Journal of Fluorine Chemistry 242 (2021) 109720

Contents lists available at ScienceDirect

Journal of Fluorine Chemistry

journal homepage: www.elsevier.com/locate/fluor

Synthesis of polyfluorinated 4-hydroxyquinolin-2(1*H*)-ones based on the cyclization of 2-alkynylanilines with carbon dioxide

Larisa Politanskaya [a,*], Evgeny Tretyakov [a,b], Chanjuan Xi [c]

[a] N.N. Vorozhtsov Novosibirsk Institute of Organic Chemistry, Siberian Branch of Russian Academy of Sciences, Ac. Lavrentiev Ave., 9, Novosibirsk, 630090, Russia
[b] Novosibirsk State University, Pirogova Street, 2, Novosibirsk, 630090, Russia
[c] MOE Key Laboratory of Bioorganic Phosphorus Chemistry&Chemical Biology, Department of Chemistry, Tsinghua University, Beijing, 100084, China

ARTICLE INFO

Keywords:
Polyfluorinated alkynylanilines
Polyfluorinated heterocycles
Carbon dioxide incorporation
Intermolecular heterocyclization reaction

ABSTRACT

Convenient and efficient synthesis of polyfluorinated 4-hydroxyquinolin-2(1*H*)-ones from the corresponding *o*-alkynylaniline derivatives and CO_2 (1 atm), mediated by 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) and $AgNO_3$ in acetonitrile was performed. This synthetic methodology may be used to prepare fluorinated heterocycles containing peripheral alkynyl and amino groups but is not suitable for silylethynyl derivatives that give indoles as the main products. The reaction takes place under mild conditions (60 °C) and involves readily available starting materials that include cheap and renewable carbon dioxide.

1. Introduction

Fluorine-containing compounds are of great interest in organic chemistry in that they have found a wide range of applications in pharmaceuticals, medicine, agrochemicals and material science [1]. Due to fluorine atom has high electronegativity and a small atomic radius, introducing a fluorine atom or fluoride group into functional molecules tends to change chemical, physical, and physiologic properties (such as metabolic stability and fat) of the parent molecule [2]. Much effort of researchers is aimed at finding new synthetic strategies for fluorine incorporation into organic molecules. The objective of our study was to find universal and efficient approaches to the synthesis of new fluorinated benzoheterocycles [3]. Today a large number of fluorinated bioactive heterocycles are known [4]. A special place among them belongs to fluoroquinolones [5–7]. Numerous representatives of biologically active compounds have also been found among 4-hydroxyquinolin-2(1*H*)-one derivatives (Fig. 1); furthermore, some of them have been isolated from natural products [8,9]. In particular, 4-hydroxyquinolin-2(1*H*)-ones have been reported to be selective 5-HT_3 [10] and GnRH [11] receptor antagonists and NMDA [12–16] and HIV [9] inhibitors. Besides some representatives of this class of compounds possess antimicrobial [16,17], antibacterial [8,17–19], anticancer [7], antifungal [16–18], antimalarial [16], molluscicidal [20], antiparasitic [21], antioxidant [18] and antiallergic [22] activities.

Because of the importance of 4-hydroxyquinolin-2(1*H*)-one derivatives, efficient synthesis of these compounds has attracted much attention. Various approaches to obtaining this class of compounds are known today, e.g., the synthesis from *o*-X-substituted anilines (X = H [7,23,24], COOMe [11,14,15], COMe [25]) or their congeners [22,26], from 4-cloroquinolin-2(1*H*)-one or 3-bromoquinolin-4(1*H*)-one [27], and from 2-methyl-3,1-benzoxazin-4-ones [28,29].

An alternative method of 4-hydroxyquinolin-2(1*H*)-one synthesis is based on the 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) – promoted intramolecular rearrangement reaction of 2-alkynylanilines with carbon dioxide in DMSO in the presence of $AgNO_3$ [30] or CuI [31]. We were inspired by this highly efficient and convenient synthetic method because the fixation of carbon dioxide into valuable organic compounds is an environmentally friendly and sustainable process [32] and CO_2 is an economical, renewable, noncorrosive, inflammable and nontoxic carbon source [33]. Moreover, chemical utilization of carbon dioxide could also help to reduce its concentration in the atmosphere, since it is assumed that the increasing levels of CO_2 has a detrimental effect on the climate and is the major contributing factor to recent global warmingehe [34].

In present work we investigated the synthetic usefulness of carbon dioxide incorporation into polyfluorinated *o*-alkynylanilines to obtain new potentially biologically active fluorine-contained 4-hydroxyquinolin-2(1*H*)-ones.

* Corresponding author.
E-mail address: plv@nioch.nsc.ru (L. Politanskaya).

https://doi.org/10.1016/j.jfluchem.2020.109720
Received 12 November 2020; Received in revised form 23 December 2020; Accepted 26 December 2020
Available online 31 December 2020

2. Results and discussion

Given that CO_2 is highly thermodynamically and kinetically stable, organic reactions with CO_2 usually require a relatively high-energy reactant and transition metal catalysts [35]. The application of catalysts that can activate CO_2 or starting materials and accelerate the reaction by lowering the energy barrier of the transition state is the key to implementing a thermodynamically favored reaction. It is well known that carbon dioxide easily combines with amines at ambient temperature and atmospheric pressure to produce carbamic acids [36].

Comparing synthetic methods for obtaining of 4-hydroxyquinolin-2(1*H*)-one based on the cyclization of *o*-alkynylanilines with carbon dioxide [30,31], we chose the method developed by Yamada and co-authors, in which the conversion of reagents is carried out at atmospheric pressure of CO_2 owing to silver salt catalysis [30]. It should be noted that there are other examples of the interaction of *o*-alkynylanilines with carbon dioxide, leading to the heterocyclic products, for example, palladium-catalyzed multicomponent reactions between *o*-alkynylanilines, aryl iodides and atmospheric pressure of CO_2, giving a number of 3,3-diaryl 2,4-quinolinediones [37].

As starting materials, we used polyfluorinated *o*-alkynylaniline **1a**–**i** synthesized according to previously described methods [35,39,40]. *o*-Alkynylaniline **1j** was obtained by cross-coupling of 3,6-difluoro-2,4-diiodoaniline [40] with terminal alkynes under Sonogashira conditions: bis(triphenylphosphine) palladium dichloride (8 mol.%), copper(I) iodide (18 mol.%) and triethylamine as catalysts in dry MeCN as a solvent (Scheme 1). The reaction was carried out at 60 °C in a tightly closed Schlenk flask in an argon atmosphere for 4 h.

Silylethynyl derivatives **1n** and trimethyl((perfluorophenyl)ethynyl) silane (**4**) [42] were synthesized under similar but milder reaction conditions (Scheme 2).

The synthesis of *p*-alkynylaniline **1k** was based on transformations of **4** (Scheme 3). The action of K_2CO_3 in MeOH led not only to the removal of the TMS group but also to nucleophilic substitution of the *p*-fluorine atom on the aromatic ring of the polyfluorinated substrate. The relatively low yield of 1-ethynyl-2,3,5,6-tetrafluoro-4-methoxybenzene (**5**) is due to the high volatility of this compound. Next, the resulting ethynyl derivative was reacted with 2,3,4-trifluoro-6-iodoaniline [3c] under Sonogashira reaction conditions (Scheme 3).

In accordance with the purpose of our work, the obtained fluorinated *o*-alkynylanilines **1** were next subjected to the interaction with carbon dioxide in the presence of DBU and $AgNO_3$. The reaction was allowed to proceed in CO_2 atmosphere (at normal pressure) in MeCN at 60 °C in a Schlenk apparatus for 25 h, and the results are summarized in Table 1.

The analysis of data in Table 1 indicates that most of the polyfluorinated *o*-alkynylanilines reacted smoothly with carbon dioxide in the presence of DBU and $AgNO_3$, thereby giving rise to the cyclized products (4-hydroxyquinolin-2(1*H*)-ones **2**) in 80–92% yields (entries

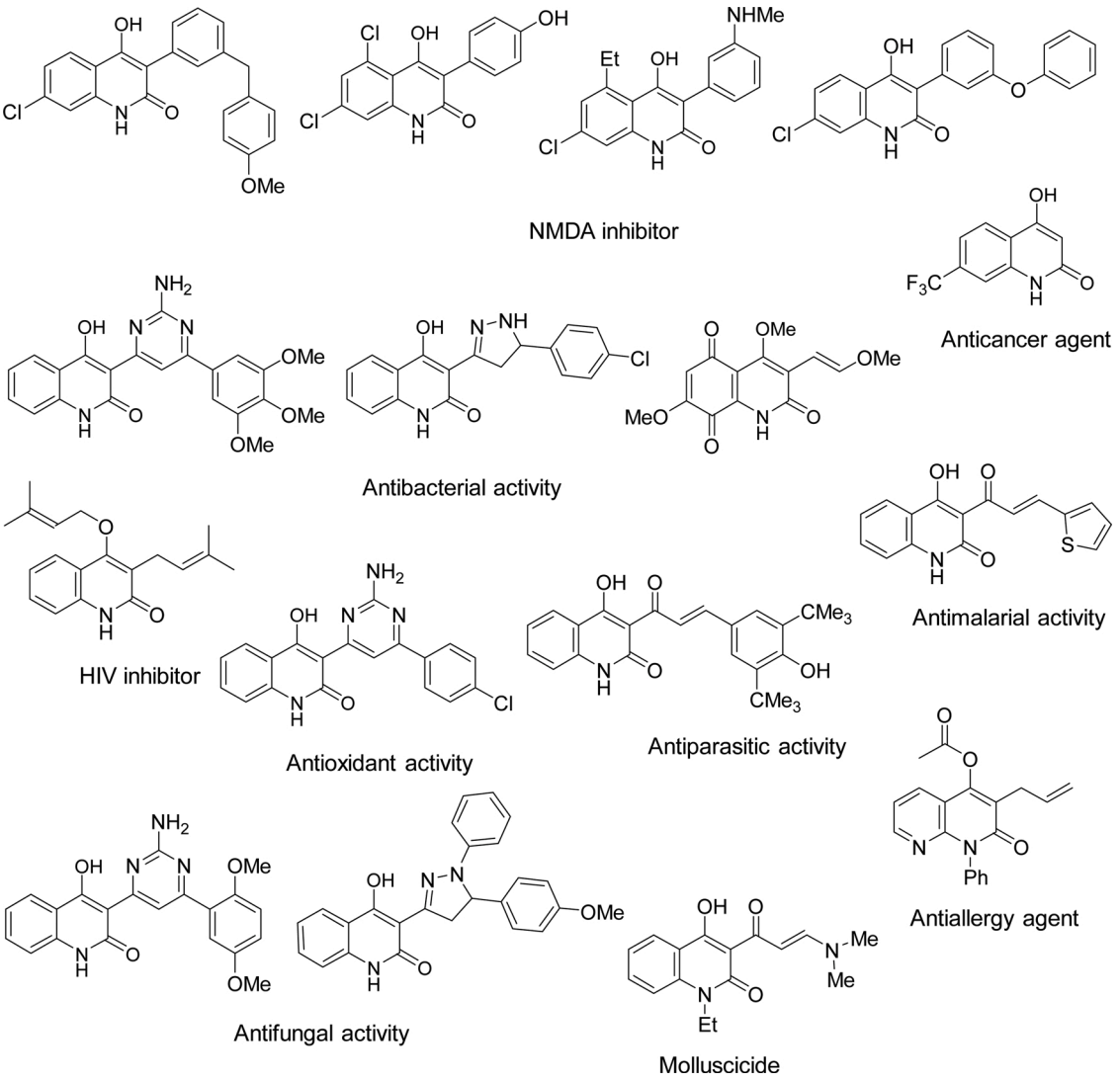
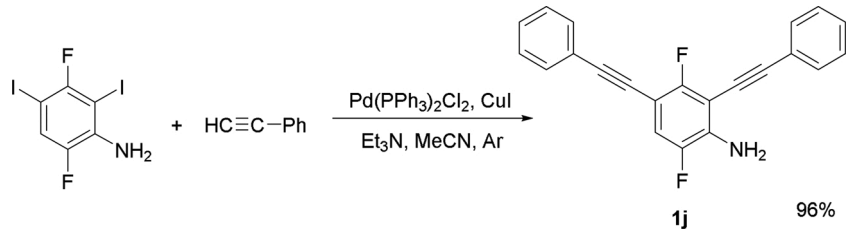
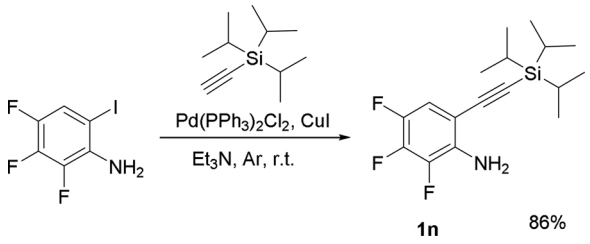


Fig. 1. Examples of some biologically active 4-hydroxyquinolin-2(1*H*)-ones.



Scheme 1. Synthesis of fluorinated alkynylaniline **1 j**.



Scheme 2. Synthesis of fluorinated alkynylaniline **1n**.

1–5, 10, 11 in Table 1).

The newly developed procedure for isolation of the target reaction products includes dilution of the reaction mixture with 1 M aqueous NaOH and subsequent obligatory filtration of the resulting solution through a dense paper filter under normal pressure. This procedure was used for mechanical removal of catalyst residues and of contamination with the initial compounds, which stayed on the surface of the paper in film form. Then, the filtered solution was acidified with 2 M HCl (aqueous solution), and the precipitate was separated and dried in vacuum to a constant weight. These manipulations allowed to obtain polyfluorinated 4-hydroxyquinolin-2(1*H*)-ones in pure form without additional purification such as extraction (compare with [30]). This is important, given the extremely low solubility of polyfluorinated compounds **2**.

Alkynes **1a**–**f**, **1j**, **1k,** containing an aromatic substituent at the triple bond give reaction products in a higher yield than do those with an aliphatic *n*-Bu moiety. The presence of fluorine atoms and electron-donating groups (OMe, NH_2) in the aromatic part at a triple bond does not significantly affect the course of the reaction, and the yields of the corresponding 4-hydroxyquinolin-2(1*H*)-ones in these cases are comparable to those for Ph-substituted substrates (entries 3 and 11, 1 and 5 in Table 1). It was found that the additional triple bond located at a distance from the reaction center of the molecule **1j** remained unchanged in the reaction product **2j** (entry 10, Table 1).

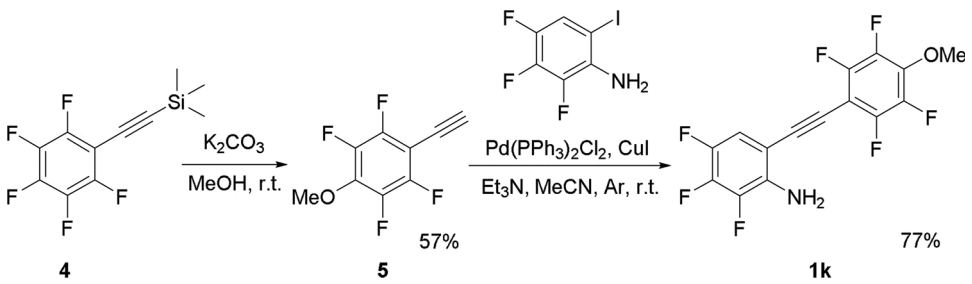
Our analysis of the experimental and literature data [30,31] allows us to interpret the mechanism of interaction of polyfluorinated *o*-alkynylanilines **1** with CO_2 in the presence of DBU and transition metal catalysts (M) as follows in Scheme 4.

Activated by the action of DBU the amino group of the substrate (**A**) interacts with the CO_2 molecule. In this reaction, one of the C═O bond in CO_2 must be broken to form carbamic acid (**B**). Next, by action of the transition metal (M), the triple C≡C bond is transformed, and a cyclic transition state (**C**) is formed, similar to that previously assumed for the reaction of 2-aminobenzonitrile and CO_2 in the presence of $[WO_4]^{2-}$ [42]. It should be noted that the interaction of *N*-alkyl substituted derivatives of *o*-alkynylanilines with CO_2 under similar conditions (M = $AgNO_3$) stopped at the stage of the corresponding benzoxazine-2-ones formation, which were the final reaction products [43]. In contrast, the DBU-promoted cleavage of N–H bond in the intermediate **C** produced the heterocyclic structure **D**, which is then transformed into an isocyanate derivative **E** via breaking the single C–O bond. The resulting enol product **F** undergoes an intramolecular cyclization reaction to form a quinoline-2,4-diol (**G**), which is next transformed into a thermodynamically more stable final product – 4-hydroxyquinolin-2(1*H*)-one **2.**

It is noteworthy that in none of our reactions of polyfluorinated anilines with CO_2 in the presence of DBU, were the products detectable that correspond to nucleophilic substitution of the fluorine atom at *o*-positions relative to the amino group (**H**). Such transformations were observed previously in reactions of polyfluorinated anilines and hydrazines with CS_2 in the presence of DBU. The reaction products were the respective polyfluorinated benzothiazolethione [3e,44]. The reaction with CS_2 proceeded via a nucleophilic attack on the carbon atom of CS_2 by the nitrogen atom of the NH_2 group in an arene followed by selective intramolecular fluorine atom substitution at the *o*-position toward the amino group. Nonetheless, as our experiments showed, the nucleophilic activity of O^- is not sufficient (in comparison with S^-) for such a transformation in the reaction of polyfluorinated anilines with CO_2, at least when the reaction is carried out under normal CO_2 pressure.

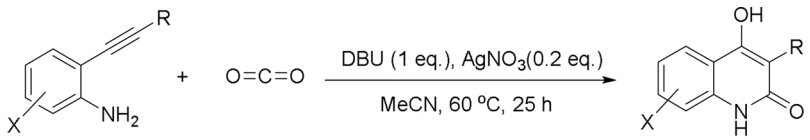
The maintaining of 2,3,5-trifluoro-6-(phenylethynyl)-4-(trifluoromethyl)aniline [38] under standard reaction conditions led to the formation of indole **3a** (Scheme 5). Apparently, due to the strong acceptor effect of the *p*-trifluoromethyl group (in combination with that of the four fluorine atoms present on the ring), the amino group of substrates could not interact effectively with the CO_2 molecule to form a carbamic acid (structure **B** in Scheme 4). Nevertheless, by action of a transition metal catalyst, the triple bond was transformed, which led to the closure of the pyrrole heterocycle as a result of an intramolecular reaction (product **3**, Scheme 4) [3a].

A similar indole skeleton **3b** [45] was detected after the interaction of silylethynyl derivatives **1m** and **1n** with $AgNO_3$ in presence of DBU

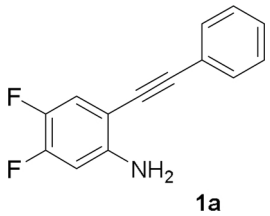
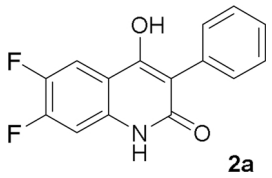
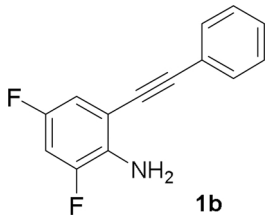
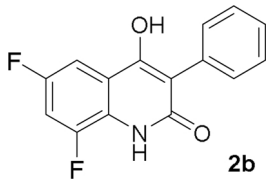
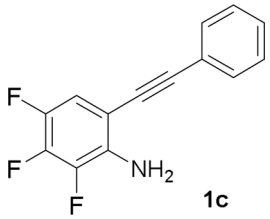
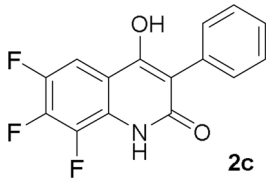
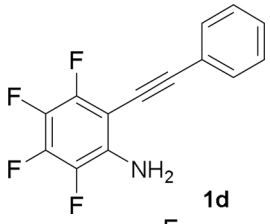
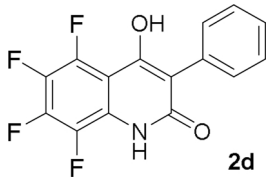
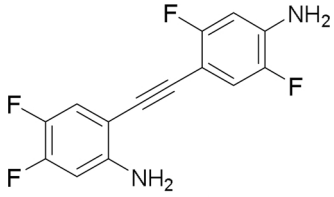
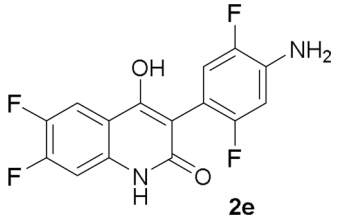
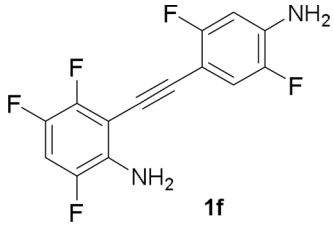
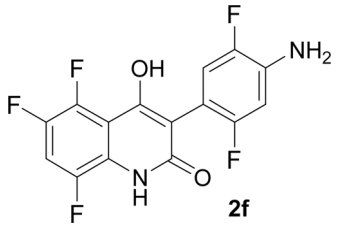
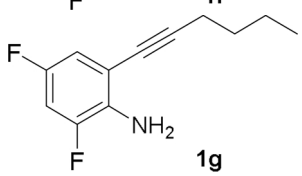
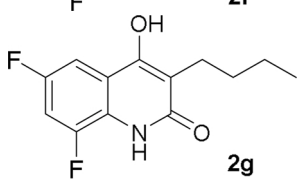


Scheme 3. Synthesis of fluorinated *o*-alkynylaniline **1k**.

Table 1
Synthesis of fluorinated 4-hydroxyquinolin-2(1*H*)-one derivatives.

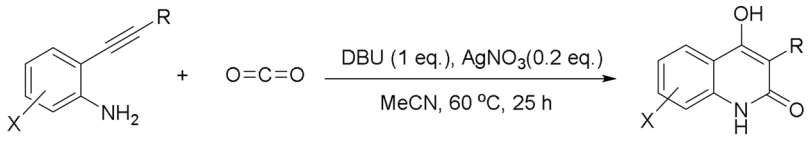


1 **2**

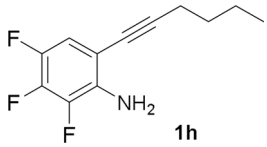
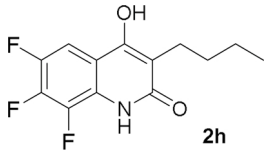
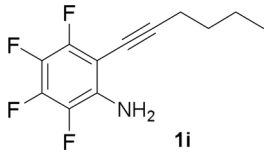
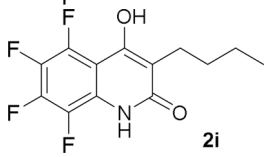
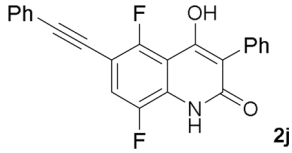
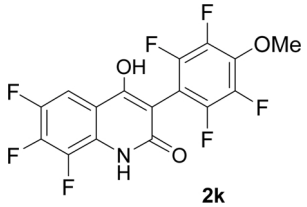
Entry	Substrate **1**	Product	Yield (%)
1	 **1a**	 **2a**	80
2	 **1b**	 **2b**	92
3	 **1c**	 **2c**	85
4	 **1d**	 **2d**	91
5	 **1e**	 **2e**	87
6	 **1f**	 **2f**	57
7	 **1g**	 **2g**	60
8			78

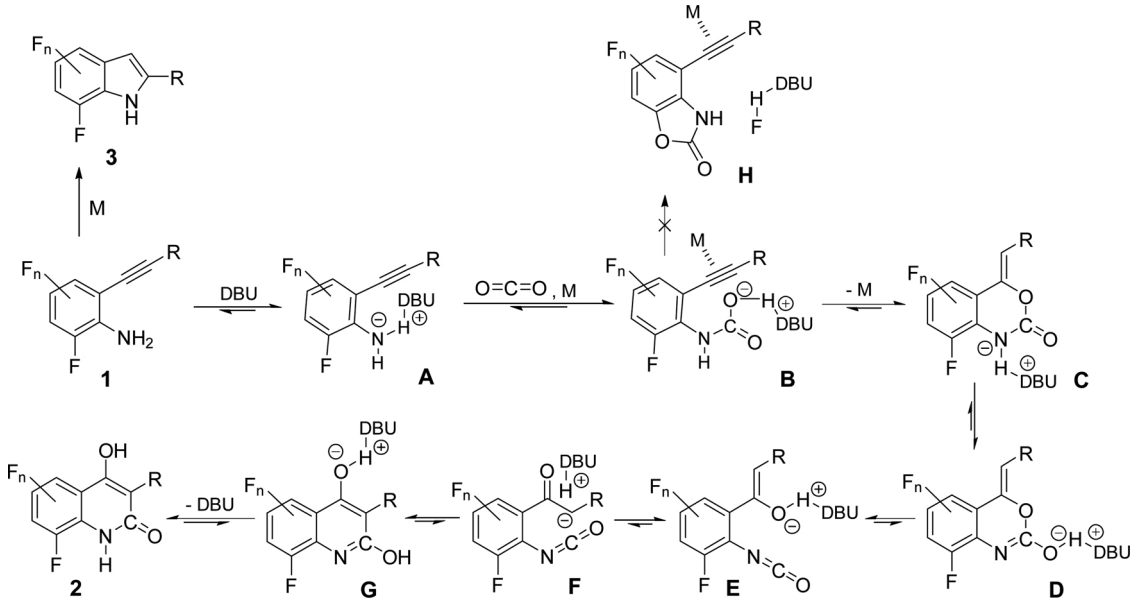
(*continued on next page*)

Table 1 (*continued*)



1 **2**

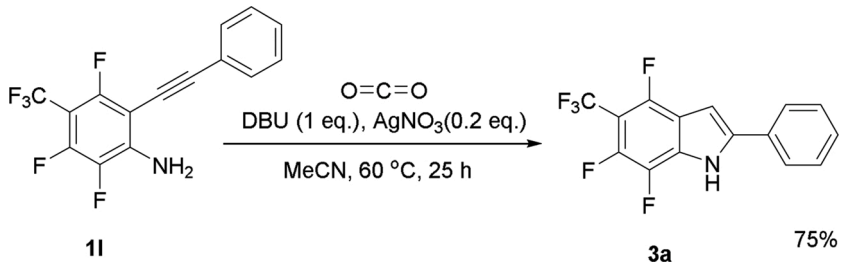
Entry	Substrate **1**	Product	Yield (%)
9	 **1h**	 **2h**	25
	 **1i**	 **2i**	
10	**1 j**	 **2j**	90
11	**1k**	 **2k**	82



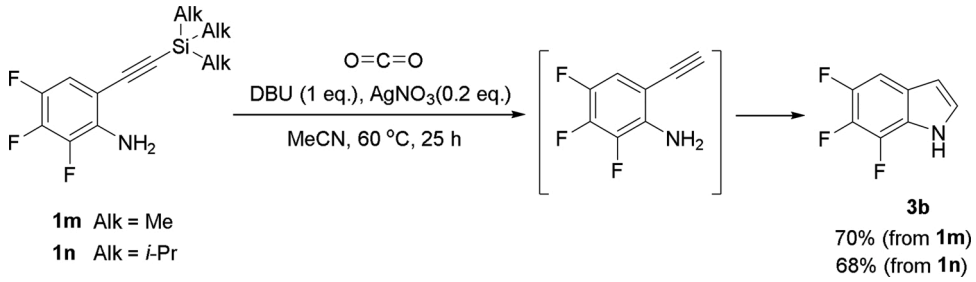
Scheme 4. The mechanism proposed for the DBU and transition metal (M) catalyzed reaction of polyfluorinated *o*-alkynylaniline **1** with carbon dioxide.

and CO_2 (Scheme 6). Apparently, 6-ethynyl-2,3,4-trifluoroaniline [45] was formed by action of the base (DBU) at the first stage of the reaction in both cases. This mechanism follows from the finding that the yield of the reaction product does not depend on the nature of the alkyl moieties in the substituent at the triple bond (TMS or TIPS). After that, the transformation typical for polyfluorinated *o*-alkynylanilines was carried out in the presence of transition metal salts, namely, cyclization to the indole.

Thus, polyfluorinated *o*-alkynylanilines reacted with $AgNO_3$ in the presence of DBU and CO_2 to produce heterocyclic products. In most cases, 4-hydroxyquinolin-2(1*H*)-ones are formed, i.e., products of incorporation of the CO_2 molecule into the heterocycle. On the other hand, polyfluorinated *o*-[(trialkylsilyl)ethynyl]anilines give rise to indoles unsubstituted on the pyrrole ring: the result of an intramolecular



Scheme 5. Synthesis of fluorinated indole **3a**.



Scheme 6. Synthesis of fluorinated indole **3b**.

cyclization reaction. The direction of the reaction is influenced not only by the substituent at the triple bond but also by the combined effect of the substituents on the aromatic ring of polyfluorinated substrates.

3. Conclusion

We demonstrated the possibility of a simple and efficient $AgNO_3$- and DBU-promoted *one-pot* transformation of polyfluorinated *o*-alkynylanilines into 4-hydroxyquinolin-2(1*H*)-one derivatives via an interaction with CO_2 in MeCN. The protocol involves utilization of simple and readily available starting materials and affords the corresponding polyfluorinated heterocycles under mild conditions (1 atm) in good yields. Polyfluorinated TIPS- and TMS-acetylene derivatives are transformed into indoles unsubstituted at position 2. Therefore, this work can be useful for researchers interesting in preparing and studying of fluorinated analogs of biologically active 4-hydroxyquinolin-2(1*H*)-ones.

4. Experimental section

4.1. General

All solvents were purified by standard procedures. Acetonitrile and triethylamine were kept over CaH_2 before use. The starting materials were synthesized according to previously described methods [3c,40–43,45]. Other chemicals were obtained from commercial sources and were used without further purification. Preparative TLC was performed on Merck precoated silica gel 60 PF_{254} containing gypsum. Visualization of the developed chromatograms was performed by means of UV light.

NMR spectra were recorded on Bruker Avance-300 (300.13 MHz for ^{1}H and 282.37 MHz for ^{19}F), Avance-400 (400.13 MHz for ^{1}H and 100.62 MHz for ^{13}C), and DRX-500 (500.13 MHz for ^{1}H, 125.76 MHz for ^{13}C) spectrometers. $CDCl_3$, Acetone-d_6 and DMSO-d_6 were served as solvents, with residual $CHCl_3$ ($\delta_H = 7.26$), $CDCl_3$ ($\delta_C = 77.0$) and acetone ($\delta_H = 2.15$), acetone-d_6 ($\delta_C = 28.6$ and 205.0) or DMSO-d_6 ($\delta_C = 39.5$) acting as internal standards, C_6F_6 ($\delta_F = 163.0$) was used as an external reference for recording ^{19}F NMR spectra. ^{13}C NMR spectra were recorded with C–H spin decoupling. Masses of molecular ions were determined by HRMS on a DFS Thermoscientific instrument (EI, 70 eV). Melting points were recorded on a Mettler-Toledo FP81 Thermosystem apparatus. The IR spectra were recorded on a Bruker Vector 22 spectrometer (KBr or thin film).

The structures of all new polyfluorinated compounds prepared here were corroborated by their ^{19}F, ^{1}H, and ^{13}C NMR spectroscopy, high-resolution mass spectrometry, and IR-spectroscopy data (see Supplementary data).

4.2. Synthetic procedures

4.2.1. 3,6-Difluoro-2,4-bis(phenylethynyl)aniline (1 j)

To a solution of 3,6-difluoro-2,4-diiodoaniline [40] (0.51 g, 1.34 mmol) and phenylacetylene (0.55 g, 5.39 mmol) in MeCN (15 mL) $Pd(PPh_3)_2Cl_2$ (73 mg, 0.10 mmol), CuI (45 mg, 0.24 mmol) and Et_3N (4 mL) were added in a Schlenk flask under argon. The reaction mixture was stirred at 60 °C for 6.5 h. Then, the mixture was placed directly onto a chromatography plate (silica gel) and air-dried. The alkynylaniline **1j** were isolated by TLC using EtOAc/hexane as the eluent.

White solid; yield: 0.42 g (96%); R_f = 0.80 (EtOAc/hexane, 1:10); mp 84.2–84.7 °C. IR (KBr): 3500, 3396, 3057, 3020, 2927, 2854, 2212, 1635, 1599, 1574, 1500, 1481, 1444, 1387, 1323, 1302, 1194, 1128, 1097, 1070, 1026, 904, 862, 756, 688, 567, 524, 503 cm^{-1}. ^{1}H NMR (300 MHz, Acetone-d_6): 7.68–7.64 (m, 2 H, H_m), 7.57–7.54 (m, 2 H, H'_m), 7.46–7.41 (m, 6 H, $H_o + H_p$), 7.23 (d, J (H^3,F^2) = 11.3 Hz, J (H^3,F^5) = 6.3 Hz, 1 H, H^3), 5.87 (br s, 2 H, NH_2). ^{13}C NMR (100 MHz, Acetone-d_6): δ = 159.5 (d, ^1J (C^5,F^5) = 248.7 Hz, C^5), 146.1 (d, ^1J (C^2,F^2) = 236.0 Hz, C^2), 140.0 (dd, ^2J (C^1,F^2) = 15.3 Hz, ^3J (C^1,F^5) = 3.9 Hz, C^1), 131.6 (s, C^{10}), 131.2 (s, $C^{10'}$), 129.0 (s, C^{12}), 128.6 (s, C^{11} + $C^{11'}$), 128.5 (s, $C^{12'}$), 123.1 (s, C^9), 122.6 (s, $C^{9'}$), 117.9 (d, ^2J (C^3,F^2) = 21.5 Hz, C^3), 100.1 (s, C^7), 97.8 (dd, ^2J (C^4,F^5) = 21.2 Hz, ^3J (C^4,F^2) = 6.2 Hz, C^4), 96.9 (dd, ^2J (C^6,F^5) = 18.2 Hz, ^3J (C^6,F^2) = 9.7 Hz, C^6), 92.3 (s, $C^{7'}$), 82.1 (s, C^8), 78.1 (s, $C^{8'}$). ^{19}F NMR (282 MHz, Acetone-d_6): δ = –110.6 (dd, J (F^5,F^2) = 14.1 Hz, J (F^5,H^3) = 6.3 Hz, 1 F, F^5), –137.8 (dd, J (F^2, F^5) = 14.1 Hz, J (F^2,H^3) = 11.3 Hz, 1 F, F^2). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{22}H_{13}F_2N$: 329.1011; found: 329.1007.

4.2.2. 2,3,4-Trifluoro-6-((triisopropylsilyl)ethynyl)aniline (1n)

To a solution of 2,3,4-trifluoro-6-iodoaniline [3c] (1.00 g, 3.66 mmol) and ethynyltriisopropylsilane (1.00 g, 5.50 mmol) in Et_3N (20 mL) $Pd(PPh_3)_2Cl_2$ (128 mg, 0.18 mmol) and CuI (70 mg, 0.36 mmol) were added in a Schlenk flask under argon. The reaction mixture was stirred at r. t. for 70 h. Then, the mixture was placed

directly onto a chromatography plate (silica gel) and air-dried. The alkynylaniline **1n** were isolated by TLC using hexane as the eluent.

Yellowish oil; yield: 1.03 g (86%); R_f = 0.68 (hexane). IR (thin): 3494, 3392, 2945, 2893, 2866, 2148, 1587, 1520, 1481, 1371, 1300, 1163, 1072, 1018, 997, 918, 883, 858, 733, 679, 567, 519, 472 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): 6.92 (m, J (H^3,F^4) = 10.4 Hz, J (H^3,F^5) = 7.7 Hz, J (H^3,F^6) = 2.3 Hz, 1 H, H^3), 4.20 (br s, 2 H, NH_2), 1.11–1.10 (m, 21 H, *i*-Pr). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 142.6 (ddd, ^1J (C^4,F^4) = 239.5 Hz, ^2J (C^4,F^5) = 10.8 Hz, C^4), 140.9 (ddd, ^1J (C^5,F^5) = 251.9 Hz, ^2J (C^5,F^4) = 16.5 Hz, ^2J (C^5,F^6) = 13.2 Hz, C^5), 139.8 (ddd, ^1J (C^6,F^6) = 242.5 Hz, ^2J (C^6,F^5) = 12.4 Hz, C^6), 134.8 (dm, ^2J (C^1,F^6) = 10.6 Hz, C^1), 114.1 (dd, ^2J (C^3,F^4) = 19.1 Hz, ^3J (C^3,F^5) = 3.5 Hz, C^3), 103.3 (m, C^2), 100.2 (m, C^7), 98.1 (m, C^8), 18.5 (s, C^9), 11.0 (s, C^{10}). ^{19}F NMR (282 MHz, $CDCl_3$): δ = –151.2 (dd, J (F^4,F^5) = 21.4 Hz, J (F^4,H^3) = 10.4 Hz, 1 F, F^4), –156.6 (dd, J (F^6,F^5) = 19.5 Hz, J (F^6,H^3) = 2.3 Hz, 1 F, F^6), –159.2 (m, J (F^5,F^4) = 21.4 Hz, J (F^5,F^6) = 19.5 Hz, J (F^5,H^3) = 7.7 Hz, 1 F, F^5). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{17}H_{24}F_3NSi$: 327.1625; found: 327.1623.

4.2.3. 1-Ethynyl-2,3,5,6-tetrafluoro-4-methoxybenzene (5)

To a solution of trimethyl((perfluorophenyl)ethynyl)silane [41] (0.72 g, 2.73 mmol) in MeOH (15 mL) K_2CO_3 (0.75 g, 5.43 mmol) was added. The reaction mixture was stirred at r. t. for 20 h, then placed directly onto a chromatography plate (silica gel), and air-dried. Ethynylarene **5** was isolated by TLC with hexane as the eluent.

White solid; yield: 0.32 g (57%); R_f = 0.45 (hexane); mp 55.7 °C (decomp.). IR (KBr): 3288, 2960, 2123, 1643, 1491, 1448, 1425, 1298, 1196, 1136, 983, 908, 704, 650, 420 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): 4.09 (s, 3 H, OCH_3), 3.51 (s, 1 H, CCH). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 148.0 (dddd, ^1J (C^2,F^2) = ^1J (C^6,F^6) = 252.4 Hz, ^2J (C^2,F^3) = ^2J (C^6,F^5) =13 Hz, C^2 + C^6), 140.3 (ddt, ^1J (C^3,F^3) = ^1J (C^5,F^5) = 247.3 Hz, ^2J (C^3,F^2) = ^2J (C^5,F^6) = 14.2 Hz, C^3 + C^5), 96.3 (t, ^2J (C^1,F^2) = ^2J (C^1,F^6) = 18.1 Hz, C^1), 88.3 (t, C^8), 68.5 (t, C^7), 62.0 (t, C^9). ^{19}F NMR (282 MHz, $CDCl_3$): δ = –136.0 (dm, J (F^2,F^3) = J (F^6,F^5) ≈ 23 Hz, 2 F, F^2 + F^6), –156.2 (dm, J (F^3,F^2) = J (F^5,F^6) ≈ 23 Hz, 2 F, F^3 + F^5). HRMS (EI): *m/z* $[M]^+$ calcd for $C_9H_4F_4$: 204.0193; found: 204.0196.

4.2.4. 2,3,4-Trifluoro-6-((2,3,5,6-tetrafluoro-4-methoxyphenyl)ethynyl) aniline (1k)

To a solution of 2,3,4-trifluoro-6-iodoaniline [3c] (0.27 g, 1.00 mmol) **5** (0.20 g, 1.00 mmol) in MeCN (10 mL) $Pd(PPh_3)_2Cl_2$ (35 mg, 0.05 mmol), CuI (19 mg, 0.10 mmol) and Et_3N (2 mL) were added in a Schlenk flask under argon. The reaction mixture was stirred at r. t. (30 °C) for 18 h. Then, the mixture was placed directly onto a chromatography plate (silica gel) and air-dried. The alkynylaniline **1k** were isolated by TLC using EtOAc/hexane as the eluent.

Yellowish solid; yield: 0.26 g (77%); R_f = 0.83 (EtOAc/hexane, 1:7, four times); mp 89.1–91.8 °C. IR (KBr): 3494, 3396, 2966, 2218, 1647, 1597, 1525, 1489, 1456, 1431, 1375, 1300, 1205, 1159, 1107, 1022, 985, 924, 860, 609 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): 7.00 (m, J (H^3,F^4) = 10.1 Hz, J (H^3,F^5) = 7.7 Hz, J (H^3,F^6) =2.3 Hz, 1 H, H^3), 4.12 (t, 3 H, OCH_3), 3.83 (br s, 2 H, NH_2). ^{13}C NMR (126 MHz, $CDCl_3$): δ = 146.8 (dddd, ^1J (C^{10},F^{10}) = ^1J (C^{14},F^{14}) = 251.2 Hz, ^2J (C^{10},F^{11}) = ^2J (C^{14},F^{13}) = 13.2 Hz, C^{10} + C^{14}), 142.9 (ddd, ^1J (C^4,F^4) =240.3 Hz, ^2J (C^4,F^5) = 11.0 Hz, C^4), 141.4 (ddd, ^1J (C^5,F^5) = 253.7 Hz, ^2J (C^5,F^4) = 16.7 Hz, ^2J (C^5,F^6) = 13.2 Hz, C^5), 140.6 (ddt, ^1J (C^{11},F^{11}) = ^1J (C^{13},F^{13}) = 252.4 Hz, ^2J (C^{11},F^{10}) = ^2J (C^{13},F^{14}) = 14.4 Hz, C^{11} + C^{13}), 139.7 (ddd, ^1J (C^6,F^6) = 243.1 Hz, ^2J (C^6,F^5) = 12.5 Hz, C^6), 139.2 (tm, ^2J (C^{12},F^{11}) = ^2J (C^{12},F^{13}) = 11.6 Hz, C^{12}), 134.9 (dm, ^2J (C^1,F^6) = 11.0 Hz, C^1), 113.7 (dd, ^2J (C^3,F^4) = 19.4 Hz, ^3J (C^3,F^5) = 3.5 Hz, C^3), 101.4 (m, C^2), 97.1 (t, ^2J (C^9,F^{10}) = ^2J (C^9,F^{14}) = 18.0 Hz, C^9), 93.8 (m, C^7), 80.7 (m, C^8), 62.1 (t, C^{15}). ^{19}F NMR (282 MHz, $CDCl_3$): δ = –136.2 (dm, J (F^{10}, F^{11}) = J (F^{14},F^{13}) ≈ 24 Hz, 2 F, F^{10} + F^{14}), –147.4 (dd, J (F^4,F^5) = 21.5 Hz, J (F^4,H^3) = 10.2 Hz, 1 F, F^4), –153.0 (dd, J (F^6,F^5) = 19.4 Hz, J (F^6,H^3) = 2.3 Hz, 1 F, F^6), –154.3 (m, J (F^5,F^4) = 21.4 Hz, J (F^5,F^6) = 19.4 Hz, J (F^5,H^3) = 7.7 Hz, 1 F, F^5), –155.9 (dm, J (F^{11},F^{10}) = J (F^{13}, F^{14}) ≈ 24 Hz, 2 F, F^{11} + F^{13}). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{15}H_6F_7NO$: 349.0332; found: 349.0324.

4.2.5. 4-Hydroxyquinolin-2(1 H)-ones 2; General Procedure

A 25 mL Schlenk flask containing a stir bar was purged with CO_2 from a balloon three times. A solution of substrate **1** (1.0 mmol) in MeCN (10 mL) and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) (152 mg, 1.0 mmol) were added in a Schlenk flask under CO_2 atmosphere. Then a bubbler was lowered into the resulting solution in a Schlenk flask and CO_2 was bubbled with intensive stirring at r. t. for 15 min. After that, the bubbler was removed, $AgNO_3$ (74 mg, 0.2 mmol) was added, and the reaction vessel was quickly and tightly closed. The reaction mixture was stirred at 60 °C for 25 h. Then 1 M aqueous NaOH (3 × 15 mL) was added in a Schlenk flask, reaction flack was closed again and shaken intensely. The combined aqueous extract was filtered through a dense paper under normal pressure and acidified with 2 M aqueous HCl (~5 mL). After cooling at 5 °C for 2 h the precipitate was separated, washed with H_2O (10 mL) and dried in vacuum to a constant weight.

4.2.5.1. 6,7-Difluoro-4-hydroxy-3-phenylquinolin-2(1 H)-one (2a).

White solid; yield: 218 mg (80%); mp undefined (decomp. without melting). IR (KBr): 3082, 2926, 2860, 1653, 1616, 1523, 1454, 1370, 1352, 1300, 1269, 1250, 1186, 1171, 1097, 885, 791, 779, 750, 704, 694, 580, 540, 509 cm^{-1}. ^1H NMR (500 MHz, DMSO-d_6): δ = 11.57 (s, 1 H, H^1), 10.35 (s, 1 H, H^4), 7.91 (dd, J (H^5,F^6) = 11.6 Hz, J (H^5,F^7) = 8.6 Hz, 1 H, H^5), 7.41 – 7.30 (m, 5 H, 2 H_m + 2 H_o + H_p), 7.23 (dd, J (H^8, F^7) = 11.4 Hz, J (H^8,F^6) = 7.1 Hz, 1 H, H^8). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 162.5 (s, C^2), 156.3 (s, C^4), 151.0 (dd, ^1J (C^7,F^7) = 249.5 Hz, ^2J (C^7,F^6) = 14.7 Hz, C^7), 144.7 (dd, ^1J (C^6,F^6) = 240.2 Hz, ^2J (C^6,F^7) = 13.8 Hz, C^6), 135.1 (d, ^3J (C^{8a},F^7) = 9.9 Hz, C^{8a}), 132.7 (s, C^9), 131.0 (s, C^{10}), 127.6 (s, C^{11}), 127.0 (s, C^{12}), 113.0 (m, C^3), 112.1 (dm, ^3J (C^{4a},F^6) = 5.6 Hz, C^{4a}), 111.2 (d, ^2J (C^5,F^6) = 20.0 Hz, C^5), 103.0 (d, ^2J (C^8,F^7) = 21.1 Hz, C^8). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –134.0 (m, J (F^7,F^6) = 23.4 Hz, J (F^7,H^8) = 11.3 Hz, J (F^7,H^5) = 8.7 Hz, 1 F, F^7), –146.2 (m, J (F^6,F^7) = 23.4 Hz, J (F^6,H^5) = 11.5 Hz, J (F^6,H^8) = 7.1 Hz, 1 F, F^6). HRMS (EI): *m/z* $[M-H]^+$ calcd for $C_{15}H_8F_2NO_2$: 272.0518; found: 272.0512.

4.2.5.2. 6,8-Difluoro-4-hydroxy-3-phenylquinolin-2(1 H)-one (2b).

White solid; yield: 251 mg (92%); mp 267.2 °C (decomp.). IR (KBr): 3145, 3053, 2983, 1655, 1626, 1599, 1508, 1469, 1413, 1336, 1298, 1263, 1192, 1169, 1113, 997, 897, 866, 793, 702, 631, 592, 546, 532, 494 cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ = 11.50 (br s, 1 H, H^1), 7.56 (dm, J (H^5,F^6) = 9.7 Hz, J (H^5,H^7) = 2.8 Hz, 1 H, H^5), 7.47 (m, J (H^7,F^8) = 11 Hz, J (H^7,F^6) = 8.8 Hz, J (H^7,H^5) = 2.8 Hz, 1 H, H^7), 7.43 – 7.38 (m, 4 H, 2 H_m + 2 H_o), 7.34 – 7.30 (m, 1 H, H_p). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 162.6 (s, C^2), 156.8 (t, C^4), 156.0 (dd, ^1J (C^6,F^6) = 239.1 Hz, ^3J (C^6,F^8) = 11.0 Hz, C^6), 149.0 (dd, ^1J (C^8,F^8) = 248.5 Hz, ^3J (C^8,F^6) = 12.7 Hz, C^8), 133.3 (s, C^9), 131.4 (s, C^{10}), 128.0 (s, C^{11}), 127.4 (s, C^{12}), 124.4 (d, ^2J (C^{8a},F^8) = 14.8 Hz, C^{8a}), 118.3 (dd, ^3J (C^{4a},F^6) = 9.7 Hz, ^3J (C^{4a},F^8) = 4.7 Hz, C^{4a}), 114.9 (s, C^3), 105.5 (dd, ^2J (C^7,F^6) = 28.6 Hz, ^2J (C^7,F^8) = 21.7 Hz, C^7), 104.6 (dd, ^2J (C^5,F^6) = 24.2 Hz, C^5). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –118.1 (tm, J (F^6,H^5) ≈ J (F^6,H^8) = 9.5 Hz, 1 F, F^6), –125.0 (dm, J (F^8,H^7) = 10 Hz, 1 F, F^8). HRMS (EI): *m/z* $[M-H]^+$ calcd for $C_{15}H_8F_2NO_2$: 272.0518; found: 272.0519.

4.2.5.3. 6,7,8-Trifluoro-4-hydroxy-3-phenylquinolin-2(1 H)-one (2c).

White solid; yield: 247 mg (85%); mp 305.3–306.5 °C. IR (KBr): 3130, 3020, 2980, 2848, 1743, 1631, 1597, 1522, 1458, 1437, 1369, 1346, 1309, 1288, 1213, 1186, 1103, 1041, 1026, 874, 827, 793, 744, 706, 690, 598, 532, 501 cm^{-1}. ^1H NMR (500 MHz, DMSO-d_6): δ = 11.72 (br s, 1 H, H^1), 7.72 (m, J (H^5,F^6) = 11 Hz, J (H^5,F^7) = 7.9 Hz, 1 H, H^5), 7.42 – 7.39 (m, 2 H, H_m), 7.34 – 7.31 (m, 3 H, H_p+ 2 H_o). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 162.4 (s, C^2), 156.2 (t, C^4), 144.8 (dd, ^1J (C^8,F^8) = 241.2 Hz, ^2J (C^8,F^7) = 11.2 Hz, C^8), 140.1 (ddd, ^1J (C^7,F^7) = 250.7 Hz,

^2J (C^7,F^6) = 17.7 Hz, ^2J (C^7,F^8) = 12.8 Hz, C^7), 137.5 (ddd, ^1J (C^6,F^6) = 251.0 Hz, ^2J (C^6,F^7) = 13.8 Hz, C^6), 132.6 (s, C^9), 131.0 (s, C^{10}), 127.8 (s, C^{11}), 127.2 (s, C^{12}), 125.1 (d, ^2J (C^{8a},F^8) = 11.4 Hz, C^{8a}), 113.8 (s, C^3), 111.9 (dm, ^3J (C^{4a},F^6) = 7.6 Hz, C^{4a}), 105.5 (dd, ^2J (C^5,F^6) = 19.8 Hz, C^5). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –142.0 (dd, J (F^6,F^7) = 23.0 Hz, J (F^6,H^5) = 11.3 Hz, 1 F, F^6), –149.0 (dd, J (F^8,F^7) = 20 Hz, 1 F, F^8), –155.6 (ddd, J (F^7,F^6) = 23.0 Hz, J (F^7,F^8) = 20.1 Hz, J (F^7,H^5) = 7.9 Hz, 1 F, F^7). HRMS (EI): *m/z* $[M\text{-}H]^+$ calcd for $C_{15}H_7F_3NO_2$: 290.0423; found: 290.0420.

4.2.5.4. 5,6,7,8-Tetrafluoro-4-hydroxy-3-phenylquinolin-2(1 H)-one (2d). White solid; yield: 281 mg (91%); mp 296.2 °C (decomp.). IR (KBr): 3425, 3139, 3022, 2852, 1666, 1635, 1523, 1508, 1462, 1435, 1415, 1356, 1296, 1261, 1211, 1080, 1036, 935, 821, 764, 735, 694, 638, 561, 530, 463 cm^{-1}. ^{1}H NMR (500 MHz, DMSO-d_6): δ = 11.91 (br s, 1 H, H^1), 7.43 – 7.31 (m, 5 H, 2 H_m+ 2 H_o+ H_p). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 162.1 (s, C^2), 156.3 (t, C^4), 143.8 (dm, ^1J (C^5,F^5) = 255 Hz, ^2J (C^5,F^6) = 11 Hz, C^5), 140.6 (dt, ^1J (C^7,F^7) = 250 Hz, ^2J (C^7,F^6) ≈ ^2J (C^7,F^8) = 14 Hz, C^7), 134.8 (dt, ^1J (C^6,F^6) = 241.5 Hz, ^2J (C^6,F^5) ≈ ^2J (C^6,F^7) = 15 Hz, C^6), 134.1 (dm, ^1J (C^8,F^8) = 245 Hz, ^2J (C^8,F^7) = 11 Hz, C^8), 131.9 (s, C^9), 131.2 (s, C^{10}), 128.2 (s, C^{11}), 127.7 (s, C^{12}), 124.8 (d, ^2J (C^{8a},F^8) = 11.5 Hz, C^{8a}), 114.9 (s, C^3), 102.8 (dm, ^2J (C^{4a},F^5) = 7.2 Hz, C^{4a}). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –141.7 (m, 1 F, F^5), –154.6 (t, J (F^7,F^6) ≈ J (F^7,F^8) = 20.4 Hz, 1 F, F^7), –156.0 (m, 1 F, F^8), –167.4 (t, J (F^6,F^7) ≈ J (F^6,F^5) = 21.1 Hz, 1 F, F^6). HRMS (EI): *m/z* $[M\text{-}H]^+$ calcd for $C_{15}H_6F_4NO_2$: 308.0329; found: 308.0331.

4.2.5.5. 3-(4-Amino-2,5-difluorophenyl)-6,7-difluoro-4-hydroxyquinolin-2(1 H)-one (2e). White solid; yield: 282 mg (87%); mp undefined (decomp.). IR (KBr): 3483, 3421, 3078, 2947, 1647, 1618, 1523, 1475, 1448, 1431, 1371, 1352, 1296, 1246, 1190, 1169, 883, 830, 792, 702, 667, 561, 530 cm^{-1}. ^{1}H NMR (500 MHz, DMSO-d_6 + Acetone-d_6): δ = 11.57 (s, 1 H, H^1), 10.49 (br s, 1 H, H^4), 7.82 (dd, J (H^5,F^6) = 11.4 Hz, J (H^5,F^7) = 8.6 Hz, 1 H, H^5), 7.21 (dd, J (H^8,F^7) = 11.5 Hz, J (H^8,F^6) = 7.1 Hz, 1 H, H^8), 6.88 (dd, J (H^{14},F^{13}) = 11.7 Hz, J (H^{14},F^{10}) = 6.5 Hz, 1 H, H^{14}), 6.55 (dd, J (H^{11},$F^{1\circ}$) = 11.2 Hz, J (H^{11},F^{13}) = 7.8 Hz, 1 H, H^{11}). ^{13}C NMR (125 MHz, DMSO-d_6 + Acetone-d_6): δ = 162.4 (s, C^2), 157.5 (s, C^4), 157.1 (d, ^1J (C^{10},F^{10}) = 238.1 Hz, C^{10}), 151.0 (dd, ^1J (C^7,F^7) = 249.4 Hz, ^2J (C^7,F^6) = 15.0 Hz, C^7), 146.5 (dd, ^1J (C^{13},F^{13}) = 232.1 Hz, C^{13}), 144.9 (dd, ^1J (C^6,F^6) = 240.1 Hz, ^2J (C^6,F^7) = 13.9 Hz, C^6), 137.7 (dd, ^2J (C^{12},F^{13}) = 15.2 Hz, ^3J (C^{12},$F^{1\circ}$) = 12.1 Hz, C^{12}), 135.4 (d, ^3J (C^{8a},F^7) = 10.4 Hz, C^{8a}), 118.3 (dd, ^2J (C^{14},F^{13}) = 20.3 Hz, ^3J (C^{14},F^{10}) = 6.3 Hz, C^{14}), 111.9 (dm, ^3J (C^{4a},F^6) = 5.6 Hz, C^{4a}), 111.2 (d, ^2J (C^5,F^6) = 19.4 Hz, C^5), 106.6 (s, C^3), 105.9 (dd, ^2J (C^9,F^{10}) = 19.9 Hz, ^3J (C^9,F^{13}) = 6.9 Hz, C^9), 103.1 (d, ^2J (C^8,F^7) = 21.1 Hz, C^8), 102.0 (dd, ^2J (C^{11},F^{10}) = 28.1 Hz, ^3J (C^{11},F^{13}) = 5.0 Hz, C^{11}). ^{19}F NMR (282 MHz, DMSO-d_6 + Acetone-d_6): δ = –116.2 (m, J (F^{10},F^{13}) = 14.8 Hz, J (F^{10},H^{11}) = 11.2 Hz, J (F^{10},H^{14}) = 6.6 Hz, 1 F, F^{10}), –132.0 (m, J (F^7,F^6) = 23.2 Hz, J (F^7,H^8) = 11.5 Hz, J (F^7,H^5) = 8.7 Hz, 1 F, F^7), –140.0 (m, J (F^{13},F^{10}) = 14.8 Hz, J (F^{13},H^{14}) = 11.8 Hz, J (F^{13},H^{11}) = 7.7 Hz, 1 F, F^{13}), –144.4 (m, J (F^6,F^7) = 23.3 Hz, J (F^6,H^5) = 11.5 Hz, J (F^6,H^8) = 7.1 Hz, 1 F, F^6). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{15}H_8F_4NO_2$: 324.0516; found: 324.0514.

4.2.5.6. 3-(4-Amino-2,5-difluorophenyl)-5,6,8-trifluoro-4-hydroxyquinolin-2(1 H)-one (2f). White solid; yield: 195 mg (57%); mp 302.7 °C (decomp.). IR (KBr): 3402, 3234, 2981, 2929, 1599, 1556, 1525, 1435, 1410, 1336, 1257, 1169, 1136, 1026, 999, 877, 841, 821, 767, 731, 677, 631, 600, 509, 447 cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6): δ = 7.56 (m, J (H^7,F^6) ≈ J (H^7,F^8) = 10.8 Hz, J (H^7,F^5) = 6.9 Hz, 1 H, H^7), 6.82 (dd, J (H^{14},F^{13}) = 12.2 Hz, J (H^{14},F^{10}) = 6.5 Hz, 1 H, H^{14}), 6.50 (dd, J (H^{11},F^{10}) = 11.5 Hz, J (H^{11},F^{13}) = 8.1 Hz, 1 H, H^{11}). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 173.5 (s, C^4), 162.7 (s, C^2), 157.6 (d, ^1J (C^{10},F^{10}) = 237.9 Hz, C^{10}), 147.0 (d, ^1J (C^{13},F^{13}) = 231.8 Hz, C^{13}), 144.1 (dm, ^1J (C^5,F^5) ≈ ^1J (C^8,F^8) ≈ 250 Hz, C^5 + C^8), 143.2 (dt, ^1J (C^6,F^6) = 237.3 Hz, ^2J (C^6,F^5) = 12.9 Hz, C^6), 136.7 (t, ^2J (C^{12},F^{13}) = 12.8 Hz, C^{12}), 12524 (d, ^2J (C^{8a},F^8) = 13.8 Hz, C^{8a}), 119.3 (dd, ^2J (C^{14},F^{13}) = 19.8 Hz, ^3J (C^{14},F^{10}) = 6.3 Hz, C^{14}), 111.1 (m, C^{4a}), 109.5 (m, C^3), 106.1 (m, C^9), 105.9 (t, ^2J (C^7,F^6) ≈ ^2J (C^7,F^8) = 23.1 Hz, C^7), 102.8 (dd, ^2J (C^{11},F^{10}) = 28.5 Hz, ^3J (C^{11},F^{13}) = 4.2 Hz, C^{11}). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –115.2 (m, 1 F, F^{10}), –131.4 (m, 1 F, F^8), –139.9 (m, J (F^{13},F^{10}) = 14.2 Hz, 1 F, F^{13}), –145.7 (m, 1 F, F^6). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{15}H_7F_5NO_2$: 342.0422; found: 342.0415.

4.2.5.7. 3-Butyl-6,8-difluoro-4-hydroxyquinolin-2(1 H)-one (2 g). White solid; yield: 152 mg (60%); mp 192.6 °C (decomp.). IR (KBr): 3419, 3365, 3095, 2960, 2931, 2873, 1657, 1627, 1612, 1581, 1500, 1466, 1400, 1338, 1296, 1201, 1176, 1149, 1120, 1078, 1012, 995, 908, 848, 781, 766, 731, 704, 631, 598, 575, 550, 532, 482, 413 cm^{-1}. ^{1}H NMR (500 MHz, DMSO-d_6): δ = 11.36 (br s, 1 H, H^1), 7.48 – 7.43 (m, 2 H, H^5 + H^7), 2.55 (t, J (H^9,H^{10}) = 7.3 Hz, 2 H, H^9), 1.41 – 1.27 (m, 4 H, 2 H^{10} + 2 H^{11}), 0.88 (t, J (H^{12},H^{11}) = 7.2 Hz, 3 H, H^{12}). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 163.1 (s, C^2), 156.0 (t, C^4), 155.5 (dd, ^1J (C^6,F^6) = 238.7 Hz, ^3J (C^6,F^8) = 11.1 Hz, C^6), 148.6 (dd, ^1J (C^8,F^8) = 248.1 Hz, ^3J (C^8,F^6) = 12.9 Hz, C^8), 123.2 (dd, ^2J (C^{8a},F^8) = 14.4 Hz, C^{8a}), 117.7 (dd, ^3J (C^{4a},F^6) = 9.7 Hz, ^3J (C^{4a},F^8) = 4.8 Hz, C^{4a}), 114.2 (s, C^3), 104.7 (dd, ^2J (C^7,F^6) = 28.6 Hz, ^2J (C^7,F^8) = 21.7 Hz, C^7), 103.8 (dd, ^2J (C^5,F^6) = 24.0 Hz, C^5), 30.3 (s, C^9), 23.1 (s, C^{10}), 22.3 (s, C^{11}), 14.1 (s, C^{12}). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –119.6 (tm, J (F^6,H^5) ≈ J (F^6,H^8) = 9.4 Hz, 1 F, F^6), –126.9 (dm, J (F^8,H^7) = 10 Hz, 1 F, F^8). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{13}H_{13}F_2NO_2$: 253.0909; found: 253.0905.

4.2.5.8. 3-Butyl-6,7,8-trifluoro-4-hydroxyquinolin-2(1 H)-one (2 h). White solid; yield: 211 mg (78%); mp 193.9 °C (decomp.). IR (KBr): 3416, 3319, 3091, 2964, 2927, 1662, 1630, 1593, 1523, 1496, 1433, 1394, 1367, 1304, 1267, 1215, 1184, 1163, 1132, 1057, 1030, 972, 914, 864, 831, 764, 729, 632, 582, 472 cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6 + Acetone-d_6): δ = 7.65 (m, J (H^5,F^6) = 11.3 Hz, J (H^5,F^7) = 7.9 Hz, 1 H, H^5), 2.55 (t, J (H^9,H^{10}) = 7 Hz, 2 H, H^9), 1.44 – 1.25 (m, 4 H, 2 H^{10} + 2 H^{11}), 0.87 (t, J (H^{12},H^{11}) = 7 Hz, 3 H, H^{12}). ^{13}C NMR (125 MHz, DMSO-d_6 + Acetone-d_6): δ = 163.5 (s, C^2), 155.7 (t, C^4), 144.9 (dd, ^1J (C^8,F^8) = 240.5 Hz, ^2J (C^8,F^7) = 10.9 Hz, C^8), 139.8 (ddd, ^1J (C^7,F^7) = 249.5 Hz, ^2J (C^7,F^6) = 17.3 Hz, ^2J (C^7,F^8) = 12.5 Hz, C^7), 137.8 (ddd, ^1J (C^6,F^6) = 249.2 Hz, ^2J (C^6,F^7) = 12.6 Hz, C^6), 124.4 (d, ^2J (C^{8a},F^8) = 11.4 Hz, C^{8a}), 113.5 (d, C^3), 111.9 (m, ^3J (C^{4a},F^6) = 7.9 Hz, C^{4a}), 105.1 (dd, ^2J (C^5,F^6) = 19.7 Hz, C^5), 30.4 (s, C^9), 23.0 (s, C^{10}), 22.4 (s, C^{11}), 14.0 (s, C^{12}). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –143.1 (dd, J (F^6,F^7) = 22.5 Hz, J (F^6,H^5) = 11.4 Hz, 1 F, F^6), –149.9 (dd, J (F^8,F^7) = 19.6 Hz, 1 F, F^8), –157.7 (ddd, J (F^7,F^6) = 22.5 Hz, J (F^7,F^8) = 19.6 Hz, J (F^7,H^5) = 7.9 Hz, 1 F, F^7). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{13}H_{12}F_3NO_2$: 271.08153; found: 271.0813.

4.2.5.9. 3-Butyl-5,6,7,8-tetrafluoro-4-hydroxyquinolin-2(1 H)-one (2i). White solid; yield: 72 mg (25%); mp 180.3 °C (decomp.). IR (KBr): 3346, 3136, 2960, 2933, 2862, 1666, 1618, 1591, 1523, 1498, 1452, 1423, 1383, 1292, 1253, 1213, 1180, 1130, 1039, 982, 816, 710, 629 cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6 + Acetone-d_6): δ = 11.56 (br s, 1 H, H^1), 2.53 (t, J (H^9,H^{10}) = 7.1 Hz, 2 H, H^9), 1.39 – 1.27 (m, 4 H, 2 H^{10} + 2 H^{11}), 0.87 (t, J (H^{12},H^{11}) = 7.1 Hz, 3 H, H^{12}). ^{13}C NMR (125 MHz, DMSO-d_6 + Acetone-d_6): δ = 162.8 (s, C^2), 156.6 (m, C^4), 143.3 (ddm, ^1J (C^5,F^5) = 254.1 Hz, ^2J (C^5,F^6) = 10.7 Hz, C^5), 139.7 (dtm, ^1J (C^7,F^7) = 246.7 Hz, ^2J (C^7,F^6) ≈ ^2J (C^7,F^8) = 12 Hz, C^7), 134.5 (dtm, ^1J (C^6,F^6) = 241.2 Hz, ^2J (C^6,F^5) ≈ ^2J (C^6,F^7) = 16 Hz, C^6), 133.9 (ddm, ^1J (C^8,F^8) = 244.6 Hz, ^2J (C^8,F^7) = 10 Hz, C^8), 124.1 (dm, ^2J (C^{8a},F^8) = 10.3 Hz, C^{8a}), 113.6 (s, C^3), 103.1 (d, ^2J (C^{4a},F^5) = 8.0 Hz, C^{4a}), 30.2 (s, C^9), 22.6 (s, C^{10}), 22.3 (s, C^{11}), 13.9 (s, C^{12}). ^{19}F NMR (282 MHz, DMSO-d_6 + Acetone-d_6): δ = –146.0 (ddd, J (F^5,F^6) = 21.4 Hz, J (F^5,F^8) = 12 Hz, 1 F, F^5), –159.2 (t, J (F^7,F^6) ≈ J (F^7,F^8) = 22 Hz, 1 F, F^7), –159.6 (ddd, J (F^8,F^7) = 21.2 Hz, J (F^8,F^5) = 12 Hz, J (F^8,F^6) = 3.7 Hz, 1 F, F^8), –171.2 (td, J (F^6,F^7) ≈ J (F^6,F^5) = 21.7 Hz, J (F^6,F^8) = 3.7 Hz, 1 F, F^6). HRMS (EI):

m/z $[M]^+$ calcd for $C_{13}H_{11}F_4NO_2$: 289.0720; found: 289.0717.

4.2.5.10. 5,8-Difluoro-4-hydroxy-3-phenyl-6-(phenylethynyl)quinolin-2 (1 H)-one (2 j). White solid; yield: 336 mg (90%); mp 276.6 – 277.2 °C. IR (KBr): 3568, 3477, 3396, 3134, 2993, 2850, 2212, 1643, 1599, 1510, 1444, 1410, 1323, 1257, 1230, 1157, 1115, 1070, 1028, 978, 870, 771, 756, 717, 690, 625, 544, 528, 440 cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6 + Acetone-d_6): δ = 11.24 (br s, 1 H, H^1), 7.16 (dd, *J* (H^7,F^8) = 10.3 Hz, *J* (H^7,F^5) = 5.5 Hz, 1 H, H^6), 7.09 – 7.07 (m, 2 H, H_m), 6.97 – 6.83 (m, 8 H, 2 H'$_m$ + 2 H_o + 2 H'$_o$ + H_p + H'$_p$). ^{13}C NMR (125 MHz, DMSO-d_6 + Acetone-d_6): δ = 162.2 (s, C^2), 156.9 (m, C^4), 155.7 (dm, ^1J (C^5,F^5) = 258 Hz, C^5), 144.7 (dm, ^1J (C^8,F^8) = 242.1 Hz, C^8), 132.6 (s, C^9), 131.5 (s, C^{10}), 131.3 (s, C^{11}), 129.3 (s, C^{20}), 129.0 (s, C^{18}), 128.1 (s, C^{19}), 127.5 (s, C^{12}), 126.1 (s, C^{8a}), 122.1 (s, C^{17}), 118.0 (d, ^2J (C^7,F^8) = 22.2 Hz, C^7), 115.5 (s, C^3), 107.4 (d, ^2J (C^{4a},F^5) = 9.6 Hz, C^{4a}), 102.5 (dd, ^2J (C^6,F^5) = 19.1 Hz, ^3J (C^6,F^8) = 7.9 Hz, C^6), 94.2 (d, ^3J (C^{15},F^5) = 4.5 Hz, C^{15}), 82.0 (s, C^{16}). ^{19}F NMR (282 MHz, DMSO-d_6 + Acetone-d_6): δ = –113.6 (dd, *J* (F^5,F^8) = 17.2 Hz, *J* (F^5,H^7) = 5.5 Hz, 1 F, F^5), –134.7 (t, *J* (F^8,H^7) ≈ *J* (F^8,F^5) ≈ 12 Hz, 1 F, F^8). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{23}H_{13}F_2NO_2$: 373.0909; found: 373.0907.

4.2.5.11. 6,7,8-Trifluoro-4-hydroxy-3-(2,3,5,6-tetrafluoro-4-methoxyphenyl)quinolin-2(1 H)-one (2k). White solid; yield: 322 mg (82%); mp 278.0 °C (decomp.). IR (KBr): 3410, 3138, 2970, 2846, 1631, 1603, 1525, 1489, 1446, 1427, 1367, 1344, 1317, 1215, 1203, 1161, 1091, 1049, 1001, 985, 874, 829, 634, 615, 544, 472 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 12.06 (br s, 1 H, H^1), 7.80 (m, *J* (H^5,F^6) = 11 Hz, *J* (H^5,F^7) = 8 Hz, 1 H, H^5), 4.10 (s, 3 H, H^{15}). ^{13}C NMR (125 MHz, DMSO-d_6): δ = 161.1 (s, C^2), 159.7 (s, C^4), 145.2 (dm, ^1J (C^8,F^8) ≈ ^1J (C^{10},F^{10}) ≈ ^1J (C^{14},F^{14}) ≈ 243 Hz, C^8 + C^{10} + C^{14}), 141.0 (ddd, ^1J (C^7,F^7) = 252.2 Hz, ^2J (C^7,F^6) = 17.2 Hz, ^2J (C^7,F^8) = 12.5 Hz, C^7), 140.7 (ddt, ^1J (C^{11},F^{11}) = ^1J (C^{13},F^{13}) = 244.8 Hz, ^2J (C^{11},F^{10}) = ^2J (C^{13},F^{14}) = 15.8 Hz, C^{11} + C^{13}), 138.0 (ddm, ^1J (C^6,F^6) = 246 Hz, ^2J (C^6,F^7) = 13.3 Hz, C^6), 137.8 (tm, ^2J (C^{12},F^{13}) ≈ ^2J (C^{12},F^{11}) = 12.9 Hz, C^{12}), 126.1 (dm, ^2J (C^{8a},F^8) = 8.7 Hz, C^{8a}), 111.0 (dm, ^3J (C^{4a},F^6) = 7 Hz, C^{4a}), 106.1 (dd, ^2J (C^5,F^6) = 19.9 Hz, C^5), 106.0 (t, ^2J (C^9,F^{10}) ≈ ^2J (C^9,F^{14}) = 20 Hz, C^9), 99.2 (s, C^3), 62.5 (t, C^{15}). ^{19}F NMR (282 MHz, DMSO-d_6): δ = –140.4 (dm, *J* (F^{10},F^{11}) = *J* (F^{14},F^{13}) ≈ 23 Hz, 2 F, F^{10} + F^{14}), –143.6 (dd, *J* (F^6,F^7) = 22.2 Hz, *J* (F^6,H^5) = 10.9 Hz, 1 F, F^6), –150.1 (d, *J* (F^8,F^7) = 19.8 Hz, 1 F, F^8), –155.9 (td, *J* (F^7,F^6) ≈ *J* (F^7,F^8) = 22.3 Hz, *J* (F^7,H^5) = 7.9 Hz, 1 F, F^7), –159.5 (dd, *J* (F^{11},F^{10}) = *J* (F^{13},F^{14}) ≈ 23 Hz, 2 F, F^{11} + F^{13}). HRMS (EI): *m/z* $[M]^+$ calcd for $C_{16}H_6F_7NO_3$: 393.0230; found: 393.0235.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

The authors thank the Russian Foundation for Basic Research (grant № 19-53-53003) and NSFC (grant № 21911530097) for financial support and the Chemical Service Center SB RAS for spectral and analytical measurements.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jfluchem.2020.109720 .

References

[1] (a) Y. Zhou, J. Wang, Z. Gu, S. Wang, W. Zhu, J.L. Acenã, V.A. Soloshonok, K. Izawa, H. Liu, Next generation of fluorine-containing pharmaceuticals, compounds currently in phase II–III clinical trials of major pharmaceutical companies: new structural trends and therapeutic areas, Chem. Rev. 116 (2016) 422–518;
(b) E.P. Gillis, K.J. Eastman, M.D. Hill, D.J. Donnelly, N.A. Meanwell, Applications of fluorine in medicinal chemistry, J. Med. Chem. 58 (2015) 8315–8359;
(c) P. Jeschke, The unique role of fluorine in the design of active ingredients for modern crop protection, Chem. Bio. Chem. 5 (2004) 570–589;
(d) T. Fujiwara, D. O'Hagan, Successful fluorine-containing herbicide agrochemicals, J. Fluorine Chem. 167 (2014) 16–29.
[2] B.M. Johnson, Y.-Z. Shu, X. Zhuo, N.A. Meanwell, Metabolic and pharmaceutical aspects of fluorinated compounds, J. Med. Chem. 63 (2020) 6315–6386.
[3] (a) L.V. Politanskaya, I.P. Chuikov, V.D. Shteingarts, Synthesis of indoles with a polyfluorinated benzene ring, Tetrahedron 69 (2013) 8477–8486;
(b) L.V. Politanskaya, I.P. Chuikov, E.V. Tretyakov, V.D. Shteingarts, L. P. Ovchinnikova, O.D. Zakharova, G.A. Nevinsky, An effective two-step synthesis, fluorescent properties, antioxidant activity and cytotoxicity evaluation of benzene fluorinated 2,2-dimethyl-2,3-dihydro-1H-quinolin-4-ones, J. Fluorine Chem. 178 (2015) 142–153;
(c) O. Zakharova, G. Nevinsky, L. Politanskaya, D. Baev, L. Ovchinnikova, E. Tretyakov, Evaluation of antioxidant activity and cytotoxicity of polyfluorinated diarylacetylenes and indoles toward human cancer cells, J. Fluorine Chem. 226 (2019), 109353;
(d) L. Politanskaya, T. Rybalova, O. Zakharova, G. Nevinsky, E. Tretyakov, *p*-Toluenesulfonic acid mediated one-pot cascade synthesis and cytotoxicity evaluation of polyfluorinated 2-aryl-2,3-dihydroquinolin-4-ones and their derivatives, J. Fluorine Chem. 211 (2018) 129–140;
(e) L. Politanskaya, Z. Duan, I. Bagryanskaya, I. Eltsov, E. Tretyakov, C. Xi, Highly efficient synthesis of polyfluorinated 2-mercaptobenzothiazole derivatives, J. Fluorine Chem. 212 (2018) 130–136;
(f) L. Politanskaya, I. Bagryanskaya, E. Tretyakov, Synthesis of polyfluorinated arylhydrazines, hydrazones and 3-methyl-1-aryl-1*H*-indazoles, J. Fluorine Chem. 214 (2018) 48–57;
(g) L. Politanskaya, N. Troshkova, E. Tretyakov, C. Xi, Synthesis of polyfluorinated benzofurans, Journal of Fluorine Chemistry 227 (2019), 109371;
(h) L. Politanskaya, E. Tretyakov, C. Xi, Synthesis of polyfluorinated *o*-hydroxyacetophenones – convenient precursors of 3-benzylidene-2-phenylchroman-4-ones, J. Fluorine Chem. 229 (2020), 109435;
(i) L. Politanskaya, E. Tretyakov, Directed synthesis of fluorine containing 2,3-dihydrobenzo[*b*][1,4]oxathiine derivatives from polyfluoroarenes, J. Fluorine Chem. 236 (2020), 109592.
[4] J. Wang, M. Sanchez-Rosello, J.L. Acen, C. del Pozo, A.E. Sorochinsky, S. Fustero, V.A. Soloshonok, H. Liu, Fluorine in pharmaceutical industry: fluorine-containing drugs introduced to the market in the last decade (2001−2011), Chem. Rev. 114 (2014) 2432–2506.
[5] P. Ball, Adverse drug reactions: implications for the development of fluoroquinolones, J. Antimicrob. Chemoth. 51 (2003) 21–27, https://doi.org/10.1093/jac/dkg209).
[6] L.A. Mitscher, Bacterial topoisomerase inhibitors: quinolone and pyridone antibacterial agents, Chem. Rev. 105 (2005) 559–592.
[7] K. Arya, M. Agarwal, Microwave prompted multigram synthesis, structural determination, and photo-antiproliferative activity of fluorinated 4-hydroxyquinolinones, Bioorg. Med. Chem. Lett. 17 (2007) 86–93.
[8] N. Fokialakis, P. Magiatis, I. Chinou, S. Mitaku, F. Tillequin, Megistoquinones I and II, two quinoline alkaloids with antibacterial activity from the bark of sarcomelicope megistophylla, Chem. Pharm. Bull. 50 (2002) 413–414.
[9] J.L. McCormick, T.C. McKee, J.H. Cardellina II, M.R. Boyd, HIV Inhibitory natural products. 26. Quinoline alkaloids from Euodia roxburghiana, J. Nat. Prod. 59 (1996) 469–471.
[10] H. Hayashi, Y. Miwa, S. Ichikawa, N. Yoda, I. Miki, A. Ishii, M. Kono, T. Yasuzawa, F. Suzuki, 5-HT_3 receptor antagonists. 2. 4-Hydroxy-3-quinolinecarboxylic acid derivatives, J. Med. Chem. 36 (1993) 617–626.
[11] R.J. DeVita, M.T. Goulet, M.J. Wyvratt, M.H. Fisher, J.-L. Lo, Y.T. Yang, K. Cheng, R.G. Smith, Investigation of the 4-O-alkylamine substituent of non-peptide quinolone GnRH receptor antagonists, Bioorg. Med. Chem. Lett. 9 (1999) 2621–2624.
[12] L.A. McQuaid, E.C.R. Smith, D. Lodge, E. Pralong, J.E. Wikel, D.O. Calligaro, P. J. O'Malley, 3-Phenyl-4-hydroxyquinolin-2(l*H*)-ones: potent and selective antagonists at the strychnine-insensitive glycine site on the N-methyl-d-aspartate receptor complex, J. Med. Chem. 35 (1992) 3423–3425.
[13] T. Fuchigami, T. Haradahira, N. Fujimoto, Y. Nojiri, T. Mukai, F. Yamamoto, T. Okauchi, J. Maeda, K. Suzuki, T. Suhara, H. Yamaguchi, M. Ogawa, Y. Magata, M. Maeda, Development of N-[^{11}C]methylamino 4-hydroxy-2(1*H*)-quinolone derivatives as PET radioligands for the glycine-binding site of NMDA receptors, Bioorg. Med. Chem. 17 (2009) 5665–5675.
[14] M. Rowley, J.J. Kulagowski, A.P. Watt, D. Rathbone, G.I. Stevenson, R.W. Carling, R. Baker, G.R. Marshall, J.A. Kemp, A.C. Foster, S. Grimwood, R. Hargreaves, C. Hurley, K.L. Saywell, M.D. Tricklebank, P.D. Leeson, Effect of plasma protein binding on in vivo activity and brain penetration of glycine/NMDA receptor antagonists, J. Med. Chem. 40 (1997) 4053–4068.
[15] P.D. Leeson, R. Baker, R.W. Caning, J.J. Kulagowski, I.M. Mawer, M.P. Ridgill, M. Rowley, J.D. Smith, I. Stansfield, G.I. Stevenson, A.C. Foster, J.A. Kemp, Amino acid bioisosteres: design of 2-quinolone derivatives as glycine-site N-methyl-D-aspartate receptor antagonists, Bioorg. Med. Chem. Lett. 3 (1993) 299–304.
[16] S. Sarveswari, V. Vijayakumar, R. Siva, R. Priya, Synthesis of 4-hydroxy-2(1*H*)-quinolone derived chalcones, pyrazolines and their antimicrobial, in silico antimalarial evaluations, Appl. Biochem. Biotechnol. 175 (2015) 43–64.
[17] R.V. Patel, P. Kumari, D.P. Rajani, K.H. Chikhalia, Synthesis, characterization and pharmacological activities of 2-[4-cyano-(3-trifluoromethyl)phenyl amino)]-4-(4-

quinoline/coumarin-4-yloxy)-6-(fluoropiperazinyl)-s-triazines, J. Fluorine Chem. 132 (2011) 617–627.
[18] A. Krishna, V. Vijayakumar, S. Sarveswari, Synthesis of new 3-(2-amino-6-arylpyrimidin-4-yl)-4-hydroxyquinolin-2(1*H*)-ones and their in vitro antimicrobial and "DPPH" scavenging activity evaluation, Chemistry Select 5 (2020) 7967–7972.
[19] S. Sarveswari, V. Vijayakumar, Synthesis and antibacterial screening of 3-(4,5-dihydro-5- aryl-1*H*-pyrazol-3-yl)-4-hydroxyquinolin-2(1*H*)-ones, Int. J. Chem. Tech. Res. 8 (6) (2015) 782–788.
[20] M. Abassa, B.B. Mostafa, Synthesis and evaluation of molluscicidal and larvicidal activities of some novel enaminones derived from 4-hydroxyquinolinones: Part IX, Bioorg. Med. Chem. 13 (2005) 6133–6144.
[21] M. Roussaki, B. Hall, S.C. Lima, A.C. da Silva, S. Wilkinson, A. Detsi, Synthesis and antiparasitic activity of a novel quinolinone–chalcone series, Bioorg. Med. Chem. Lett. 23 (2013) 6436–6441.
[22] M.H. Sherlock, J.J. Kaminski, W.C. Tom, J.F. Lee, S.-C. Wong, W. Kreutner, R. W. Bryant, A.T. McPhail, Antiallergy agents. 1. Substituted 1,8-naphthyridin-2 (1*H*)-ones as inhibitors of SRS-A release, J. Med. Chem. 31 (1988) 2108–2121.
[23] I. Im, E.S. Lee, S.J. Choi, J.-Y. Lee, Y.-C. Kim, Structure–activity relationships of heteroaromatic esters as human rhinovirus 3C protease inhibitors, Bioorg. Med. Chem. Lett. 19 (2009) 3632–3636.
[24] S.-L. Zhang, Z.-S. Huang, Y.-M. Li, A.S.C. Chan, L.-Q. Gu, Synthesis of zwitterionic 4-hydroxy-2(1*H*)-quinolinone derivatives, Tetrahedron 64 (2008) 4403–4407.
[25] J.-C. Jung, Y.-J. Jung, O.-S. Park, A convenient one-pot synthesis of 4-hydroxy-coumarin, 4-hydroxythiocoumarin and 4-hydroxythiquinolin-2(1*H*)-one, Synth. Commun. 31 (2001) 1195–1200.
[26] D.C. Dittmer, Q. Li, D.V. Avilov, Synthesis of coumarins, 4-hydroxycoumarins, and 4-hydroxyquinolinones by tellurium-triggered cyclizations, J. Org. Chem. 70 (2005) 4682–4686.
[27] T. Okamoto, E. Kimura, S. Iwasaki, K. Yamamoto, Studies on reaction of alkali-fusion of haloquinolones via aryne intermediates, Chem. Pharm. Bull. 17 (1969) 2083–2087.
[28] A. Detsi, V. Bardakos, J. Markopoulos, O. Igglessi-Markopoulou, Reactions of 2-methyl-3,1-benzoxazin-4-one with active methylene compounds: a new route to 3-substituted 4-hydroxyquinolin-2(1*H*)-ones, J. Chem. Soc. Perkin Trans. I (1996) 2909–2913.
[29] C.A. Mitsos, A.L. Zografos, O. Igglessi-Markopoulou, An efficient route to 3-aryl-substituted quinolin-2-one and 1,8-naphthyridin-2-one derivatives of pharmaceutical interest, J. Org. Chem. 68 (2003) 4567–4569.
[30] T. Ishida, S. Kikuchi, T. Yamada, Efficient preparation of 4-hydroxyquinolin-2(1*H*)-one derivatives with silver-catalyzed carbon dioxide incorporation and intramolecular rearrangement, Org. Lett. 15 (2013) 3710–3713.
[31] C.-X. Guo, W.-Z. Zhang, S. Liu, X.-B. Lu, Cu(I)-catalyzed chemical fixation of CO_2 with 2-alkynylaniline into 4-hydroxyquinolin-2(1*H*)-one, Catal. Sci. Technol. 4 (2014) 1570–1577.
[32] (a) S. Wang, C. Xi, Recent advances in nucleophile-triggered CO_2-incorporated cyclization leading to heterocycles, Chem. Soc. Rev. 48 (2019) 382–404;
(b) S. Wang, G. Du, C. Xi, Copper-catalyzed carboxylation reactions using carbon dioxide, Org. Biomol. Chem. 14 (2016) 3666–3676;
(c) Q. Liu, L. Wu, R. Jackstell, M. Beller, Using carbon dioxide as a building block in organic synthesis, M. Nat. Commun. 6 (2015) 5933–5948;
(d) N. Kielland, C.J. Whiteoak, A.W. Kleij, Stereoselective synthesis with carbon dioxide, Adv. Synth. Catal. 355 (2013) 2115–2138;
(e) B. Yu, L.-N. He, Upgrading carbon dioxide by incorporation into heterocycles, ChemSusChem 8 (2015) 52–62;
(f) T. Sakakura, J.-C. Choi, H. Yasuda, Transformation of carbon dioxide, Chem. Rev. 107 (2007) 2365–2387.
[33] M. He, Y. Sun, B. Han, Green carbon science: scientific basis for integrating carbon resource processing, utilization, and recycling, Angew. Chem. Int. Ed. 52 (2013) 9620–9633.
[34] J. Hansen, L. Nazarenko, R. Ruedy, M. Sato, J. Willis, A. Del Genio, D. Koch, A. Lacis, K. Lo, S. Menon, T. Novakov, J. Perlwitz, G. Russell, G.A. Schmidt, N. Tausnev, Earth's energy imbalance: confirmation and implications, Science 308 (2005) 1431–1435.
[35] (a) D. Yu, S.P. Teong, Y. Zhang, Transition metal complex catalyzed carboxylation reactions with CO_2, Coord. Chem. Rev. 293–294 (2015) 279–291;
(b) C.S. Yeung, V.M. Dong, Making C–C bonds from carbon dioxide via transition-metal catalysis, Top. Catal. 57 (2014) 1342–1350;
(c) K. Huang, C.-L. Sun, Z.-J. Shi, Transition-metal-catalyzed C–C bond formation through the fixation of carbon dioxide, Chem. Soc. Rev. 40 (2011) 2435–2452.
[36] D.B. Dell'Amico, F. Calderazzo, L. Labella, F. Marchetti, G. Pampalon, Converting carbon dioxide into carbamato derivatives, Chem. Rev. 103 (2003) 3857–3897.
[37] B. Wang, S. Sun, J.-T. Yu, Y. Jiang, J. Cheng, Palladium-catalyzed multicomponent reactions of *o*-alkynylanilines, aryl iodides, and CO_2 toward 3,3-diaryl 2,4-quinolinediones, Org. Lett. 19 (2017) 4319–4322.
[38] L.V. Politanskaya, I.P. Chuikov, E.A. Kolodina, M.S. Shvartsberg, V.D. Shteingarts, Synthesis of polyfluorinated *ortho*-alkynylanilines, J. Fluorine Chem. 135 (2012) 97–107.
[39] L.V. Politanskaya, V.D. Shteingarts, E.V. Tretyakov, General and efficient synthesis of polyfluorinated 2-aminotolans and 2-arylindoles, J. Fluorine Chem. 188 (2016) 85–98.
[40] L. Politanskaya, E. Tretyakov, *p*-Toluenesulfonic acid induced conversion of fluorinated trimethylsilylethynylanilines into aminoacetophenones: versatile precursors for the synthesis of benzoazaheterocycles, Synthesis 50 (2018) 555–564.
[41] F. Kloss, U. Kohn, B.O. Jahn, M.D. Hager, H. Gorls, U.S. Schubert, 1 Metal-free, 5-regioselective azide–alkyne [3+2]-cycloaddition, Chem. Asian J. 6 (2011) 2816–2824.
[42] T. Kimura, H. Sunaba, K. Kamata, N. Mizuno, Efficient $[WO_4]^{2-}$-catalyzed chemical fixation of carbon dioxide with 2-aminobenzonitriles to quinazoline-2,4 (1*H*,3*H*)-diones, Inorg. Chem. 51 (2012) 13001–13008.
[43] T. Ishida, S. Kikuchi, T. Tsubo, T. Yamada, Silver-catalyzed incorporation of carbon dioxide into *o*-alkynylaniline derivatives, Org. Lett. 15 (2013) 848–851.
[44] L. Politanskaya, I. Bagryanskaya, E. Tretyakov, C. Xi, Highly efficient synthesis of novel fluorinated 3-amino-2-mercaptobenzothiazole-2(3*H*)-thione derivatives, J. Fluorine Chem. 239 (2020), 109628.
[45] L. Politanskaya, M. Petyuk, E. Tretyakov, Transformation of fluorinated 2-alkynylanilines by various catalytic systems, J. Fluorine Chem. 228 (2019), 109394.