a**	R^1 = 2-furyl (**3c**)	**4a**	 **5c** (81%)
4	**1a**	**2a**	R^1 = *p*-$MeOC_6H_4$ (**3d**)	**4a**	 **5d** (75%)
5	**1a**	**2a**	R^1 = 10-methyl phenothiazin-3-yl (**3e**)	**4a**	 **5e** (82%)

Table 1 Coupling-Isomerization-Stetter Synthesis of 1,4-Diketones **5** (continued)

Entry	(Hetero)aryl Halide **1**	Propargyl Alcohol **2**	Aldehyde **3**	Thiazolium Salt **4**	1,4-Diketone **5** (Yield)
6	**1a**	**2a**	R^1 = 2-pyrryl (**3f**)	**4a**	 **5f** (34%)
7	**1a**	**2a**	R^1 = *p*-$OHCC_6H_4$ (**3g**)	**4a**	 **5g** (69%)
8	 **1b**	(het)aryl = 3-furyl (**2b**)	**3d**	**4a**	 **5h** (70%)
9	**1a**	**2a**	R^1 = *i*-Pr (**3h**)	R′ = CH_2Ph (**4b**)	 **5i** (54%)
10	**1a**	**2a**	R^1 = *n*-pentyl (**3i**)	**4b**	 **5j** (76%)
11	**1a**	**2a**	R^1 =  (**3j**)	**4b**	 **5k** (66%)
12	**1a**	**2a**	R^1 = $(CH_2)_5OH$ (**3l**)	**4b**	 **5l** (59%)

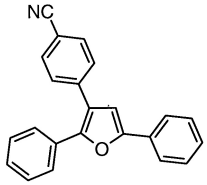
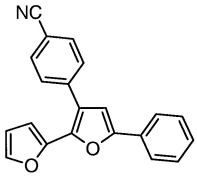
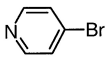
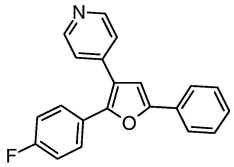
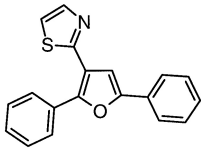
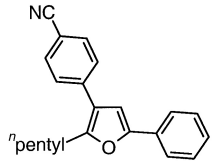
[a] THF.

CI-Stetter–Paal–Knorr Sequences to Furans and Pyrroles

Encouraged by the excellent coupling-isomerization-Stetter sequence, we set out to extend and combine this one-pot three-component reaction with a third and fourth step, i.e. a Paal–Knorr reaction for designing novel three-component furan and four-component pyrrole synthesis. This approach is particularly intriguing since it represents a consecutive combination of modern cross-coupling methodology and classic Michael addition cyclocondensation, the latter still being of significant importance in the industrial processes of numerous heterocyclic pharmaceuticals.

Thus, the CI-Stetter–Paal–Knorr synthesis of furans begins with the CI-Stetter synthesis of 1,4-diketones **5** starting from electron-deficient (hetero)aryl halides **1**, 1-phenylpropyn-1-ol (**2a**), and aromatic or aliphatic aldehydes **3**. After complete conversion of the intermediate

Table 2 Coupling-Isomerization-Stetter–Paal–Knorr Synthesis of Furans **6**

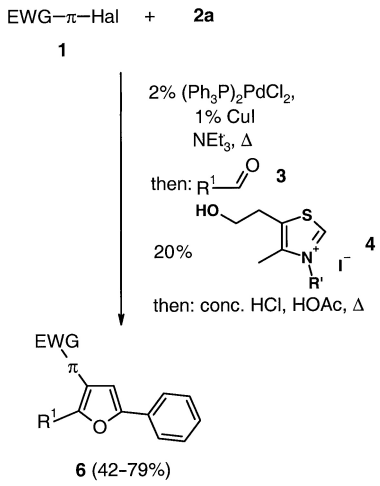
Entry	(Hetero)aryl Halide **1**	Aldehyde **3**	Thiazolium Salt **4**	Furan **6** (Yield)
1	**1a**	**3b**	**4a**	 **6a** (79%)
2	**1a**	**3c**	**4a**	 **6b** (74%)
3[a]	 **1c**	R^1 = *p*-FC_6H_4 (**3m**)	**4a**	 **6c** (46%)
4	 **1d**	**3b**	**4a**	 **6d** (42%)
5	**1a**	**3i**	**4b**	 **6e** (64%)

[a] In CH_3CN.

enones to 1,4-diketones **5** (as monitored by TLC), concentrated hydrochloric acid and acetic acid were successively added to the reaction mixture. Subsequent to heating for 5–28 hours, the furans **6** were obtained as beige solids (**6a–d**) or as a yellow resin (**6e**) in moderate to good yields (Scheme 4, Table 2).

The formation of the furan core is unambiguously supported by the spectroscopic and analytical data. In the ^{1}H NMR spectra of the 2,3,5-trisubstituted furans **6**, the distinct furyl C^4 protons can be readily assigned by the characteristic singlets at δ 6.75–7.12. In comparison to unsubstituted furan (δ 6.37),[17] these methine resonances are shifted downfield as a consequence of the anisotropic ring current of the adjacent (hetero)aromatic substituents at C^3 and C^5. Accordingly, in the ^{13}C NMR spectra, the C^3 (quaternary) and C^4 (methine) furyl carbon nuclei are characteristically shifted upfield and can be detected at δ 118.3–122.6 (C^3_{quat}) and δ 105.4–108.4 (C^4H).

Furthermore, the CIR-Stetter–Paal–Knorr synthesis of pyrroles starts with the CIR of electron-deficient (hetero)aryl halides **1**, 1-phenyl propyn-1-ol (**2a**), followed by the thiazolium salt-catalyzed Stetter reaction with aromat-



Scheme 4 CI-Stetter–Paal–Knorr synthesis of furans **6**.

ic or aliphatic aldehydes **3**. After complete conversion of the intermediate enones to 1,4-diketones **5** (as monitored by TLC), primary amines **7** or ammonium chloride (**7a**) and acetic acid were successively added to the reaction mixture. Subsequent heating for 24–33 hours led to the pyrroles **8**, which were obtained as colorless to light yellow or beige solids in moderate to good yields (Scheme 5, Table 3).

The successful pyrrole formation is unambiguously supported by the spectroscopic and analytical data. In the ^{1}H NMR spectra of the 2,3,5-trisubstituted and 1,2,3,5-tetrasubstituted pyrroles **8**, the characteristic pyrryl C^4 methine resonances can be clearly assigned by the appearance of singlets at δ 6.18–6.95. As in the case of the furans **6**, these methine resonances are shifted downfield in comparison to unsubstituted pyrrole (δ 6.05)[17] as a consequence of the anisotropic ring current of the adjacent (hetero)aromatic substituents at C^3 and C^5. For 2,3,5-trisubstituted pyrroles **8a–e**, the N-H resonances can be detected as broad singlets at δ 8.51–8.57. The α-methylene and methine protons in direct proximity to the pyrryl nitrogen atom are shifted to lower field and appear at δ 5.08 and 5.14 for benzyl derivatives **8f** and **8g**, whereas those of nonaromatic substituents can be found shifted to higher field at δ 4.22–4.61. In the ^{13}C NMR spectra, the C^3 (quaternary) and C^4 (methine) pyrryl carbon nuclei are characteristically shifted upfield and can be detected at δ 119.7–122.8 (C^3_{quat}) and δ 105.8–110.1 (C^4H).

Table 3 Coupling-Isomerization-Stetter–Paal–Knorr Synthesis of Pyrroles **8**

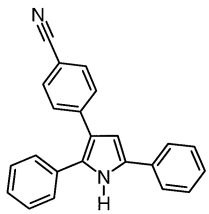
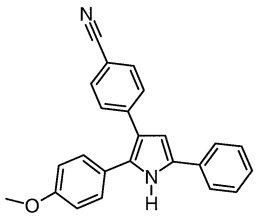
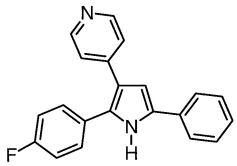
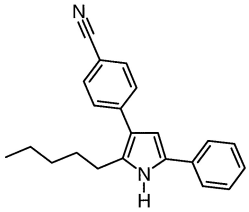
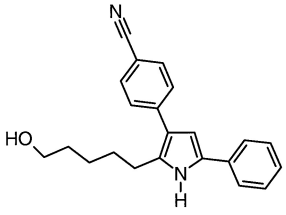
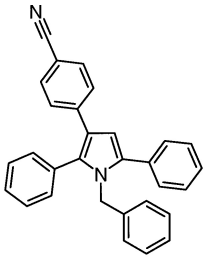
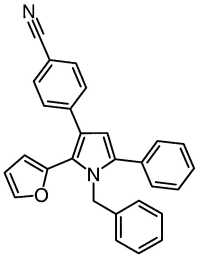
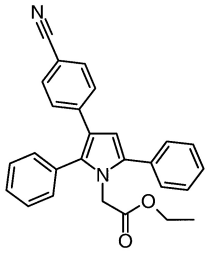
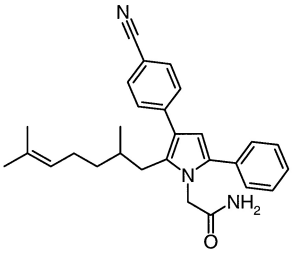
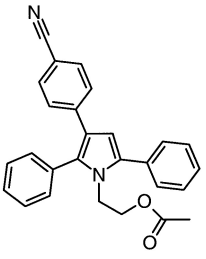
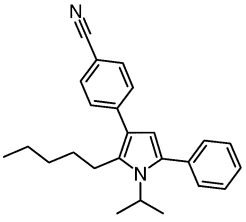
Entry	(Hetero)aryl Halide **1**	Aldehyde **3**	Thiazolium Salt **4**	Amine **7**	Pyrrole **8** (Yield)
1	**1a**	**3b**	**4a**	R^2 = H (as NH_4Cl) (**7a**)	 **8a** (70%)
2	**1a**	**3b**	**4a**	R^2 = $(CO)CH_2NH_2$ (**7b**)	**8a** (59%)
3[a]	**1a**	**3d**	**4a**	**7a**	 **8b** (60%)
4	**1c**	**3m**	**4a**	**7a**	 **8c** (54%)
5	**1a**	**3i**	**4b**	**7a**	 **8d** (59%)
6	**1a**	**3l**	**4b**	**7a**	 **8e** (53%)

Table 3 Coupling-Isomerization-Stetter–Paal–Knorr Synthesis of Pyrroles **8** (continued)

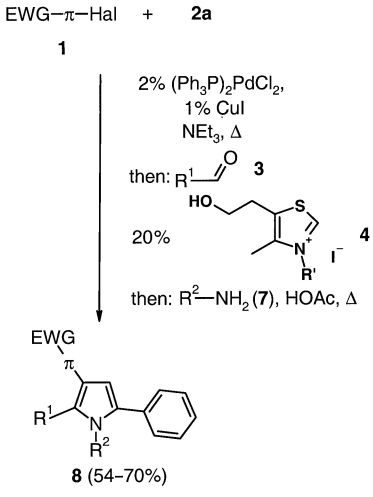
Entry	(Hetero)aryl Halide **1**	Aldehyde **3**	Thiazolium Salt **4**	Amine **7**	Pyrrole **8** (Yield)
7	**1a**	**3b**	**4a**	$R^2 = CH_2Ph$ (**7c**)	 **8f** (60%)
8	**1a**	**3c**	**4a**	**7c**	 **8g** (55%)
9	**1a**	**3b**	**4a**	$R^2 = CH_2CO_2Et$ (**7d**)	 **8h** (54%)
10	**1a**	**3j**	**4b**	**7b**	 **8i** (56%)
11	**1a**	**3b**	**4a**	$R^2 = CH_2CH_2OH$ (**7e**)	 **8j** (57%)
12	**1a**	**3i**	**4b**	$R^2 = i$-Pr (**7f**)	 **8k** (59%)

[a] In CH_3CN.

Methodologically, these novel sequential multi-component furan and pyrrole syntheses are relatively broad in their scope. Interestingly, there is no interference of the palladium/copper catalyst system, necessary for the initial CIR, with the Paal–Knorr cyclocondensation. Therefore, the substitution pattern of furans is essentially the same as that of the preceding 1,4-diketones **5**. Even notoriously acid-sensitive monofuryl substituents (**6b**, Table 2, entry 2) and *p*-fluorophenyl groups (**6c**, Table 2, entry 3), capable of nucleophilic aromatic substitution, are compatible with the reaction conditions of the sequence. For the synthesis of 2,3,5-trisubstituted pyrroles (Table 3, entries 1 and 3–6), ammonium chloride is a suitable source for the pyrryl nitrogen. Primary aliphatic amines are transformed into 1,2,3,5-tetrasubstituted pyrroles (Table 3, entries 7–12); however, in the case of glycine derivatives (Table 3, entries 9 and 10) the reaction temperature in the cyclocondensation step has to be lowered considerably to avoid C-N bond scission that leads to 1-unsubstituted pyrroles (Table 3, entry 2). Unfortunately, due to their reduced nucleophilicity, anilines cannot successfully be used for the synthesis of 1-arylpyrrole derivatives, instead *N*-acetylanilides are isolated as the major product. As a consequence of esterification of the primary alcohol that results from cyclocondensation with aminoethanol, with acetic acid the acylated product **8j** (Table 3, entry 11) can be considered to be the product of a five-component reaction.

Fluorescence of Furans 6 and Pyrroles 8

Most conspicuously, all furans **6** and pyrroles **8** display an intense blue fluorescence upon irradiation with UV light. Since fluorescent compounds are of significant interest as optical brighteners in detergents,[18] in optical data storage media,[19] as probes in fluorescence microscopy for studying biological processes on a cellular or sub-cellular level,[20] as antibody markers in immunofluorescence methods,[21] and as polarity or pH probes,[22] we set out to investigate the absorption and emission properties of the furans **6** and pyrroles **8** (Table 4).



Scheme 5 CI-Stetter–Paal–Knorr synthesis of pyrroles **8**.

Upon UV excitation of the longest wavelength absorption band, furans **6** and pyrroles **8** exhibit considerable Stokes shifts and spontaneously fluoresce with emission of blue light (Table 4). Their fluorescence behaviors are fairly similar as illustrated by furan **6a** and pyrrole **8a**, having the same substitution pattern and a difference of Stokes shifts of only 200 cm^{-1}. The phenomenon of large Stokes shifts arises from significant structural changes upon excitation from singlet ground state S_0 and subsequent relaxation to the lowest vibrational level of the first excited singlet state S_1.[23] In particular, since all furans **6** and pyrroles **8** are acceptor-substituted, a considerable charge transfer can be expected. However, the interpretation is complicated since these systems are highly substituted. Therefore, additional sub-chromophores, as in the pair **8a**/**8b**, have to be taken into account where the electron-rich anisyl group (**8b**) causes a bathochromic shift only of the emission maximum. The same situation is found in the pair **8f**/**8g** where the furyl substituent (**8g**) acts as a donor and enhances the push-pull character and its influence in the stabilization of the S_1 state.

In conclusion, we have shown that the mild reaction conditions of the CIR can be extended to a one-pot three-component synthesis of 1,4-diketones in the sense of a sequential CI-Stetter reaction. Combination of CIR, Stetter reaction and Paal–Knorr cyclocondensation culminates in the development of novel one-pot three-component furan and four-component pyrrole syntheses. Interestingly, this novel modular strategy opens a rapid access to highly substituted furan and pyrrole fluorophores. Further studies directed to extend these one-pot heterocycle syntheses to pharmaceutically and electronically interesting systems like oligopyrroles, oligofurans, and alternating oligo(pyrrylthiophenes) are currently underway.

Table 4 Selected UV Absorptions (Longest Wavelength Maxima), Fluorescence Emissions and Stokes Shifts of Furans **6** and Pyrroles **8** (Recorded in $CHCl_3$, Excitation at λ_{max} (UV) + 20 nm)

Compound	Absorption $\lambda_{max, abs}$ [nm] (ε)	Emission $\lambda_{max, em}$ [nm]	Stokes Shift Δ [cm^{-1}]
6a	313 (27600)	432	8800
6d	312 (20700)	407	7500
8a	317 (30700)	436	8600
8b	319 (26400)	451	9100
8f	318 (17000)	428	8000
8g	320 (30200)	446	8900
8h	314 (19500)	427	8400
8i	312 (9900)	401	7200
8j	315 (21100)	418	7800
8k	327 (13900)	425	7100

All reactions involving water-sensitive compounds were carried out in oven-dried Schlenk glassware under a nitrogen atmosphere. The solvents were dried according to standard procedures[24] and were distilled prior to use. Column chromatography: silica gel 60 M, 230–400 mesh (Macherey–Nagel) or aluminium oxide 5016 A basic (Fluka). Thin layer chromatography (TLC): silica gel layered aluminium foil (60 F_{254} Merck, Darmstadt) or aluminum oxide layered aluminum foil (60 F_{254} Merck, Darmstadt). Melting points (uncorrected): Büchi Melting Point B-540. The (hetero)aryl propynols **2**,[25] and the aldehydes **3e**[26] and **3l**[27] were synthesized according to literature procedures. Electron-poor (hetero)aryl halides **1**, the aldehydes **3**, 3,4-dimethyl-5-(2-hydroxyethyl) thiazolium iodide (**4a**), 3-benzyl-4-methyl-5-(2-hydroxyethyl)-thiazolium chloride (**4b**), and the amines **7** were purchased from ACROS or Merck and used without further purification. Petroleum ether (PE) used had a boiling range of 30–40 °C. ^{1}H and ^{13}C NMR spectra: Bruker ARX250, Bruker DRX 300, Bruker ARX 300, Varian VXR 400S, Bruker DRX500 or Bruker AC300 with $CDCl_3$ as a solvent. The assignments of quaternary C, CH, CH_2 and CH_3 was made on the basis of DEPT spectra. IR: Bruker Vector 22 FT-IR or Perkin Elmer Models Lambda 16. UV/VIS: Hewlett Packard HP8452 A. MS: Finnigan MAT 90, MAT 95 Q, Jeol JMS-700 and Finnigan TSQ 700. Elemental analyses were carried out in the microanalytical laboratories of Department Chemie der Universität München and the Organisch-Chemisches Institut der Universität Heidelberg.

Synthesis of 1,4-Diketones 5; General Procedure

A stirred mixture of halide **1** (1.00 mmol) and propargyl alcohol **2** (1.05 mmol) in solvent (either Et_3N, EtOH, or THF), was degassed for 5 min. Then, $Pd(PPh_3)_2Cl_2$ (14 mg, 0.02 mmol) and CuI (7 mg, 0.04 mmol) were added and the reaction mixture was heated to reflux for 14 h. After cooling to r.t., aldehyde **3** (1.20 mmol), **4a** (for aromatic aldehydes, 57 mg, 0.20 mmol) or **4b** (for aliphatic aldehydes, 54 mg, 0.20 mmol), and 0.5 mL of Et_3N were added. The mixture was then heated to reflux for the times indicated. After cooling to r.t., Et_2O (15 mL) was added and the precipitated ammonium salts were removed by filtration. The remaining solution was concentrated in vacuo and the residue was purified by chromatography on silica gel and/or recrystallized to give the pure 1,4-diketones **5** (for experimental details, see Table 5).

1,2-Bis(4-cyanophenyl)-4-phenylbutane-1,4-dione (5a)

Purification by chromatography on silica gel (PE–Et_2O, 3:1), beige crystals, mp 130 °C (EtOH).

IR (KBr): 2230 (m), 1682 (s), 1606 (m), 1581 (w), 1504 (m), 1448 (m), 1405 (m), 1363 (w), 1339 (w), 1292 (w), 1230 (m), 1208 (w), 1177 (w), 1001 (m), 952 (w), 836 (m), 762 (m), 690 (m), 571 (m), 544 (w) cm^{-1}.

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.39 (dd, *J* = 3.7, 18.0 Hz, 1 H), 4.21 (dd, *J* = 10.1, 18.1 Hz, 1 H), 5.32 (dd, *J* = 3.7, 10.1 Hz, 1 H), 7.44–7.49 (m, 4 H), 7.57–7.65 (m, 3 H), 7.74 (d, *J* = 8.5 Hz, 2 H), 7.96 (d, *J* = 7.2 Hz, 2 H), 8.08 (d, *J* = 8.4 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 43.8 (CH_2), 48.9 (CH), 112.0 (C_{quat}), 116.6 (C_{quat}), 117.8 (C_{quat}), 118.2 (C_{quat}), 128.2 (CH), 128.8 (CH), 129.1 (CH), 129.1 (CH), 132.6 (CH), 133.2 (CH), 133.8 (CH), 135.8 (C_{quat}), 139.3 (C_{quat}), 142.7 (C_{quat}), 197.1 (C_{quat}), 197.1 (C_{quat}).

MS (70 eV, EI): *m/z* (%) = 364 ($[M]^+$, 4), 234 ($[M – NCC_6H_4CO]^+$, 6), 130 ($[NCC_6H_4CO]^+$, 100), 105 ($[C_6H_5CO]^+$, 26), 102 ($[NCC_6H_5]^+$, 14), 77 ($[Ph]^+$, 16).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 250 nm (45700).

Anal. Calcd for $C_{24}H_{16}N_2O_2$ (364.4): C, 79.11; H, 4.43; N, 7.69. Found: C, 79.19; H, 4.25; N, 7.72.

2-(4-Cyanophenyl)-1,4-diphenylbutane-1,4-dione (5b)

Purification by chromatography on silica gel (PE–Et_2O, 4:1), colorless solid, mp 159–160 °C (EtOH–acetone) (Lit.[28] mp 161–162 °C).

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 3.34 (dd, *J* = 18.0, 4.2 Hz, 1 H), 4.18 (dd, *J* = 18.0, 9.5 Hz, 1 H), 5.40 (dd, *J* = 4.2, 9.5 Hz, 1 H), 7.40–7.62 (m, 10 H), 7.95–8.01 (m, 4 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 43.4 (CH_2), 48.5 (CH), 111.5 (C_{quat}), 118.4 (C_{quat}), 128.2 (CH), 128.7 (CH), 128.7 (CH), 128.9 (CH), 129.1 (CH), 132.9 (CH), 133.4 (CH), 133.6 (CH), 136.0 (C_{quat}), 136.1 (C_{quat}), 144.1 (C_{quat}), 197.2 (C_{quat}), 198.0 (C_{quat}).

Table 5 Experimental Details for the Synthesis of 1,4-Diketones **5**

(Hetero)aryl Halide **1** mg (mmol)	Propargyl Alcohol **2** mg (mmol)	NEt_3 (mL)	EtOH (mL)	Aldehyde **3** mg (mmol)	Reaction Time (h)	Yield mg (%)
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	–	157 (1.20) of **3a**	8	322 (88) of **5a**
182 (1.00) of **1a**	139 (1.05) of **2a**	3.5	6.0[a]	127 (1.20) of **3b**	24	285 (84) of **5b**
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	–	115 (1.20) of **3c**	8	261 (81) of **5c**
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	–	163 (1.20) of **3d**	8	277 (75) of **5d**
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	–	290 (1.20) of **3e**	23	387 (82) of **5e**
182 (1.00) of **1a**	139 (1.05) of **2a**	4.0	–	114 (1.20) of **3f**	24	113 (34) of **5f**
182 (1.00) of **1a**	139 (1.05) of **2a**	3.5	1.5	80 (0.60) of **3g**	24	207 (69) of **5g**
158 (1.00) of **1b**	128 (1.05) of **2b**	6.0	–	163 (1.20) of **3d**	22	234 (70) of **5h**
182 (1.00) of **1a**	139 (1.05) of **2a**	3.0	1.0	87 (1.20) of **3h**	24	165 (54) of **5i**
182 (1.00) of **1a**	139 (1.05) of **2a**	4.0	1.5	87 (1.20) of **3i**	24	254 (76) of **5j**
182 (1.00) of **1a**	139 (1.05) of **2a**	2.0	2.0	185 (1.20) of **3j**	24	255 (66) of **5k**
182 (1.00) of **1a**	139 (1.05) of **2a**	1.5	3.5	139 (1.20) of **3l**	8	205 (59) of **5l**

[a] THF.

2-(4-Cyanophenyl)-1-(2-furyl)-4-phenylbutane-1,4-dione (5c)
Light beige crystals, mp 179 °C (EtOH).

IR (KBr): 2228 (s), 1674 (s), 1604 (m), 1568 (s), 1504 (m), 1568 (s), 1396 (m), 1338 (m), 1328 (m), 1271 (m), 1238 (m), 1210 (w), 1092 (w), 1016 (s), 1002 (m), 882 (m), 781 (m), 738 (s), 760 (w), 691 (m), 592 (w), 568 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.36 (dd, *J* = 18.0, 4.3 Hz, 1 H) 4.13 (dd, *J* = 18.1, 9.6 Hz, 1 H), 5.21 (dd, *J* = 9.6, 4.4 Hz, 1 H), 6.53 (dd, *J* = 1.7, 3.6 Hz, 1 H), 7.27 (m, 1 H), 7.42–7.63 (m, 8 H), 7.96 (d, *J* = 7.2 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 40.5 (CH_2), 46.9 (CH), 109.8 (C_{quat}), 110.9 (CH), 116.8 (CH), 116.8 (C_{quat}), 126.4 (CH), 127.0 (CH), 127.5 (CH), 131.0 (CH), 131.8 (CH), 134.4 (C_{quat}), 141.9 (C_{quat}), 145.2 (CH), 150.2 (C_{quat}), 184.9 (C_{quat}), 195.3 (C_{quat}).

MS (70 eV, EI): *m/z* (%) = 329 ($[M]^+$, 17), 224 ($[M - C_6H_5CO]^+$, 11), 105 ($[C_6H_5CO]^+$, 40), 95 ($[C_4H_3OCO]^+$, 100), 77 ($[Ph]^+$, 26).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 246 (29300), 278 nm (17800).

Anal. Calcd for $C_{21}H_{15}NO_3$ (329.4): C, 76.58; H, 4.59; N, 4.25. Found: C,7 6.54; H, 4.69; N, 4.19.

2-(4-Cyanophenyl)-1-(4-methoxyphenyl)-4-phenylbutane-1,4-dione (5d)
Light beige crystals, mp 144 °C (EtOH).

IR (KBr): 2229 (m), 1674 (s), 1599 (s), 1511 (m), 1449 (w), 1420 (m), 1339 (m), 1320 (m), 1254 (s), 1169 (s), 1115 (w), 1029 (m), 1001 (m), 953 (w), 835 (m), 778 (w), 764 (w), 691 (w), 572 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.31 (dd, *J* = 4.4, 18.0 Hz, 1 H), 3.84 (s, 3 H), 4.16 (dd, *J* = 9.3, 18.0 Hz, 1 H), 5.37 (dd, *J* = 4.4, 9.3 Hz, 1 H), 6.90 (d, *J* = 8.8 Hz, 2 H), 7.43–7.61 (m, 7 H), 7.97 (d, *J* = 7.2 Hz, 2 H), 7.99 (d, *J* = 8.8 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 43.7 (CH_2), 48.5 (CH), 55.9 (CH_3), 111.7 (C_{quat}), 114.3 (CH), 118.9 (C_{quat}), 128.5 (CH), 129.0 (CH), 129.3 (C_{quat}), 129.4 (CH), 131.6 (CH), 133.3 (CH), 133.9 (CH), 136.6 (C_{quat}), 145.0 (C_{quat}), 164.2 (C_{quat}), 196.7 (C_{quat}), 197.7 (C_{quat}).

MS (FAB): *m/z* (%) = 392 ($[M + Na]^+$, 14), 135 ($[MeOC_6H_4CO]^+$, 100), 77 ($[Ph]^+$, 7).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 246 (31600), 286 nm (19500).

Anal. Calcd for $C_{24}H_{19}NO_3$ (369.4): C, 78.03; H, 5.18; N, 3.79. Found: C, 77.73; H, 5.16; N, 3.77.

2-(4-Cyanophenyl)-1-(10-methyl-10*H*-phenothiazin-3-yl)-4-phenylbutane-1,4-dione (5e)
Purification by chromatography on silica gel (PE–Et_2O, 3:1), yellow crystals, mp 116–117 °C (EtOH–acetone).

IR (KBr): 2228 (m), 1673 (s), 1598 (s), 1573 (m), 1503 (w), 1466 (s), 1396 (w), 1340 (s), 1258 (s), 1228 (m), 1142 (m), 1002 (w), 845 (w), 819 (w), 752 (m), 690 (w), 573 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.30 (dd, *J* = 4.3, 18.1 Hz, 1 H), 3.37 (s, 3 H), 4.14 (dd, *J* = 17.9, 9.3 Hz, 1 H), 5.30 (dd, *J* = 4.3, 9.4 Hz, 1 H), 6.74–6.81 (m, 2 H), 6.95 (dt, *J* = 0.9, 7.4 Hz, 1 H), 7.08–7.19 (m, 2 H), 7.42–7.49 (m, 7 H), 7.75 (d, *J* = 2.0 Hz, 1 H), 7.82 (dd, *J* = 8.5, 1.9 Hz, 1 H), 7.95 (d, *J* = 7.2 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 35.6 (CH_3), 43.3 (CH_2), 48.0 (CH), 111.4 (C_{quat}), 113.4 (CH), 114.6 (CH), 118.5 (C_{quat}), 122.6 (C_{quat}), 123.5 (CH), 123.5 (C_{quat}), 127.3 (CH), 127.7 (CH), 127.8 (CH), 128.2 (CH), 128.7 (CH), 129.0 (CH), 129.3 (CH), 130.2 (C_{quat}), 132.9 (CH), 133.5 (CH), 136.2 (C_{quat}), 144.2 (C_{quat}), 144.4 (C_{quat}), 150.2 (C_{quat}), 195.7 (C_{quat}), 197.3 (C_{quat}).

MS (70 eV, EI): *m/z* (%) = 474 ($[M]^+$, 90), 240 ([methylphenothiazinylCO]$^+$, 100), 212 ([methylphenothiazinyl]$^+$, 34).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 245 (45100), 282 (22700), 384 nm (7200).

HRMS: *m/z* calcd for $C_{30}H_{22}N_2O_2S$: 474.1402; found: 474.1421.

2-(4-Cyanophenyl)-4-phenyl-1-(2-pyrrolyl)-butane-1,4-dione (5f)
Purification by chromatography on silica gel (PE–Et_2O, 2:1), pale yellow crystals, mp 170 °C (EtOH).

IR (KBr): 2229 (m), 1683 (m), 1641 (s), 1605 (w), 1545 (w), 1448 (w), 1403 (s), 1360 (w), 1323 (w), 1296 (w), 1244 (w), 1207 (w), 1110 (m), 1045 (m), 904 (w), 795 (m), 690 (w), 603 (w), 570 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.36 (dd, *J* = 18.0, 4.8 Hz, 1 H), 4.07 (dd, *J* = 18.0, 9.1 Hz, 1 H), 5.09 (dd, *J* = 9.1, 4.8 Hz, 1 H), 6.25–6.28 (m, 1 H), 6.99–7.01 (m, 2 H), 7.44 (t, *J* = 7.8, 2 H), 7.51–7.59 (m, 5 H), 7.95 (d, *J* = 7.1, 2 H), 9.29 (br s, 1 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 42.3 (CH_2), 48.5 (CH), 111.2 (CH), 111.3 (C_{quat}), 117.4 (CH), 118.5 (C_{quat}), 125.2 (CH), 128.1 (CH), 128.7 (CH), 128.9 (CH), 130.9 (C_{quat}), 132.7 (CH), 133.5 (CH), 136.3 (C_{quat}), 145.0 (C_{quat}), 187.4 (C_{quat}), 197.1 (C_{quat}).

MS (70eV, EI): *m/z* (%) = 328 ($[M]^+$, 56), 311 (14), 105 ($[C_6H_5CO]^+$, 19), 94 ($[C_4H_4NCO]^+$, 100), 77 ($[C_6H_5]^+$, 19), 66 (14).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 296 (16800), 244 nm (27800).

Anal. Calcd for $C_{21}H_{16}N_2O_2$ (328.4): C, 76.81; H, 4.91; N, 8.53. Found: C, 76.58; H, 4.90; N, 8.53.

1,4-Bis[2-(4-cyanophenyl)-4-phenylbutane-1,4-dioxo-1-yl]benzene (5g)
Colorless solid, mp 197 °C (EtOH).

IR (KBr): 2229 (m), 1681 (s), 1608 (m), 1581 (w), 1504 (m), 1449 (m), 1404 (m), 1363 (w), 1322 (w), 1290 (w), 1231 (m), 1208 (w), 1001 (m), 951 (w), 837 (w), 752 (m), 690 (m), 572 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.36 (m, 2 H), 4.18 (dd, *J* = 9.8, 18.0 Hz, 2 H), 5.33 (m, 2 H), 7.43–7.48 (m, 8 H), 7.56–7.63 (m, 6 H), 7.94 (d, *J* = 8.4 Hz, 4 H), 8.04 (s, 4 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 44.0 (CH_2), 44.1 (CH_2), 49.2 (CH), 49.2 (CH), 112.2 (C_{quat}), 118.7 (C_{quat}), 128.5 (CH), 129.1 (CH), 129.5 (CH), 129.6 (CH), 133.4 (CH), 134.1 (CH), 136.3 (C_{quat}), 139.8 (C_{quat}), 139.9 (C_{quat}), 139.9 (C_{quat}), 143.5 (C_{quat}), 143.5 (C_{quat}), 197.4 (C_{quat}), 197.5 (C_{quat}), 197.9 (C_{quat}), 198.0 (C_{quat}).

MS (FAB, NBA): *m/z* (%) = 601 ($[M + H]^+$, 12), 366 ($[M - NCC_6H_5CHCH_2COPh]^+$, 100), 348 (12), 132 ($[COC_6H_4CO]^+$, 6), 105 ($PhCO^+$, 27).

HRMS: *m/z* calcd for $C_{40}H_{28}N_2O_4 + Na^+$: 623.1947; found: 623.1873. HRMS: *m/z* calcd for $C_{40}H_{28}N_2O_4 + H^+$: 601.2127; found: 601.2098.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 246 nm (52600).

Anal. Calcd for $C_{40}H_{28}N_2O_4$ (600.7): C, 79.98; H, 4.70; N, 4.66. Found: C, 79.18; H, 4.75; N, 4.63.

4-(2-Furyl)-1-(4-methoxyphenyl)-2-pyridin-2-ylbutane-1,4-dione (5h)
Purification by chromatography on silica gel (PE–Et_2O, 1:1), light beige crystals, mp 99–100 °C (EtOH, under N_2).

IR (KBr): 1674 (s), 1600 (s), 1570 (s), 1511 (m), 1469 (s), 1434 (m), 1420 (w), 1396 (m), 1316 (m), 1250 (s), 1169 (s), 1027 (s), 947 (m), 883 (w), 843 (m), 763 (m), 596 (w), 581 (w), 553 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.40 (dd, *J* = 17.7, 4.9 Hz, 1 H), 3.83 (s, 3 H), 4.01 (dd, *J* = 17.7, 9.2 Hz, 1 H), 5.60 (dd, *J* = 9.2, 4.9 Hz, 1 H), 6.52 (dd, *J* = 3.7, 1.8 Hz, 1 H), 6.89 (d, *J* = 8.8 Hz, 2 H),

7.18–7.21 (m, 2 H), 7.39–7.71 (m, 3 H), 8.08 (d, *J* = 8.9 Hz, 2 H), 8.56 (d, *J* = 4.3 Hz, 1 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 41.6 (CH_2), 49.8 (CH), 55.5 (CH_3), 112.3 (CH), 113.8 (CH), 117.4 (CH), 122.5 (CH), 123.4 (C_{quat}), 129.1 (C_{quat}), 131.5 (CH), 138.2 (CH), 146.4 (CH), 148.6 (CH), 152.4 (C_{quat}), 158.1 (C_{quat}), 163.7 (CH), 186.5 (C_{quat}), 195.8 (C_{quat}).

MS (FAB, NBA): *m/z* (%) = 336 ([M + H]$^+$, 100), 135 ([$MeOC_6H_4CO$]$^+$, 31).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 276 nm (57200).

Anal. Calcd for $C_{20}H_{17}NO_4$ (335.4): C, 71.63; H, 5.11; N, 4.18. Found: C, 71.47; H, 4.85; N, 4.15.

3-(4-Cyanophenyl)-5-methyl-1-phenylhexane-1,4-dione (5i)
Purification by chromatography on silica gel (PE–Et_2O, 4:1), pale yellow solid, mp 127 °C (EtOH).

IR (KBr): 2225 (m), 1705 (s), 1676 (s), 1607 (m), 1596 (m), 1580 (w), 1505 (w), 1448 (m), 1370 (w), 1328 (w), 1240 (w), 1208 (w), 1179 (w), 1099 (w), 1019 (m), 988 (w), 852 (w), 746 (w), 694 (m), 571 (m) cm^{-1}.

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.93 (d, *J* = 6.9 Hz, 3 H), 1.23 (d, *J* = 7.0 Hz, 3 H), 2.79 (sept, *J* = 6.9 Hz, 1 H), 3.13 (dd, *J* = 4.1, 18.0 Hz, 1 H), 3.99 (dd, *J* = 9.8, 18.0 Hz, 1 H), 4.66 (dd, *J* = 9.7, 4.0 Hz, 1 H), 7.41–7.47 (m, 4 H), 7.54–7.59 (m, 1 H), 7.64 (d, *J* = 8.4 Hz, 2 H), 7.94 (d, *J* = 7.1 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.7 (CH_3), 19.3 (CH_3), 41.0 (CH), 43.1 (CH_2), 52.0 (CH), 112.0 (C_{quat}), 118.8 (C_{quat}), 128.4 (CH), 129.0 (CH), 129.6 (CH), 133.2 (CH), 133.8 (CH), 136.6 (C_{quat}), 144.2 (C_{quat}), 197.7 (C_{quat}), 212.4 (C_{quat}).

MS (70 eV, EI): *m/z* (%) = 305 ([M]$^+$, 2), 130 (16), 105 ($PhCO^+$, 37), 77 ([Ph]$^+$, 23), 71 ([$COCH(CH_3)_2$]$^+$, 100), 43 ([$CH(CH_3)_2$]$^+$, 66).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 244 nm (30500).

Anal. Calcd for $C_{20}H_{19}NO_2$ (305.4): C, 78.66; H, 6.27; N, 4.59. Found: C, 78.57; H, 6.21; N, 4.62.

3-(4-Cyanophenyl)-1-phenylnonane-1,4-dione (5j)
Purification by chromatography on silica gel (PE–Et_2O, 4:1), pale yellow solid, mp 82–83 °C (EtOH).

IR (KBr): 2955 (m), 2930 (m), 2228 (m), 1713 (s), 1682 (s), 1606 (m), 1504 (w), 1449 (m), 1402 (w), 1363 (w), 1244 (w), 1209 (w), 1127 (w), 1002 (w), 848 (w), 756 (m), 690 (m) cm^{-1}.

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 0.83 (t, *J* = 7.3 Hz, 3 H), 1.10–1.30 (m, 4 H), 1.43–1.66 (m, 2 H), 2.38–2.48 (m, 1 H), 2.60–2.71 (m, 1 H), 3.16 (dd, *J* = 4.0, 18.0 Hz, 1 H), 4.00 (dd, *J* = 9.7, 18.0 Hz, 1 H), 4.48 (dd, *J* = 9.7, 4.0 Hz, 1 H), 7.42 (d, *J* = 8.0 Hz, 2 H), 7.43–7.47 (m, 2 H), 7.55–7.59 (m, 1 H), 7.65 (d, *J* = 8.0 Hz, 2 H), 7.94 (d, *J* = 7.5 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.2 (CH_3), 22.7 (CH_2), 23.6 (CH_2), 31.5 (CH_2), 42.6 (CH_2), 42.7 (CH_2), 53.6 (CH), 112.0 (C_{quat}), 118.8 (C_{quat}), 128.5 (CH), 129.1 (CH), 129.5 (CH), 133.2 (CH), 133.9 (CH), 136.6 (C_{quat}), 144.0 (C_{quat}), 197.8 (C_{quat}), 208.7 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 333 ([M]$^+$, 2), 258 (37), 129 ([$NCC_6H_4CHCH_2$]$^+$, 13), 105 (Ph-CO^+, 38), 99 ([COC_5H_{11}]$^+$, 100), 77 ([Ph]$^+$, 22), 71 ([C_5H_{11}]$^+$, 29), 43 ([$CH_3CH_2CH_2$]$^+$, 29).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 243 nm (32300).

Anal. Calcd for $C_{22}H_{23}NO_2$ (333.4): C, 79.25; H, 6.95; N, 4.20. Found: C, 78.86; H, 6.82; N, 4.17.

3-(4-Cyanophenyl)-6,10-dimethyl-1-phenylundecan-9-en-1,4-dione (5k)
Purification by chromatography on silica gel (PE–Et_2O, 6:1), colorless oil.

IR (film): 2962 (m), 2915 (m), 2229 (m), 1716 (s), 1685 (s), 1606 (m), 1598 (m), 1504 (m), 1449 (m), 1400 (w), 1364 (w), 1323 (w), 1248 (w), 1209 (w), 1180 (w), 989 (w), 758 (m), 735 (w), 690 (m), 581 (w) cm^{-1}.

^{1}H NMR ($CDCl_3$, 300 MHz), inseparable 1:1 mixture of diastereomers: δ = 0.68 (d, *J* = 6.6 Hz, 3 H), 0.87 (d, *J* = 6.7 Hz, 3 H), 0.94–1.34 (m, 4 H), 1.50 (s, 3 H), 1.55 (s, 3 H), 1.63 (s, 3 H), 1.65 (s, 3 H), 1.79–2.02 (m, 6 H), 2.19–2.68 (m, 4 H), 3.14 (dd, *J* = 5.1, 18.0 Hz, 2 H), 3.98 (dd, *J* = 9.6, 18.0 Hz, 2 H), 4.41–4.48 (m, 2 H), 4.94–5.05 (m, 2 H), 7.38–7.45 (m, 8 H), 7.55 (t, *J* = 7.4 Hz, 2 H), 7.63 (d, *J* = 7.5 Hz, 4 H), 7.93 (d, *J* = 7.2 Hz, 4 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 17.4 (CH_3), 17.4 (CH_3), 19.2 (CH_3), 19.4 (CH_3), 25.0 (CH_2), 25.2 (CH_2), 25.4 (CH_3), 25.5 (CH_3), 28.1 (CH), 28.1 (CH), 36.3 (CH_2), 36.6 (CH_2), 41.8 (CH_2), 42.0 (CH_2), 49.4 (CH_2), 49.5 (CH_2), 53.3 (CH), 53.5 (CH), 111.4 (C_{quat}), 111.4 (C_{quat}), 118.2 (C_{quat}), 124.0 (CH), 127.8 (CH), 128.4 (CH), 129.0 (CH), 129.0 (CH), 131.2 (C_{quat}), 131.2 (C_{quat}), 132.6 (CH), 133.2 (CH), 136.0 (C_{quat}), 136.0 (C_{quat}), 143.2 (C_{quat}), 143.3 (C_{quat}), 197.1 (C_{quat}), 197.1 (C_{quat}), 207.4 (C_{quat}), 207.6 (C_{quat}).

MS (70 eV, EI): *m/z* (%) = 387 ([M]$^+$, 9), 267 ([M – PhCOMe]$^+$, 48), 235 (14), 153 ([$CH_3(CH_3)C{=}CHCH_2CH_2CH(CH_3)CH_2CO$]$^+$, 100), 135 ([$CH_2CHC(O)CH_2CHCH_2CH_2CHC$]$^+$, 14), 130 (16), 109 (78), 105 ($PhCO^+$, 62), 81 ([$CH_3(CH_3)C{=}CHCH_2CH_2$-$CH(CH_3)CH_2CO$, –CO, $-CH_2$, $-2 \times CH_3$]$^+$, 23), 77 ([Ph]$^+$, 26), 69 ([$CH_3(CH_3)C{=}CHCH_2$]$^+$, 74), 55 ([$CH_3(CH_3)C{=}CH$]$^+$, 15), 41 ([CH_2CCH_3]$^+$, 25).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 244 nm (28400).

Anal. Calcd for $C_{26}H_{29}NO_2$ (387.5): C, 80.59; H, 7.54; N, 3.61. Found: C, 80.23; H, 7.53; N, 3.69.

3-(4-Cyanophenyl)-9-hydroxy-1-phenylnonane-1,4-dione (5l)
Purification by chromatography on silica gel (PE–Et_2O, 1:1), colorless oil.

IR (film): 3063 (w), 2937 (s), 2864 (m), 2229 (m), 1715 (s), 1683 (s), 1606 (m), 1597 (m), 1581 (w), 1491 (m), 1449 (m), 1363 (m), 1248 (m), 1208 (m), 1052 (w), 1002 (w), 757 (w), 733 (m), 690 (m) cm^{-1}.

^{1}H NMR ($CDCl_3$, 300 MHz): δ = 1.44–1.69 (m, 6 H), 2.36–2.47 (m, 1 H), 2.64–2.74 (m, 1 H), 3.14 (dd, *J* = 3.6, 18.0 Hz, 1 H), 3.55–3.59 (m, 2 H), 4.45 (dd, *J* = 3.3, 18.1 Hz, 1 H), 4.45 (dd, *J* = 10.0, 3.7 Hz, 1 H), 7.38–7.45 (m, 4 H), 7.53–7.57 (m, 1 H), 7.61–7.64 (m, 2 H), 7.90–7.92 (m, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 23.1 (CH_2), 24.9 (CH_2), 32.2 (CH_2), 42.1 (CH_2), 42.3 (CH_2), 53.1 (CH), 62.4 (CH_2), 111.6 (C_{quat}), 118.4 (C_{quat}), 128.0 (CH), 128.6 (CH), 129.1 (CH), 132.8 (CH), 133.5 (CH), 136.0 (C_{quat}), 143.4 (C_{quat}), 197.4 (C_{quat}), 208.2 (C_{quat}).

MS (FAB, NBA) *m/z* (%): 350 ([M + H]$^+$, 12), 349 ([M]$^+$, 3) 332 ([M – OH]$^+$, 100).

HRMS: *m/z* calcd for $C_{22}H_{23}NO_3 + H^+$: 350.1756; found: 350.1748.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 244 nm (24700).

Synthesis of Furans 6; General Procedure
A stirred mixture of the halide **1** (1.00 mmol), the propargyl alcohol **2a** (1.05 mmol), and solvent (Et_3N, EtOH or MeCN) was degassed for 5 min. Then, $Pd(PPh_3)_2Cl_2$ (14 mg, 0.02 mmol), and CuI (7 mg, 0.04 mmol) were added and the reaction mixture was heated to reflux for 14 h. After cooling to r.t., the aldehyde **3** (1.20 mmol), **4a** (for aromatic aldehydes, 57 mg, 0.20 mmol) or **4b** (for aliphatic aldehydes, 54 mg, 0.20 mmol), and Et_3N (0.5 mL) were added, and

Table 6 Experimental Details for the Synthesis of Furans **6**

(Hetero)aryl Halide **1** mg (mmol)	Propargyl Alcohol **2** mg (mmol)	NEt_3 (mL)	EtOH (mL)	Aldehyde **3** mg (mmol)	Reaction Time t_1 (h)	Reaction Time t_2 (h)	Yield mg (%)
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	–	254 (2.40) of **3b**	8.5	12	507 (79) of **6a**
182 (1.00) of **1a**	139 (1.05) of **2a**	4.0	–	115 (1.20) of **3c**	23	9	231 (74) of **6b**
194 (1.00) of **1c**	139 (1.05) of **2a**	2.5	1.5[a]	149 (1.20) of **3m**	24	28	146 (46) of **6c**
164 (1.00) of **1d**	139 (1.05) of **2a**	3.0	1.0	127 (1.20) of **3b**	23	5.75	128 (42) of **6d**
182 (1.00) of **1a**	139 (1.05) of **2a**	3.5	1.5	120 (1.20) of **3j**	24	5.75	197 (64) of **6e**

[a] CH_3CN.

then the mixture was heated to reflux for 8.5–24 h (t_1). After cooling to r.t., glacial HOAc (0.5 mL) and concentrated HCl (2.5 mL) were added and the mixture was heated to reflux for 5.75–12 h (t_2). Then, after cooling to r.t., a sat. aq solution of K_2CO_3 was added. The aqueous phase was extracted several times with Et_2O or EtOAc, and the combined organic layers were dried with anhydrous Na_2SO_4 and filtered. The remaining solution was concentrated in vacuo and the residue was purified by chromatography on silica gel and/or recrystallized to give the pure furans **6** (for experimental details see Table 6).

4-(2,5-Diphenyl-3-furyl)benzonitrile (6a)
After an aqueous workup and extraction with EtOAc, beige solid, mp 130–131 °C (EtOH).

IR (KBr): 2227 (s), 1607 (s), 1550 (w), 1508 (w), 1490 (s), 1446 (m), 1178 (w), 1148 (m), 1075 (w), 1053 (w), 1027 (w), 953 (m), 932 (w), 916 (w), 847 (m), 825 (w), 768 (s), 697 (s), 673 (w), 599 (m), 565 (m), 552 (w), 484 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 6.80 (s, 1 H), 7.24–7.44 (m, 6 H), 7.54 (d, *J* = 8.5 Hz, 4 H), 7.63 (d, *J* = 6.7 Hz, 2 H), 7.74 (d, *J* = 7.2 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 108.3 (CH), 110.8 (C_{quat}), 118.9 (C_{quat}), 122.6 (C_{quat}), 123.9 (CH), 126.6 (CH), 127.9 (CH), 128.3 (CH), 128.7 (CH), 128.8 (CH), 129.1 (CH), 130.0 (C_{quat}),130.4 (C_{quat}), 132.5 (CH), 139.2 (C_{quat}), 149.0 (C_{quat}), 153.4 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 321 ($[M]^+$, 100), 216 ($[M – OCPh]^+$, 14).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 253 (23300), 313 nm (27600).

Fluorescence ($CHCl_3$): λ_{max} = 432 nm.

Anal. Calcd for $C_{23}H_{15}NO$ (321.4): C, 85.59; H, 4.65; N, 4.33. Found: C, 85.35; H, 4.70; N, 4.32.

4-(5-Phenyl-2,2′-bifuran-3-yl)benzonitrile (6b)
After an aqueous workup and extraction with Et_2O and trituration with EtOH, beige solid, mp 118–120 °C (EtOH).

IR (KBr): 2225 (s), 1607 (s), 1535 (w), 1487 (m), 1462 (w), 1448 (w), 1256 (w), 1174 (m), 1160 (w), 1077 (w), 1012 (w), 965 (m), 930 (w), 895 (m), 852 (m), 824 (m), 809 (w), 760 (s), 739 (w), 702 (w), 691 (s), 594 (m), 567 (w), 551 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 6.49 (dd, *J* = 1.8, 3.4 Hz, 1 H), 6.68 (dd, *J* = 0.7, 3.4 Hz, 1 H), 6.82 (s, 1 H), 7.28–7.34 (m, 1 H), 7.40–7.45 (m, 3 H), 7.64–7.74 (m, 6 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 107.8 (CH), 108.4 (CH), 110.8 (C_{quat}), 111.6 (CH), 119.0 (C_{quat}), 122.8 (C_{quat}), 124.0 (CH), 128.1 (CH), 128.8 (CH), 129.2 (CH), 129.8 (C_{quat}), 132.1 (CH), 138.0 (C_{quat}), 141.2 (C_{quat}), 142.5 (CH), 145.7 (C_{quat}), 153.5 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 311 ($[M]^+$, 100), 282 ($[M – CHO]^+$, 38).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 257 (23900), 319 nm (22700).

Anal. Calcd for $C_{21}H_{13}NO_2$ (311.3): C, 81.01; H, 4.21; N, 4.50. Found: C, 80.89; H, 4.70; N, 4.55.

4-[2-(4-Fluorophenyl)-5-phenyl-3-furyl]pyridine (6c)
After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 1:1), beige solid, mp 120–122 °C (isopropanol).

IR (KBr): 3072 (w), 1604 (s), 1578 (w), 1543 (m), 1511 (s), 1490 (s), 1418 (w), 1409 (w), 1225 (s), 1159 (m), 1097 (w), 1054 (w), 836 (s), 815 (s), 760 (s), 716 (m), 691 (m), 665 (m), 588 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 6.84 (s, 1 H), 7.03–7.08 (m, 2 H), 7.25–7.45 (m, 5 H), 7.53–7.58 (m, 2 H), 7.74 (d, *J* = 7.0 Hz, 2 H), 8.60 (d, *J* = 6.2 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 107.7 (CH), 115.6 (d, 21,8 Hz, CH), 121.3 (C_{quat}), 122.8 (CH), 123.7 (CH), 126.4 (d, *J* = 3.5 Hz, C_{quat}), 127.8 (CH), 128.4 (d, *J* = 8.2 Hz, CH), 128.6 (CH), 129.7 (C_{quat}), 141.9 (C_{quat}), 148.3 (C_{quat}), 150.0 (CH), 153.3 (C_{quat}), 162.5 (d, *J* = 249 Hz, C_{quat}).

MS (70 eV, EI) *m/z* (%): 315 ($[M]^+$, 100).

HRMS: *m/z* calcd for $C_{21}H_{14}FNO$: 315.1059; found: 315.1062.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 232 (10200), 306 nm (10900).

Anal. Calcd for $C_{21}H_{14}FNO$ (315.3): C, 79.99; H, 4.47; N, 4.44. Found: C, 79.48, H, 4.61; N, 4.51.

2-(2,5-Diphenyl-3-furyl)-1,3-thiazole (6d)
After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 6:1), beige solid, mp 88 °C (hexane).

IR (KBr): 3054 (m), 1593 (m), 1552 (m), 1509 (m), 1490 (s), 1476 (s), 1447 (m), 1155 (m), 1131 (s), 1076 (w), 1052 (s), 931 (w), 919 (s), 872 (s), 812 (m), 763 (s), 695 (s), 673 (w), 535 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 7.12 (s, 1 H), 7.29 (d, *J* = 3.3 Hz, 1 H), 7.32–7.34 (m, 1 H), 7.41–7.46 (m, 5 H), 7.77–7.80 (m, 2 H), 7.88 (d, *J* = 3.3 Hz, 1 H), 7.99–8.02 (m, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 108.2 (CH), 118.3 (C_{quat}), 118.8 (CH), 124.0 (CH), 127.7 (CH), 128.0 (CH), 128.5 (CH), 128.8 (CH), 129.0 (CH), 130.0 (C_{quat}), 130.2 (C_{quat}), 143.1 (CH), 150.6 (C_{quat}), 153.0 (C_{quat}), 161.1 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 303 ($[M]^+$, 86), 302 ($[M – H]^+$, 100).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 290 (20900), 312 nm (20700).

Fluorescence ($CHCl_3$): λ_{max} = 407 nm.

Anal. Calcd for $C_{19}H_{13}NOS$ (303.4): C, 75.22; H, 4.32; N, 4.62; S, 10.57. Found: C, 75.03; H, 4.35; N, 4.67; S, 10.48.

4-(2-Pentyl-5-phenyl-3-furyl)benzonitrile (6e)
After an aqueous workup and extraction with Et_2O and purification by chromatography on silica gel (hexane–EtOAc 6:1), yellow resin.

IR (KBr): 2956 (s), 2930 (s), 2871 (m), 2228 (s), 1702 (s), 1658 (s), 1599 (s), 1554 (w), 1504 (m), 1449 (s), 1405 (w), 1377 (w), 1275 (s), 1216 (s), 1179 (m), 1019 (w), 844 (m), 762 (m), 693 (s) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 0.87–0.92 (m, 3 H), 1.30–1.41 (m, 4 H), 1.72–1.82 (m, 2 H), 2.83 (t, *J* = 7.4 Hz, 2 H), 6.75 (s, 1 H), 7.25–7.29 (m, 1 H), 7.37–7.42 (m, 2 H), 7.51 (d, *J* = 8.5 Hz, 2 H), 7.66–7.76 (m, 4 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 13.7 (CH_3), 22.1 (CH_2), 27.0 (CH_2), 27.9 (CH_2), 31.3 (CH_2), 105.4 (CH), 109.7 (C_{quat}), 118.8 (C_{quat}), 121.4 (C_{quat}), 123.4 (CH), 127.2 (CH), 127.8 (CH), 128.5 (CH), 130.2 (C_{quat}), 132.2 (CH), 138.8 (C_{quat}), 152.1 (C_{quat}), 152.9 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 315 ($[M]^+$, 51), 258 ($[M – C_4H_9]^+$, 100).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 248 (14200), 294 nm (15500).

Anal. Calcd for $C_{22}H_{21}NO$ (315.4): C, 83.78; H, 6.71; N, 4.44. Found: C, 83.63; H, 6.81; N, 4.31.

Synthesis of Pyrroles 8; General Procedure
A stirred mixture of the halide **1** (1.0 equiv), propargyl alcohol **2a** (1.05 equiv), and solvent (Et_3N, EtOH or MeCN) was degassed for 5 min. Then, $Pd(PPh_3)_2Cl_2$ (0.02 equiv) and CuI (0.01 equiv) were added and the reaction mixture was heated to reflux for 14 h. After cooling to r.t., the aldehyde 3 (1.20 equiv), **4a** (for aromatic aldehydes, 0.20 equiv) or **4b** (for aliphatic aldehydes, 0.20 equiv), and Et_3N (0.5 mL) were added, and the mixture was heated to reflux for 9–24 h (t_1). After cooling to r.t., glacial acetic acid (2.5 mL) and the primary amine or ammonium chloride **7** were added, and the mixture was heated to reflux for 22–120 h (t_2). Then, after cooling to r.t., a sat. aq solution of NH_4Cl was added. The aqueous phase was extracted several times with Et_2O or EtOAc and the combined organic layers were dried with anhydrous Na_2SO_4 and filtered. The remaining solution was concentrated in vacuo and the residue was purified by chromatography on silica gel and/or recrystallized to give the pure pyrroles **8** (for experimental details see Table 7).

4-(2,5-Diphenyl-1*H*-pyrrol-3-yl)benzonitrile (8a)
After an aqueous workup and extraction with Et_2O and trituration with EtOH, light beige crystals, mp 233–234 °C (EtOH).

IR (KBr): 3316 (s), 2226 (s), 1604 (s), 1510 (m), 1488 (m), 1468 (w), 1458 (w), 1180 (m), 956 (w), 844 (m), 806 (m), 762 (s), 695 (s), 552 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 6.71 (d, *J* = 2.9 Hz, 1 H), 7.25–7.56 (m, 14 H), 8.51 (br s, 1 H, NH).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 107.8 (CH), 109.0 (C_{quat}), 119.4 (C_{quat}), 121.8 (C_{quat}), 123.9 (CH), 127.0 (CH), 127.8 (CH), 127.9 (CH), 128.5 (CH), 129.0 (CH), 129.1 (CH), 130.7 (C_{quat}), 131.8 (C_{quat}), 132.2 (CH), 132.4 (C_{quat}), 132.9 (C_{quat}), 141.3 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 320 ($[M]^+$, 100).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 272 (27100), 317 nm (30700).

Fluorescence ($CHCl_3$): λ_{max} = 436 nm.

Anal. Calcd for $C_{23}H_{16}N_2$ (320.4): C, 86.22; H, 5.03; N, 8.74. Found: C, 86.07; H, 4.95; N, 8.80.

4-[2-(4-Methoxyphenyl)-5-phenyl-1*H*-pyrrol-3-yl]benzonitrile (8b)
After an aqueous workup and extraction with Et_2O and trituration with EtOH, light yellow crystals, mp 225–226 °C (EtOH).

IR (KBr): 2225 (m), 1603 (s), 1518 (m), 1493 (s), 1454 (m), 1293 (w), 1249 (s), 1177 (m), 1029 (m), 834 (m), 807 (w), 760 (m), 562 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 3.84 (s, 3 H), 6.70 (d, *J* = 2.8 Hz, 1 H), 6.91 (d, *J* = 8.9 Hz, 2 H), 7.23–7.33 (m, 3 H), 7.38–7.46 (m, 4 H), 7.51–7.55 (m, 4 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 55.7 (CH_3), 107.9 (CH), 109.1 (C_{quat}), 114.9 (CH), 119.8 (C_{quat}), 121.5 (C_{quat}), 124.2 (CH), 125.3

Table 7 Experimental Details for the Synthesis of Pyrroles **8**

(Hetero)aryl Halide **1** mg (mmol)	Propargyl Alcohol **2** mg (mmol)	NEt_3 (mL)	EtOH (mL)	Aldehyde **3** mg (mmol)	Reaction Time t_1 (h)	Amine **7** mg (mmol)	Reaction Time t_2 (h)	Yield mg (%)
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	-	127 (1.20) of **3b**	24	111 (1.50) of **7b**	33	189 (59) of **8a**
364 (2.00) of **1a**	278 (2.10) of **2a**	6.0	-	254 (2.40) of **3b**	9	428 (8.00) of **7a**	30	224 (70) of **8a**
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	-	326 (2.40) of **3d**	9	428 (8.00) of **7a**	24	422 (60) of **8b**
388 (2.00) of **1c**	278 (2.10) of **2a**	2.5	2.0[a]	298 (2.40) of **3m**	24	535 (10.0) of **7a**	30	339 (54) of **8c**
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	-	240 (2.40) of **3j**	9	214 (4.00) of **7a**	24	507 (81) of **8d**
364 (2.00) of **1a**	278 (2.10) of **2a**	3.5	1.5	279 (2.40) of **3l**	24	428 (8.00) of **7a**	24[b]	348 (53) of **8e**
182 (1.00) of **1a**	139 (1.05) of **2a**	6.0	-	127 (1.20) of **3b**	24	129 (1.20) of **7c**	56	248 (60) of **8f**
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	-	230 (2.40) of **3c**	10	857 (8.00) of **7c**	120	444 (55) of **8g**
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	-	254 (2.40) of **3b**	9	255 (2.50) of **7d**	111[c]	440 (54) of **8h**
364 (2.00) of **1a**	278 (2.10) of **2a**	3.0	1.0	370 (2.40) of **3j**	24	553 (5.00) of **7b**	24[d]	480 (56) of **8i**
364 (2.00) of **1a**	278 (2.10) of **2a**	4.0	-	254 (2.40) of **3b**	10	488 (8.00) of **7e**	22	462 (57) of **8j**
364 (2.00) of **1a**	278 (2.10) of **2a**	2.5	1.5	240 (2.40) of **3j**	24	296 (7.00) of **7f**	120	418 (59) of **8k**

[a] In CH_3CN.
[b] At 65 °C (oil bath).
[c] At 80 °C (oil bath).
[d] At 85 °C (oil bath).

(C_{quat}), 127.2 (CH), 128.6 (CH), 129.4 (CH), 129.7 (CH), 131.2 (C_{quat}), 132.2 (C_{quat}), 132.5 (CH), 132.8 (C_{quat}), 141.8 (C_{quat}), 159.8 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 350 ($[M]^+$, 100), 335 ($[M - CH_3]^+$, 43).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 270 (24000), 319 nm (26400).

Fluorescence ($CHCl_3$): λ_{max} = 451 nm.

Anal. Calcd for $C_{24}H_{18}N_2O$ (350.4): C, 82.26; H, 5.18; N, 7.99. Found: C, 82.02; H, 5.17; N, 7.95.

4-[2-(4-Fluorophenyl)-5-phenyl-1*H*-pyrrol-3-yl]pyridine (8c)
After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 1:2), beige powder, mp >300 °C (isopropanol).

IR (KBr): 1600 (s), 1513 (m), 1493 (m), 1421 (w), 1222 (m), 1158 (w), 1095 (w), 1000 (w), 964 (w), 838 (m), 814 (m), 761 (m), 723 (w), 695 (m), 668 (w), 612 (w), 585 (w), 520 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 6.95 (d, *J* = 2.6 Hz, 1 H), 7.19–7.31 (m, 5 H), 7.37–7.49 (m, 4 H), 7.79 (d, *J* = 7.2 Hz, 2 H), 8.40 (d, *J* = 4.9 Hz, 2 H), 11.67 (br s, 1 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 107.4 (CH), 115.7 (d, *J* = 21.4 Hz, CH), 119.7 (C_{quat}), 122.1 (CH), 124.2 (CH), 126.4 (CH), 128.8 (CH), 129.0 (d, *J* = 3.1 Hz, C_{quat}), 130.4 (C_{quat}), 131.0 (d, *J* = 8.1 Hz, CH), 132.1 (C_{quat}), 132.7 (C_{quat}), 143.9 (C_{quat}), 149.7 (CH), 161.8 (d, *J* = 243.3 Hz, C_{quat}).

MS (70 eV, EI) *m/z* (%): 314 ($[M]^+$, 100).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 256 (19300), 308 nm (25800).

Anal. Calcd for $C_{21}H_{15}N_2F$ (350.4): C, 80.24; H, 4.81; N, 8.91. Found: C, 79.93; H, 4.96; N, 8.76.

4-(2-Pentyl-5-phenyl-1*H*-pyrrol-3-yl)benzonitrile (8d)
After an aqueous workup and extraction with Et_2O and trituration with EtOH, colorless solid, mp 156 °C (EtOH).

IR (KBr): 3336 (s), 2956 (w), 2929 (m), 2854 (w), 2224 (s), 1600 (s), 1524 (m), 1498 (m), 1459 (m), 1266 (w), 1178 (m), 1000 (w), 840 (m), 806 (m), 768 (m), 758 (m), 694 (m), 642 (w), 552 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 0.89 (t, *J* = 7.1 Hz, 3 H), 1.31–1.42 (m, 4 H), 1.64–1.74 (m, 2 H), 2.81 (t, *J* = 7.7 Hz, 2 H), 6.60 (d, *J* = 2.9 Hz, 1 H), 7.19–7.25 (m, 1 H), 7.35–7.41 (m, 2 H), 7.48–7.53 (m, 4 H), 7.64 (d, *J* = 8.5 Hz, 2 H), 8.35 (br s, 1 H, NH).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.4 (CH_3), 22.8 (CH_2), 27.3 (CH_2), 29.9 (CH_2), 32.0 (CH_2), 106.4 (CH), 108.7 (C_{quat}), 119.9 (C_{quat}), 121.5 (C_{quat}), 124.0 (CH), 126.8 (CH), 128.2 (CH), 129.4 (CH), 131.3 (C_{quat}), 132.1 (C_{quat}), 132.5 (C_{quat}), 132.7 (CH), 142.2 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 314 ($[M]^+$, 32), 257 ($[M - CH_3(CH_2)_3]^+$, 100).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 266 (19500), 307 nm (18300).

Anal. Calcd for $C_{22}H_{22}N_2$ (314.4): C, 84.04; H, 7.05; N, 8.91. Found: C, 83.60; H, 6.98; N, 8.82.

4-[2-(5-Hydroxypentyl)-5-phenyl-1*H*-pyrrol-3-yl]benzonitrile (8e)
After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 2:1), colorless solid, mp 142–144 °C (isopropanol).

IR (KBr): 3340 (s), 2935 (w), 2859 (w), 2224 (s), 1640 (w), 1600 (s), 1524 (w), 1498 (w), 1459 (w), 1414 (w), 1179 (w), 1160 (w), 1053 (w), 842 (w), 804 (w), 761 (m), 694 (w), 640 (w), 552 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.48–1.68 (m, 4 H), 1.71–1.78 (m, 2 H), 2.81–2.86 (m, 2 H), 3.64–3.68 (m, 2 H), 6.60 (d, *J* = 2.8 Hz, 1 H), 7.19–7.24 (m, 1 H), 7.35–7.37 (m, 2 H), 7.48–7.52 (m, 4 H), 7.64 (d, *J* = 8.4 Hz, 2 H), 8.57 (br s, 1 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 25.2 (CH_2), 26.4 (CH_2), 29.2 (CH_2), 31.8 (CH_2), 62.4 (CH_2), 105.8 (CH), 108.2 (C_{quat}), 119.3 (C_{quat}), 121.0 (C_{quat}), 123.4 (CH), 126.2 (CH), 127.5 (CH), 128.7 (CH), 130.9 (C_{quat}), 131.1 (C_{quat}), 131.9 (C_{quat}), 132.1 (CH), 141.6 (C_{quat}).

MS (FAB, NBA) *m/z* (%): 330 ($[M]^+$, 100), 257 ($[M - (CH_2)_4\text{-}OH]^+$, 69).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 268 (16800), 306 (16000), 328 nm (14500).

Anal. Calcd for $C_{22}H_{22}N_2O$ (349.4): C, 79.97; H, 6.71; N, 8.48. Found: C, 79.48; H, 6.75; N, 8.50.

4-(1-Benzyl-2,5-diphenyl-1*H*-pyrrol-3-yl)benzonitrile (8f)
After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 6:1), colorless crystals, mp 137 °C (EtOH).

IR (KBr): 2223 (s), 1604 (s), 1508 (w), 1496 (w), 1486 (w), 1467 (w), 1452 (m), 1342 (m), 844 (m), 806 (w), 756 (s), 731 (m), 700 (s), 558 (m), 516 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 5.08 (s, 2 H), 6.58 (s, 1 H), 6.62–6.67 (m, 2 H), 7.09–7.43 (m, 17 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 48.5 (CH_2), 108.0 (C_{quat}), 109.1 (CH), 119.5 (C_{quat}), 121.5 (C_{quat}), 126.0 (CH), 127.0 (CH), 127.6 (CH), 127.6 (CH), 128.3 (CH), 128.3 (CH), 128.5 (CH), 128.7 (CH), 129.1 (CH), 131.1 (CH), 131.9 (CH), 132.4 (C_{quat}), 132.9 (C_{quat}), 133.6 (C_{quat}), 136.2 (C_{quat}), 138.6 (C_{quat}), 141.1 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 410 ($[M]^+$, 100), 319 ($[M - benzyl]^+$, 99), 91 ($[benzyl]^+$, 20).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 277 (22600), 318 nm (17000).

Fluorescence ($CHCl_3$): λ_{max} = 428 nm.

Anal. Calcd for $C_{30}H_{22}N_2$ (410.5): C, 87.77; H, 5.40; N, 6.82. Found: C, 87.36; H, 4.45; N, 6.82.

4-[1-Benzyl-2-(2-furyl)-5-phenyl-1*H*-pyrrol-3-yl]benzonitrile (8g)
After an aqueous workup and extraction with Et_2O and purification by chromatography on silica gel (hexane–EtOAc 6:1), colorless crystals, mp 104–105 °C (EtOH, low decomp. in air).

IR (KBr): 3062 (w), 3030 (w), 2224 (s), 1605 (s), 1508 (w), 1496 (w), 1454 (m), 1350 (m), 1179 (m), 1007 (w), 946 (w), 894 (w), 841 (m), 761 (s), 732 (m), 700 (s), 552 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 5.14 (s, 2 H), 6.15 (d, *J* = 3.1 Hz, 1 H), 6.36 (dd, *J* = 1.8 Hz, *J* = 3.2 Hz, 1 H), 6.55 (s, 1 H), 6.81–6.84 (m, 2 H), 7.18–7.25 (m, 3 H), 7.31–7.36 (m, 7 H), 7.43 (d, *J* = 1.4 Hz, 1 H), 7.50 (d, *J* = 8.4 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 48.9 (CH_2), 108.8 (C_{quat}), 109.2 (CH), 111.2 (CH), 112.1 (CH), 119.4 (C_{quat}), 122.3 (C_{quat}), 124.6 (C_{quat}), 125.9 (CH), 127.1 (CH), 127.6 (CH), 127.9 (CH), 128.5 (CH), 128.5 (CH), 129.1 (CH), 132.1 (CH), 132.5 (C_{quat}), 137.4 (C_{quat}), 138.6 (C_{quat}), 140.6 (C_{quat}), 143.0 (CH), 145.1 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 400 ($[M]^+$, 86), 309 ($[M - C_6H_5CH_2]^+$, 100), 281 (21), 91 ($[C_6H_5CH_2]^+$, 32).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 275 nm (30200).

Fluorescence ($CHCl_3$): λ_{max} = 446 nm.

Anal. Calcd for $C_{28}H_{20}N_2O$ (400.5): C, 83.98; H, 5.03; N, 7.00. Found: C, 83.88; H, 4.96; N, 6.97.

Ethyl [3-(4-Cyanophenyl)-2,5-diphenyl-1*H*-pyrrol-1-yl]acetate (8h)

After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 6:1), colorless solid, mp 108–109 °C (isopropanol).

IR (KBr): 2223 (s), 1750 (s), 1605 (s), 1508 (w), 1486 (w), 1469 (w), 1448 (w), 1375 (w), 1350 (w), 1206 (s), 1180 (m), 1028 (w), 846 (w), 806 (w), 761 (m), 702 (s), 555 (m), 517 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.13 (t, *J* = 7.1 Hz, 3 H), 4.08 (q, *J* = 7.2 Hz, 2 H), 4.44 (s, 2 H), 6.55 (s, 1 H), 7.26–7.33 (m, 5 H), 7.35–7.46 (m, 9 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.1 (CH_3), 47.2 (CH_2), 61.5 (CH_2), 108.3 (C_{quat}), 108.9 (CH), 119.5 (C_{quat}), 121.4 (C_{quat}), 127.7 (CH), 127.9 (CH) 128.7 (CH), 128.7 (CH), 129.1 (CH), 129.2 (CH), 131.1 (CH), 132.0 (CH), 132.1 (C_{quat}), 132.5 (C_{quat}), 133.5 (C_{quat}), 136.3 (C_{quat}), 141.0 (C_{quat}), 169.3 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 406 ($[M]^+$, 100), 333 ($[M – COOEt]^+$, 40).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 273 (25000), 314 nm (19500).

Fluorescence ($CHCl_3$): λ_{max} = 427 nm.

Anal. Calcd for $C_{27}H_{22}N_2O_2$ (406.5): C, 79.78; H, 5.46; N, 6.89. Found: C, 79.48; H, 5.37; N, 6.82.

***rac*-2-[3-(4-Cyanophenyl)-2-(2,6-dimethylhept-5-en-1-yl)-5-phenyl-1*H*-pyrrol-1-yl]acetamide (8i)**

After an aqueous workup and extraction with EtOAc and purification by chromatography on silica gel (hexane–EtOAc 3:1), colorless solid, mp 111–113 °C (isopropanol).

IR (KBr): 2959 (w), 2924 (w), 2225 (m), 1681 (s), 1604 (s), 1449 (w), 1178 (w), 846 (w), 762 (w), 702 (w), 573 (w) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 0.77 (d, *J* = 6.6 Hz, 3 H), 1.06–1.35 (m, 2 H), 1.54 (s, 3 H), 1.65 (s, 3 H), 1.57–1.68 (m, 1 H), 1.85–1.96 (m, 2 H), 2.60 (dd, *J* = 8.6, 15.2 Hz, 1 H), 2.77 (dd, *J* = 6.4, 15.2 Hz, 1 H), 4.61 (s, 2 H), 4.94 (t, *J* = 7.0 Hz, 1 H), 5.33 (br s, 1 H), 5.78 (br s, 1 H), 6.38 (s, 1 H), 7.33–7.45 (m, 5 H), 7.52 (d, *J* = 8.5 Hz, 2 H), 7.64 (d, *J* = 8.5 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 17.5 (CH_3), 19.2 (CH_3), 25.2 (CH_2), 25.5 (CH_3), 32.1 (CH_2), 33.4 (CH), 36.6 (CH_2), 48.0 (CH_2), 108.9 (C_{quat}), 110.1 (CH), 119.0 (C_{quat}), 122.8 (C_{quat}), 123.8 (CH), 127.8 (CH), 128.3 (CH), 128.7 (CH), 128.7 (CH), 130.9 (C_{quat}), 131.6 (C_{quat}), 131.7 (C_{quat}), 132.1 (CH), 134.8 (C_{quat}), 141.7 (C_{quat}), 171.0 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 425 (M^+, 65), 314 ($[M – CH_3(CH_3)C{=}CHCH_2CH_2CHCH_3]^+$, 100), 269 ($[M – CH_2CONH_2$, $–CH_3$, $–CH_3(CH_3)C{=}CHCH_2CH_2]^+$, 23), 257 ([2-methyl-3-(4-cyanophenyl)-5-phenylpyrrole]$^+$, 24).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 246 (24000), 266 (15500), 312 nm (9900).

Fluorescence ($CHCl_3$): λ_{max} = 401 nm.

Anal. Calcd for $C_{28}H_{31}N_3O$ (330.4): C, 79.02; H, 7.34; N, 9.87. Found: C, 78.89; H, 7.35; N, 9.78.

2-[3-(4-Cyanophenyl)-2,5-diphenyl-1*H*-pyrrol-1-yl]ethyl Acetate (8j)

After an aqueous workup and extraction with Et_2O and purification by chromatography on silica gel (hexane–EtOAc 4:1), colorless solid, mp 151–153 °C (EtOH).

IR (KBr): 3060 (w), 2962 (w), 2219 (s), 1740 (s), 1603 (s), 1532 (w), 1507 (w), 1487 (m), 1468 (m), 1379 (w), 1367 (w), 1342 (m), 1225 (s), 1064 (w), 1048 (m), 846 (m), 766 (s), 701 (s), 560 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 1.76 (s, 3 H), 3.76 (t, *J* = 5.7 Hz, 2 H), 4.22 (t, *J* = 5.7 Hz, 2 H), 6.48 (s, 1 H), 7.22 (d, *J* = 8.5 Hz, 2 H), 7.33–7.51 (m, 12 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 21.0 (CH_3), 43.8 (CH), 63.5 (CH), 108.6 (C_{quat}), 110.0 (CH), 119.9 (C_{quat}), 122.1 (C_{quat}), 128.1 (CH), 128.1 (CH), 129.0 (CH), 129.1 (CH), 129.5 (CH), 129.6 (CH), 131.5 (CH), 132.3 (CH), 132.6 (C_{quat}), 133.3 (C_{quat}), 133.7 (C_{quat}), 136.5 (C_{quat}), 141.4 (C_{quat}), 170.7 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 406 ($[M]^+$, 100), 333 ($[M – CH_3COOCH_2]^+$, 18), 320 ([3-cyanophenyl-2,5-diphenyl pyrrole]$^+$, 15), 87 ($[CH_3COOCH_2CH_2]^+$, 22).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 272 nm (21100).

Fluorescence ($CHCl_3$): λ_{max} = 418 nm.

Anal. Calcd for $C_{27}H_{22}N_2O_2$ (406.5): C, 79.78; H, 5.46; N, 6.89. Found: C, 79.64; H, 5.22; N, 6.83.

4-(1-Isopropyl-2-pentyl-5-phenyl-1*H*-pyrrol-3-yl)benzonitrile (8k)

After an aqueous workup and extraction with EtOAc and trituration with EtOH, colorless solid, mp 129 °C (EtOH).

IR (KBr): 2959 (s), 2931 (s), 2869 (w), 2222 (s), 1603 (s), 1528 (w), 1468 (w), 1370 (w), 1356 (m), 1270 (w), 1174 (w), 1074 (w), 742 (m), 787 (w), 773 (m), 704 (m), 558 (m) cm^{-1}.

^1H NMR ($CDCl_3$, 300 MHz): δ = 0.88 (t, *J* = 6.9 Hz, 3 H), 1.29–1.37 (m, 4 H), 1.42 (d, *J* = 7.1 Hz, 6 H), 1.53–1.63 (m, 2 H), 2.82–2.87 (m, 2 H), 4.53 (sept, *J* = 7.1 Hz, 1 H), 7.37–7.40 (m, 6 H), 7.50 (d, *J* = 8.6 Hz, 2 H), 7.62 (d, *J* = 8.6 Hz, 2 H).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 14.4 (CH_3), 22.6 (CH_2), 23.8 (CH_3), 26.6 (CH_2), 30.8 (CH_2), 32.4 (CH_2), 48.8 (CH), 108.4 (C_{quat}), 110.1 (CH), 120.0 (C_{quat}), 120.8 (C_{quat}), 127.9 (CH), 128.3 (CH), 128.4 (CH), 130.8 (CH), 132.1 (C_{quat}), 132.5 (CH), 134.5 (C_{quat}), 135.1 (C_{quat}), 143.1 (C_{quat}).

MS (70 eV, EI) *m/z* (%): 356 ($[M]^+$, 45), 299 ($[M – C_4H_9]^+$, 100), 257 ($[M – C_4H_9, – C_3H_6]^+$, 76).

UV/Vis ($CHCl_3$): λ_{max} (ε) = 273 (16600), 327 nm (13900).

Fluorescence ($CHCl_3$): λ_{max} = 425 nm.

Anal. Calcd for $C_{25}H_{28}N_2$ (356.5): C, 84.23; H, 7.92; N, 7.86. Found: C, 84.55; H, 7.89; N, 7.93.

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