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One-step synthesis of 1,4-bis(het)arylisoquinolines by the reaction of 1,2,4-triazines with arynes

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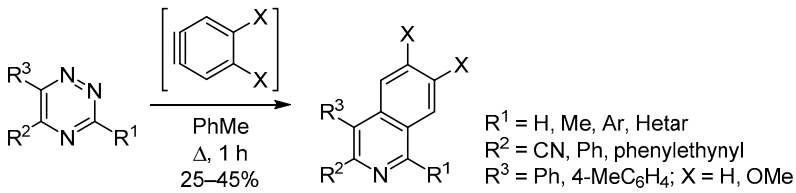


The reaction of 3,6-bis(het)aryl-1,2,4-triazines (hetaryl ≠ 2-pyridyl) with aryne intermediates generated *in situ* was studied. As a result, novel 1,4-bis(het)arylisoquinolines were synthesized with yields of up to 45%. The main rules of the reactions were studied, and the obtained experimental data were compared with those described in the literature.

Keywords: anthranilic acids, aryne intermediates, 1,2,4-triazines, aza-Diels–Alder reaction.

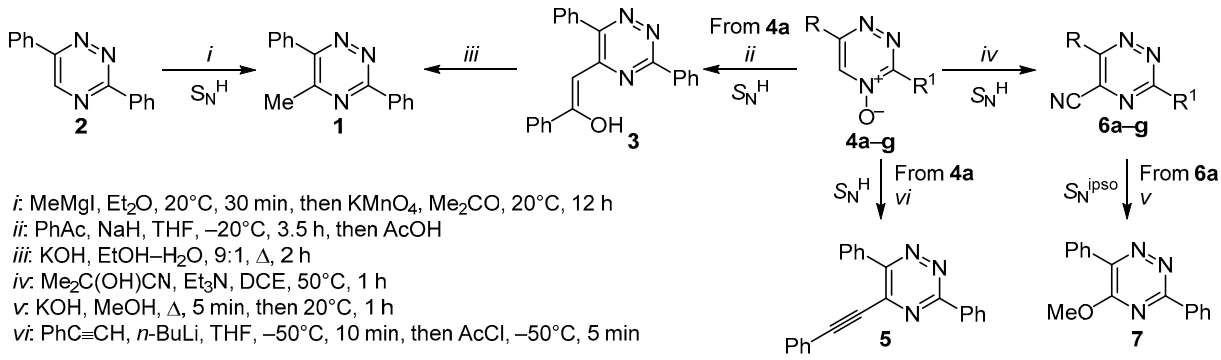
The isoquinoline system is a common component of naturally occurring compounds, in particular alkaloids.[1,2] Compounds of this class have various types of biological activity,[3] including antiHIV[4] and antitumor[5] activity. In addition, (benzo)(iso)quinolines are widely found in the composition of fluorescent chemosensors/ligands of transition metal cations,[6] explosives,[7] as well as fluorophores or fluorescent labels/(bio)probes for various purposes.[8] The introduction of conjugated or annulated aromatic fragments into the (iso)quinoline ring improves the photophysical properties of these compounds.[9]

Till to date, a number of methods for the synthesis of derivatives of isoquinolines have been described,[10] of which the "1,2,4-triazine" approach should be noted. Within its framework, isoquinolines can be obtained in two stages *via* intermediate 5,6,7,8-tetrahydro derivatives[11] or in a single step as a result of the reaction of 1,2,4-triazines with aryne intermediates.

Earlier, our research group studied in detail the reaction of 1,2,4-triazines containing a fragment of 2-pyridyl or its analogs in the C-3 position with arynes. Moreover, in reactions with aryne or its 4,5-dimethoxy derivative, domino transformation products were unexpectedly obtained as main products.[12] At the same time, 5-cyano-3-(2-pyridyl)-1,2,4-triazines in the reaction with arynes mainly formed isoquinolines,[13] (benz)isoquinolines, or 2-aza-anthracenes, which represent push-pull fluorophores with promising physicochemical properties.[14] Finally, only the domino transformation products were observed in the reaction of 3-(2-pyridyl)-1,2,4-triazines or 5-cyano-3-(2-pyridyl)-1,2,4-triazines with di- or tetrafluorinated arynes instead of isoquinolines.[15,16]

The object of the investigation within the framework of this work are isoquinolines containing a fragment different from 2-pyridyl or its analogs in the C-1 position. The synthesis of isoquinolines based on 1,2,4-triazines is currently mainly limited by examples of the preparation of compounds with electron-withdrawing substituents at the position C-1, such as ester or cyano groups.[17–19] In particular, isoquinolines containing (hetero)aromatic substituents in positions C-1 and C-4, despite the promising applications of these compounds (in particular, the possibility of using isoquinolines as fluorophores[20]), have not been previously obtained by the "aryne" method. It is

Scheme 1



i: MeMgI, Et_2O, 20°C, 30 min, then $KMnO_4$, Me_2CO, 20°C, 12 h
ii: PhAc, NaH, THF, –20°C, 3.5 h, then AcOH
iii: KOH, EtOH–H_2O, 9:1, Δ, 2 h
iv: $Me_2C(OH)CN$, Et_3N, DCE, 50°C, 1 h
v: KOH, MeOH, Δ, 5 min, then 20°C, 1 h
vi: PhC≡CH, *n*-BuLi, THF, –50°C, 10 min, then AcCl, –50°C, 5 min

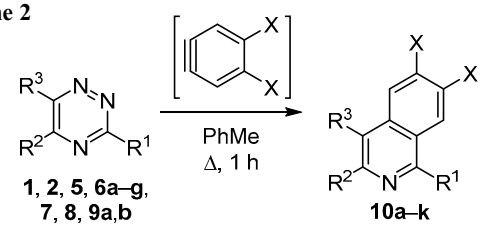
a R = R^1 = Ph; **b** R = Ph, R^1 = 2-FC_6H_4; **c** R = Tol, R^1 = 4-FC_6H_4; **d** R = Ph, R^1 = thiophen-2-yl; **e** R = Tol, R^1 = Me; **f** R = 4-FC_6H_4, R^1 = H; **g** R = Tol, R^1 = 3-$O_2NC_6H_4$

also necessary to note the wide possibilities for pre-functionalization of the C-5 position of the precursor 1,2,4-triazines, in particular when using nucleophilic hydrogen substitution reactions.[21] In this article, we present the results of a study of the possibilities of using 3,6-di(het)-aryl-1,2,4-triazines containing various substituents at position C-5 in reactions with aryl intermediates (both 1,2-dehydrobenzene and its 4,5-difluoro and 4,5-dimethoxy derivatives).

The methods shown in Scheme 1 can be used to obtain 5-functionalized 3,6-di(het)aryl-1,2,4-triazines. In particular, 5-methyl-1,2,4-triazines **1** can be obtained by several methods, for example, as a result of the reaction of 3,6-diphenyl-1,2,4-triazine (**2**) with methylmagnesium iodide followed by oxidative aromatization of the σ^H-adduct.[22] In addition, a methyl group at position C-5 can be formed as a result of alkaline hydrolysis of 1,2,4-triazine **3**, substituted in this position by a fragment of acetophenone,[23] which, in turn, forms as a result of direct CH functionalization of 5*H*-1,2,4-triazine 4-oxide **4a**.[24] The reaction of 1,2,4-triazine 4-oxide **4a** with lithium phenylacetylenide followed by deoxygenative aromatization of the σ^H-adduct allows to obtain 5-phenylethynyl-1,2,4-triazine **5**.[25] 1,2,4-Triazine-5-carbonitriles **6a**–**g** are formed as a result of the reaction of 1,2,4-triazine 4-oxides **4a**–**g** with acetone cyanohydrin in the presence of Et_3N.[26] Cyano group at position C-5 is very labile, and its subsequent *ipso* substitution in compound **6a** by the action of KOH, for example, leads to 5-methoxy-1,2,4-triazine **7**.[26] The remaining triazines – 3,5,6-triphenyl-1,2,4-triazine (**8**),[27] as well as unsubstituted at position 5 1,2,4-triazines **2** and **9a**,**b**[28,29] – were prepared by the procedures described above using various heterocyclization methods.

Next, we investigated the reactivity of the obtained 1,2,4-triazines with unsubstituted aryne, 1,2-dehydrobenzene, and with its difluoro and dimethoxy derivatives (Scheme 2, Table 1). We showed that 1,2,4-triazines unsubstituted at position C-5 (as exemplified by compound **2**) or containing electron-donating substituents at position C-5, for example, a methyl or methoxy group (triazines **1** and **7**) do not react with unsubstituted aryne. During the reaction of 1,2,4-triazines **9a**,**b** containing a 3- or 4-pyridyl fragment at the C-3 position with 1,2-dehydrobenzene, a complex unidentifiable mixture of products forms. This is probably due to competitive transformations initiated by the nucleophilic attack of the pyridine nitrogen atom carrying an unshared electron pair at the formal triple bond of the aryne intermediate. The possible mechanism of aryne-initiated domino transformations in the series of 3-(2-pyridyl)-1,2,4-triazines in the reaction with arynes was previously discussed.[13,15]

Scheme 2



1, **2**, **5**, **6a–g**, **7**, **8**, **9a**,**b** → **10a–k**

Table 1. The results of the reaction of 1,2,4-triazines **1**, **2**, **5**, **6a**–**g**, **7**, **8**, **9a**,**b** with aryne intermediates

Triazine	R^1	R^2	R^3	X	Product (yield, %)
1	Ph	Me	Ph	H	–*
1	Ph	Me	Ph	OMe	–
2	Ph	H	Ph	H	–
2	Ph	H	Ph	OMe	–
5	Ph	PhC≡C	Ph	H	**10k** (27)
5	Ph	PhC≡C	Ph	OMe	–
6a	Ph	CN	Ph	H	**10b** (42)
6b	2-FC_6H_4	CN	Ph	H	**10c** (39)
6c	4-FC_6H_4	CN	4-MeC_6H_4	H	**10d** (37)
6d	Thiophen-2-yl	CN	Ph	H	**10e** (45)
6e	Me	CN	4-MeC_6H_4	H	**10f** (40)
6f	H	CN	4-FC_6H_4	H	**10g** (40)
6c	4-FC_6H_4	CN	4-MeC_6H_4	OMe	**10h** (25)
6b	2-FC_6H_4	CN	Ph	OMe	**10i** (27)
6g	3-$O_2NC_6H_4$	CN	4-MeC_6H_4	H	**10j** (39)
7	Ph	OMe	Ph	H	–
7	Ph	OMe	Ph	OMe	–
8	Ph	Ph	Ph	H	**10a** (45)
8	Ph	Ph	Ph	OMe	–
9a	3-Py	H	Ph	H	Mixture
9b	4-Py	H	Ph	H	Mixture

* No reaction.

The introduction of an aromatic substituent in the C-5 position of 1,2,4-triazine changes the situation. Thus, the reaction of 3,5,6-triphenyl-1,2,4-triazine (**8**) with 1,2-dehydrobenzene results in the formation of the corresponding isoquinoline **10a**. The reaction of 1,2,4-triazines having electron-withdrawing substituents at position C-5 (triazines **5** and **6a**–**g**) with 1,2-dehydrobenzene also proceeds successfully and leads to the formation of isoquinolines **10b-j**,**k**, although in the former case the yield of the product is somewhat lower. Moreover, the nature of the substituent at position C-3 in 1,2,4-triazine-5-carbonitriles ((hetero)aromatic substituent, methyl group, or hydrogen atom) does not affect the result. As for the possibilities of using 4,5-dimethoxy-1,2-dehydrobenzene, in reactions with 1,2,4-triazines, its reactivity as a dienophile turned out to be significantly lower compared to unsubstituted aryne. In particular, the reaction successfully proceeded only in the presence of the strongly electron-withdrawing cyano group at the C-5 position of 1,2,4-triazines, the yields of the resulting 6,7-dimethoxyisoquinolines were lower. If there are substituents of a different nature at the C-5 atom, the reaction with this aryne does not proceed even with the use of higher boiling solvents (for example, *o*-xylene).

All attempts to conduct the reactions of the most electron-deficient 4,5-difluoro-1,2-dehydrobenzene with 1,2,4-triazines **1**, **2**, **5**–**9** discussed above in no case led to the formation of the expected 6,7-difluoroisoquinolines: the starting 1,2,4-triazines were recovered from the reaction mixture unchanged even under the conditions of using higher boiling solvents (*o*-xylene, 1,2-dichlorobenzene). These results correlate with the conclusions presented earlier,[15] namely, with the fact that in all cases of using fluorinated arynes in reactions with 3-(2-pyridyl)-1,2,4-triazines or their aza analogs, the reaction only proceeds as a domino transformation, but not the classic aza-Diels–Alder reaction.

The structures of products **10a**–**k** were confirmed by ^{1}H, ^{13}C NMR spectroscopy, mass spectrometry, and elemental analysis. In particular, ^{1}H NMR spectra showed resonance signals of protons of the isoquinoline fragment (for example, two singlets in the spectra of 6,7-dimethoxyisoquinolines; in the case of compound **10i**, one of the signals appears as a doublet due to the interaction of a proton with a fluorine atom at position 2 of the adjacent aromatic substituent). Notably, the proton signals of all substituents of the starting 1,2,4-triazine are preserved upon a change in chemical shifts; no transformations of these fragments during the reaction with arynes have been observed. In this aspect, it should be noted that earlier, when enamines were used as dienophiles, along with the expected aza-Diels–Alder reaction, chemical transformations involving the nitro or cyano group in the 1,2,4-triazine ring or its substituents were noted.[30]

The structures of the two obtained isoquinoline-3-carbonitriles **10c**,**d** were also confirmed by X-ray structural analysis (Figs. 1, 2).

To conclude, we have shown the possibility of using aryne intermediates as dienophiles in the aza-Diels–Alder reactions with 1,2,4-triazines (azadienes) containing (hetero)-aromatic substituents at positions C-3 and C-6 of the triazine ring and additionally functionalized by various groups, such as phenyl, cyano, and phenylethynyl at the C-5 position, for a one-step synthesis of 1,4-bis(het)-arylisoquinolines with yields of up to 45%. Moreover, the reactivity of unsubstituted 1,2-dehydrobenzene in these reactions was higher than its 4,5-dimethoxy derivative, while 4,5-difluoroaryne did not react with triazines, and the corresponding isoquinolines were not formed.

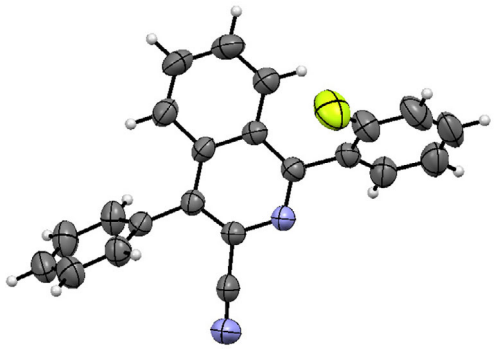


Figure 1. Molecular structure of isoquinoline **10c** with atoms represented as thermal vibration ellipsoids of 50% probability.

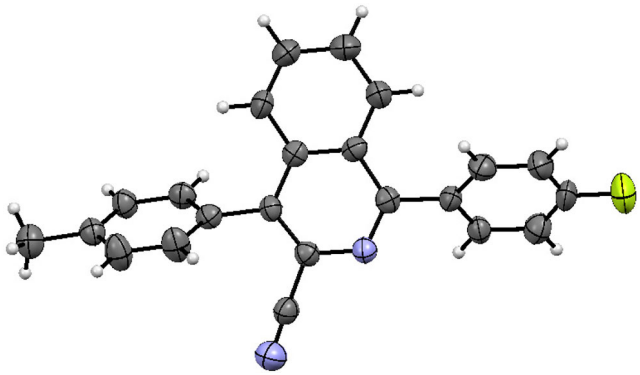


Figure 2. Molecular structure of isoquinoline **10d** with atoms represented as thermal vibration ellipsoids of 50% probability.

Experimental

^{1}H, ^{13}C, and ^{19}F NMR spectra were acquired on a Bruker Avance II (400, 100, 376 MHz, respectively), with TMS (for ^{1}H and ^{13}C nuclei) or $CFCl_3$ (for ^{19}F nuclei, δ 0 ppm) as internal standard. Mass spectra were recorded on a Bruker Daltonics MicrOTOF-Q II mass spectrometer, electrospray ionization. Monitoring of the reaction progress and assessment of the purity of synthesized compounds were done by TLC on Sigma-Aldrich 91835 plates. Products were purified by column chromatography on silica gel supplied by Sigma-Aldrich (230–400 mesh).

The starting 3,6-diphenyl-1,2,4-triazine (**2**),[28] 2-(3,6-diphenyl-1,2,4-triazin-5-yl)-1-phenylethanol (**3**),[24] 3,6-diphenyl-5-phenylethynyl-1,2,4-triazine (**5**),[25] 1,2,4-triazine-5-carbonitriles **6a**,**e**,[26]**c**,**d**,[14] 5-methoxy-3,6-diphenyl-1,2,4-triazine (**7**),[26] 3,5,6-triphenyl-1,2,4-triazine (**8**),[27] 6-phenyl-3-(3-pyridyl)-1,2,4-triazine (**9a**),[29] and 6-phenyl-3-(4-pyridyl)-1,2,4-triazine (**9b**)[29] were synthesized by literature methods.

3-(2-Fluorophenyl)-6-phenyl-1,2,4-triazine-5-carbonitrile (6b) was prepared by a published procedure.[26] Yield 103 mg (76%), yellow crystals, mp >250°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.26–7.30 (1H, m, H fluorophenyl); 7.35 (1H, t, *J* = 7.6, H fluorophenyl); 7.52–7.55 (1H, m, H fluorophenyl); 7.63–7.70 (3H, m, H Ph); 8.15–8.20 (2H, m, H Ph); 8.23–8.28 (1H, m, H fluorophenyl). Mass spectrum, *m*/*z* (I_{rel}, %): 277 $[M+H]^+$ (100). Found, %: C 69.69; H 3.15; N 20.12. $C_{16}H_9FN_4$. Calculated, %: C 69.56; H 3.28; N 20.28.

6-(4-Fluorophenyl)-1,2,4-triazine-5-carbonitrile (6f) was prepared by a published procedure.[26] Yield 99 mg (74%), yellow crystals, mp >250°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.40–7.44 (2H, m, H fluorophenyl); 8.17–8.21 (2H, m, H fluorophenyl); 10.07–10.11 (1H, m, H-3). Mass spectrum, *m*/*z* (I_{rel}, %): 201 $[M+H]^+$ (100). Found, %: C 60.16; H 2.63; N 27.85. $C_{10}H_5FN_4$. Calculated, %: C 60.00; H 2.52; N 27.99.

6-(4-Methylphenyl)-3-(3-nitrophenyl)-1,2,4-triazine-5-carbonitrile (6g) was prepared by a published procedure.[26] Yield 106 mg (80%), yellow crystals, mp >250°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 2.51 (3H, s, CH_3); 7.50 (2H, d, *J* = 7.6, H methylphenyl); 7.97 (1H, t, *J* = 8.0, H-5 nitrophenyl); 8.03 (2H, d, *J* = 8.0, H methylphenyl); 8.49–8.51 (1H, m, *J* = 8.4, H-6 nitrophenyl); 8.92–8.94 (1H, m, *J* = 8.4, H-4 nitrophenyl); 9.25–9.26 (1H, m, H-2 nitrophenyl). Mass spectrum, *m*/*z* (I_{rel}, %): 318 $[M+H]^+$ (100). Found, %: C 64.24; H 3.38; N 22.18. $C_{17}H_{11}N_5O_2$. Calculated, %: C 64.35; H 3.49; N 22.07.

5-Methyl-3,6-diphenyl-1,2,4-triazine (1). 2-(3,6-Diphenyl-1,2,4-triazin-5-yl)-1-phenylethanol (**3**) (210 mg, 0.60 mmol) was dissolved in a mixture of EtOH (45 ml) and H_2O (5 ml), KOH (101 mg, 1.80 mmol) was added, and the resulting mixture was heated under reflux for 2 h. The product was extracted with CH_2Cl_2 (3×25 ml). The combined organics were dried over anhydrous Na_2SO_4, the solvent was evaporated under reduced pressure, and the residue was recrystallized from EtOH. Yield 123 mg (83%), light-yellow crystals, mp 129–131°C (mp 122–124°C[22]). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 2.71 (3H, s, CH_3); 7.51–7.59 (6H, m, H Ph); 7.70–7.74 (2H, m, H Ph); 8.58–8.62 (2H, m, H Ph). Mass spectrum, *m*/*z* (I_{rel}, %): 248 $[M+H]^+$ (100). Found, %: C 77.58; H 5.21; N 17.20. $C_{26}H_{16}N_3$. Calculated, %: C 77.71; H 5.30; N 16.99.

Synthesis of isoquinolines 10a–k (General method). The corresponding triazine **1**, **2**, **5**, **6a–g**, **7**, **8**, **9a**,**b** (1.5 mmol) was suspended in dry PhMe (50 ml), and isoamyl nitrite (0.8 ml, 6 mmol) was added. The resulting mixture was stirred under reflux under an argon atmosphere, and a solution of the respective anthranilic acid (6 mmol) in dry 1,4-dioxane (15 ml) was added dropwise over 30 min. The mixture was heated under reflux for 1 h and cooled to room temperature. The reaction mixture was washed with 3 M aqueous NaOH (3×75 ml), the organic layer was dried over anhydrous Na_2SO_4, the solvent was evaporated under reduced pressure. The products were isolated by column chromatography on silica gel, eluent CH_2Cl_2, R_f 0.5. Analytical samples of products were obtained by recrystallization from MeCN.

1,3,4-Triphenylisoquinoline (10a). Yield 241 mg (45%), colorless crystals, mp 178–180°C (mp 178–180°C[12d]). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 7.15–7.19 (3H, m, H Ph); 7.28–7.32 (2H, m, H Ph); 7.34–7.45 (5H, m, H Ph); 7.48–7.62 (5H, m, H Ph); 7.72 (1H, dd, *J* = 8.0, *J* = 1.2, H-8); 7.81–7.83 (2H, m, H-6,7); 8.18 (1H, dd, *J* = 8.0, *J* = 1.2, H-5). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm : 125.5; 126.1; 126.6; 127.0; 127.3; 127.5; 127.6; 128.3; 128.4; 128.6; 129.8; 130.0; 130.3; 130.5; 131.4; 137.0; 137.6; 139.9; 141.0; 149.7; 159.8. Mass spectrum, *m*/*z* (I_{rel}, %): 358 $[M+H]^+$ (100). Found: C 90.52; H 5.25; N 3.66. $C_{27}H_{19}N$. Calculated, %: C 90.72; H 5.36; N 3.92.

1,4-Diphenylisoquinoline-3-carbonitrile (10b). Yield 193 mg (42%), colorless crystals, mp >250°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.52–7.57 (2H, m, H Ph); 7.58–7.69 (6H, m, H Ph); 7.69–7.77 (3H, m, H Ph, H-5); 7.78–7.87 (2H, m, H-6,7); 8.21 (1H, dd, *J* = 7.6, *J* = 1.5, H-8). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 117.7; 125.7; 126.7; 127.6; 128.1; 128.6; 129.0; 129.4 (2C); 129.8; 130.1; 130.3; 131.4; 133.8; 135.5; 138.1; 139.4; 161.7. Mass spectrum, *m*/*z* (I_{rel}, %): 307 $[M+H]^+$ (100). Found, %: C 86.08; H 4.53; N 9.00. $C_{22}H_{14}N_2$. Calculated, %: C 86.25; H 4.61; N 9.14.

1-(2-Fluorophenyl)-4-phenylisoquinoline-3-carbonitrile (10c). Yield 190 mg (39%), colorless crystals, mp 165–167°C. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 7.27–7.29 (1H, m, H fluorophenyl); 7.39 (1H, dd, *J* = 7.6, *J* = 7.3, *J* = 1.0, H fluorophenyl); 7.51–7.58 (3H, m, H Ar); 7.59–7.68 (4H, m, H Ar); 7.69–7.78 (2H, m, H Ar); 7.80–7.82 (1H, m, H fluorophenyl); 7.92–7.94 (1H, m, H isoquinoline). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 116.0 (d, *J* = 22.5); 117.5; 124.7 (d, *J* = 4.0); 126.6; 127.8 (d, *J* = 2.7); 128.2; 128.8; 128.9; 129.5; 130.0; 130.2; 130.9; 131.5 (d, *J* = 8.6); 131.6; 132.0 (d, *J* = 2.7); 132.5; 133.6; 135.0; 140.1; 157.2; 160.0 (d, *J* = 249.1). Mass spectrum, *m*/*z* (I_{rel}, %): 325 $[M+H]^+$ (100). Found, %: C 81.55; H 3.89; N 8.29. $C_{22}H_{13}FN_2$. Calculated, %: C 81.47; H 4.04; N 8.64.

1-(4-Fluorophenyl)-4-(4-methylphenyl)isoquinoline-3-carbonitrile (10d). Yield 186 mg (37%), colorless crystals, mp 158–160°C. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 2.50 (3H, s, CH_3); 7.24–7.31 (3H, m, H fluorophenyl, H isoquinoline); 7.39–7.45 (4H, m, H methylphenyl); 7.69–7.77 (3H, m, H fluorophenyl, H isoquinoline); 7.84–7.86 (1H, m, H isoquinoline) 8.17–8.19 (1H, m, H isoquinoline). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 21.4; 115.6; 115.8; 117.7; 125.7; 126.9; 127.5; 127.7; 129.1; 129.7; 130.1; 130.6; 132.0; 132.1; 134.2 (d, *J* = 3.0); 135.7; 139.5 (d, *J* = 10.5); 160.3; 163.6 (d, *J* = 249.5). Mass spectrum, *m*/*z* (I_{rel}, %): 339 $[M+H]^+$ (100). Found, %: C 81.47; H 4.31; N 8.02. $C_{23}H_{15}FN_2$. Calculated, %: C 81.64; H 4.47; N 8.28.

4-Phenyl-1-(thiophen-2-yl)isoquinoline-3-carbonitrile (10e). Yield 211 mg (45%), colorless crystals, mp 169–171°C (mp 169–171°C[13b]). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.31 (1H, dd, *J* = 4.8, *J* = 3.6, H-4 thiophene); 7.51–7.55 (2H, m, H Ph); 7.60–7.68 (3H, m, H Ph); 7.71–7.73 (1H, m, H isoquinoline); 7.79 (1H, dd, *J* = 3.6, *J* = 0.8, H-3 thiophene); 7.82 (1H, dd, *J* = 4.8, *J* = 0.8, H-5

thiophene); 7.85–7.94 (2H, m, H isoquinoline); 8.66–8.68 (1H, m, H isoquinoline). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 117.5; 125.6; 126.9 (2C); 127.4; 127.8; 129.0; 129.3; 129.4; 130.0; 130.3; 131.5; 133.7; 135.8; 139.0; 141.0; 154.5. Mass spectrum, *m*/*z* (I_{rel}, %): 313 $[M+H]^+$ (100). Found, %: C 76.72; H 3.78; N 8.81. $C_{20}H_{12}N_2S$. Calculated, %: C 76.90; H 3.87; N 8.97.

1-Methyl-4-(4-methylphenyl)isoquinoline-3-carbonitrile (10f). Yield 155 mg (40%), colorless crystals, mp 115–117°C. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 2.48 (3H, s, $C_6H_4C\underline{H}_3$); 3.03 (3H, s, CH_3); 7.33–7.40 (4H, m, H Ar); 7.69–7.79 (3H, m, H-6,7,8); 8.20–8.25 (1H, m, H-5). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 21.4; 22.5; 118.0; 125.2; 125.9; 127.0; 128.3; 129.6; 129.7; 130.1; 130.8; 131.2; 134.5; 139.1; 139.2; 159.7. Mass spectrum, *m*/*z* (I_{rel}, %): 259 $[M+H]^+$ (100). Found, %: C 83.56; H 5.34; N 10.99. $C_{18}H_{14}N_2$. Calculated, %: C 83.69; H 5.46; N 10.84.

4-(4-Fluorophenyl)isoquinoline-3-carbonitrile (10g). Yield 145 mg (40%), colorless crystals, mp 111–113°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.25–7.32 (2H, m, H Ar); 7.45–7.50 (2H, m, H Ar); 7.70–7.74 (1H, m, H-8); 7.76–7.84 (2H, m, H-6,7); 8.10–8.14 (1H, m, H-5); 9.05 (1H, s, H-1). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 115.2 (d, *J* = 21.0); 124.9; 127.1; 128.1; 128.3 (d, *J* = 3.8); 129.1; 129.9; 131.0; 131.1; 133.3; 138.3; 152.2; 162.4 (d, *J* = 250.0). ^{19}F NMR spectrum (DMSO-d_6), δ, ppm: –111.32 (1F, s). Mass spectrum, *m*/*z* (I_{rel}, %): 249 $[M+H]^+$ (100). Found, %: C 77.29; H 3.52; N 11.13. $C_{16}H_9FN_2$. Calculated, %: C 77.41; H 3.65; N 11.28.

1-(4-Fluorophenyl)-6,7-dimethoxy-4-(4-methylphenyl)-isoquinoline-3-carbonitrile (10h). Yield 149 mg (25%), colorless crystals, mp 155–157°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 2.47 (3H, s, $C_6H_4C\underline{H}_3$); 3.35 (3H, s, OCH_3); 3.85 (3H, s, OCH_3); 7.00 (1H, s, H-8); 7.41 (1H, s, H-5); 7.41–7.53 (6H, m, H Ar); 7.81–7.87 (2H, m, H Ar). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 21.5; 56.1 (2C); 105.0; 105.8; 115.6; 115.9; 118.1; 123.9; 124.8; 129.8; 129.9; 131.1; 131.6 (d, *J* = 8.1); 132.4; 134.7 (d, *J* = 3.9); 138.1; 139.3; 151.1; 154.1; 157.7, 163.4 (d, *J* = 249.0). Mass spectrum, *m*/*z* (I_{rel}, %): 399 $[M+H]^+$ (100). Found, %: C 75.46; H 4.89; N 7.13. $C_{25}H_{19}FN_2O_2$. Calculated, %: C 75.36; H 4.81; N 7.03.

1-(2-Fluorophenyl)-6,7-dimethoxy-4-phenylisoquinoline-3-carbonitrile (10i). Yield 156 mg (27%), colorless crystals, mp 160–162°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 3.78 (3H, s, OCH_3); 3.83 (3H, s, OCH_3); 6.94 (1H, s, H-5); 7.04 (1H, d, *J* = 3.8, H-8); 7.33–7.35 (1H, m, H fluorophenyl); 7.41–7.43 (1H, m, H fluorophenyl); 7.48–7.69 (6H, m, H Ph, H fluorophenyl). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz): 56.1 (2C); 104.6; 105.7 (d, *J* = 2.9); 115.9 (d, *J* = 21.7); 117.8; 124.8 (2C); 124.9; 126.3 (d, *J* = 16.2); 129.0; 129.4; 130.0; 131.3 (d, *J* = 8.6); 131.8; 132.0 (d, *J* = 3.7); 134.2; 138.5; 152.1; 153.6; 154.3; 159.9 (d, *J* = 247.8). Mass spectrum, *m*/*z* (I_{rel}, %): 385 $[M+H]^+$ (100). Found, %: C 74.76; H 4.31; N 7.09. $C_{24}H_{17}FN_2O_2$. Calculated, %: C 74.99; H 4.46; N 7.29.

4-(4-Methylphenyl)-1-(3-nitrophenyl)isoquinoline-3-carbonitrile (10j). Yield 213 mg (39%), colorless crystals, mp >250°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 2.54 (3H, s, CH_3); 7.43–7.51 (4H, m, H Ar); 7.81–7.97 (4H, m, H-5,6 nitrophenyl, H-6,7); 8.17–8.21 (2H, m, H-5,8); 8.45–8.47 (1H, m, H-4 nitrophenyl); 8.55 (1H, dd, *J* = 1.8, *J* = 1.8, H-2 nitrophenyl). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 21.5; 117.6; 124.2; 125.1; 125.7; 127.0; 127.2; 129.8; 129.9; 130.1 (2C); 130.3; 130.6; 131.9; 135.8; 136.1; 139.6; 139.7; 140.5; 148.3; 158.6. Mass spectrum, *m*/*z* ($I_{rel.}$, %): 366 $[M+H]^+$ (100). Found, %: C 75.77; H 4.21; N 11.42. $C_{23}H_{15}N_3O_2$. Calculated, %: C 75.60; H 4.14; N 11.50.

1,4-Diphenyl-3-(phenylethynyl)isoquinoline (10k). Yield 154 mg (27%), colorless crystals, mp 129–131°C. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm (*J*, Hz): 7.20–7.25 (5H, m, H Ph); 7.48–7.63 (10H, m, H Ph); 7.69–7.72 (1H, m, H-8); 7.74–7.77 (2H, m, H-6,7); 8.08–8.12 (1H, m, H-5). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 89.8; 92.5; 122.9; 125.9; 127.4; 128.0; 128.2; 128.3; 128.4; 128.8; 129.7; 129.9; 130.1; 130.4; 130.5; 130.9; 131.8; 133.0; 134.8; 135.9; 136.0; 136.8; 139.2; 160.8. Mass spectrum, *m*/*z* (I_{rel}, %): 382 $[M+H]^+$ (100). Found, %: C 91.22; H 5.17; N 3.81. $C_{29}H_{19}N$. Calculated, %: C 91.31; H 5.02; N 3.67.

Scale-up of isoquinoline 10a synthesis method. Isoamyl nitrite (3.45 ml, 25.88 mmol) was added to a suspension of triazine **8** (2.00 g, 6.47 mmol) in dry PhMe (250 ml). A solution of anthranilic acid (3.55 g, 25.88 mmol) in dry 1,4-dioxane (60 ml) was added dropwise over 30 min with stirring and heating under reflux under an argon atmosphere. The mixture was heated under reflux for 1 h and cooled to room temperature. The reaction mixture was washed with 3 M aqueous NaOH (3×250 ml), the organic layer was dried over anhydrous Na_2SO_4, the solvent was evaporated under reduced pressure. The product was isolated by recrystallization from MeCN. Yield 1.00 g (43%).

X-ray structural analysis of compounds 10c,d was performed on an Xcalibur 3 (Oxford Diffraction) diffractometer. Solving and refinement of structures was carried out using the SHELXTL software package.[31] The structures were solved with the direct method and refined against F^2 by the least-squares technique in the full-matrix anisotropic (isotropic for hydrogen atoms) approximation. Main crystallographic parameters of compound **10c** (empirical formula $C_{22}H_{13}FN_2$, M_r 324.36): monoclinic crystal system; space symmetry group $P2_1/c$; *a* 10.860(7), *b* 16.074(3), *c* 9.681(6) Å; β 104.51(5)°; *V* 1635.9(15) Å^3; *Z* 4; μ 0.086 mm^{-1}. 9930 reflections were collected at scattering angles $5.64 < 2\Theta < 52.8°$, of which 3339 were independent (R_{int} 0.0399). The final refinement parameters: R_1 0.0497 ($I > 2\sigma(I)$), R_1 0.1212, wR_2 0.0963 (all reflections) with the quality factor *GOOF* 1.002. Residual electron density peaks 0.28/–0.31 eÅ^{-3}. Main crystallographic parameters of compound **10d** (empirical formula $C_{23}H_{15}FN_2$, M_r 338.37): rhombic crystal system; space symmetry group *Pbca*; *a* 17.1411(16), *b* 9.8087(10), *c* 20.2589(17) Å; *V* 3406.2(5) Å^3; *Z* 8; μ 0.086 mm^{-1}. 12538 reflections were collected at scattering angles $4.68 < 2\Theta < 61.66°$, of which 4711 were independent (R_{int} 0.0684). The final refinement parameters: R_1 0.0604,

wR_2 0.0949 ($I > 2\sigma(I)$), R_1 0.1893, wR_2 0.1375 (all reflections) with the quality factor *GOOF* 0.974. Residual electron density peaks 0.23/–0.19 eÅ^{-3}. The full set of X-ray structural data for compounds **12c**,**d** were deposited at the Cambridge Crystallographic Data Center (deposits CCDC 1921341 and CCDC 1921342, respectively).

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References

1. (a) *Heterocycles in Natural Product Synthesis*; Majumdar, K. C.; Chattopadhyay, S. K., Eds.; Wiley-VCH: Weinheim, 2011. (b) *The Chemistry of Heterocyclic Compounds*; Coppola, G. M.; Schuster, H. F.; Wiley: New York, 1981, Vol. 38, Part 3, p. 552.
2. Merck, G. *Ann. Chem. Pharm*. **1848**, *66*, 125.
3. (a) Handley, D. A.; Van Valen, R. G.; Melden, M. K.; Houlihan, W. J.; Saunders, R. N. *J. Pharmacol. Exp. Ther*. **1988**, *247*, 617. (b) Houlihan, W. J.; Cheon, S. H.; Parrino, V. A.; Handley, D. A.; Larson, D. A. *J. Med. Chem*. **1993**, *36*, 3098. (c) Scholz, D.; Schmidt, H.; Prieschl, E. E.; Csonga, R.; Scheirer, W.; Weber, V.; Lembachner, A.; Seidl, G.; Werner, G.; Mayer, P.; Baumruker, T. *J. Med. Chem*. **1998**, *41*, 1050. (d) Griffin, R. J.; Fontana, G.; Golding, B. T.; Guiard, S.; Hardcastle, I. R.; Leahy, J. J. J.; Martin, N.; Richardson, C.; Rigoreau, L.; Stockley, M.; Smith, G. C. M. *J. Med. Chem*. **2005**, *48*, 569.
4. (a) Iwasa, K.; Moriyasu, M.; Tachibana, Y.; Kim, H. S.; Wataya, Y.; Wiegrebe, W.; Bastow, K. F.; Cosentino, L. M.; Kozuka, M.; Lee, K. H. *Bioorg. Med. Chem*. **2001**, *9*, 2871. (b) Miller, J. F.; Gudmundsson, K. S.; D'Aurora Richardson, L.; Jenkinson, S.; Spaltenstein, A.; Thomson, M.; Wheelan, P. *Bioorg. Med. Chem. Lett*. **2010**, *20*, 3026. (c) Kashiwada, Y.; Aoshima, A.; Ikeshiro, Y.; Chen, Y.-P.; Furukawa, H.; Itoigawa, M.; Fujioka, T.; Mihashi, K.; Cosentino, L. M.; Morris-Natschke, S. L.; Lee, K. H. *Bioorg. Med. Chem*. **2005**, *13*, 443.
5. (a) Mukherjee, A.; Dutta, S.; Sanyal, U. *J. Cancer Res. Ther*. **2013**, *9*, 442. (b) Fontana, A.; Cavaliere, P.; Wahidulla, S.; Naik, C. G.; Cimino, G. *Tetrahedron* **2000**, *56*, 7305.
6. (a) Jiang, Y.; Kong, W.; Shen, Y.; Wang, B. *Tetrahedron* **2015**, *71*, 5584. (b) Kho, Y.-M.; Shin, E. J. *Molecules* **2017**, *22*, 1569.
7. (a) Halder, S.; Ghosh, P.; Hazra, A.; Banerjee, P.; Roy, P. *New J. Chem*. **2018**, *42*, 8408. (b) Ma, Y.; Hao, Li, H.; Peng, S.; Wang, L. *Anal. Chem*. **2012**, *84*, 8415. (c) Zyryanov, G. V.; Kopchuk, D. S.; Kovalev, I. S.; Nosova, E. V.; Rusinov, V. L.; Chupakhin, O. N. *Russ. Chem. Rev*. **2014**, *83*, 783. [*Usp. Khim.* **2014**, *83*, 783.]
8. (a) Kumar, N. S.; Rao, L. C.; Babu, N. J.; Meshram, H. M. *RSC Adv*. **2015**, *5*, 95539. (b) Roya, B.; Hazraab, P. *J. Mol. Liq*. **2018**, *261*, 520. (c) Zhao, Y.; Zhang, G.; Liu, Z.; Guo, C.; Peng, C.; Pei, M.; Li, P. *J. Photochem. Photobiol., A* **2016**, *314*, 52. (c) Li, G.; Zhu, D.; Xue, L.; Jang, H. *Org. Lett*. **2013**, *15*, 5020.
9. (a) Rotzoll, S.; Willy, B.; Schönhaber, J.; Rominger, F.; Müller, T. J. J. *Eur. J. Org. Chem*. **2010**, 3516. (b) Woody, K. B.; Henry, E. M.; Jagtap, S.; Collard, D. M. *Macromolecules* **2011**, *44*, 9118. (c) Schaffroth, M.; Lindner, B. D.; Vasilenko, V.; Rominger, F.; Bunz, U. H. F. *J. Org. Chem*. **2013**, *78*, 3142. (d) Kopchuk, D. S.; Khasanov, A. F.; Kim, G. A.; Nosova, E. V.; Zyryanov, G. V.; Kovalev, I. S.; Rusinov, V. L.; Chupakhin, O. N. *Russ. Chem. Bull., Int. Ed*. **2015**, *64*, 872. [*Izv. Akad. Nauk, Ser. Khim.* **2015**, 872.] (e) Moni, L.; Gers-Panther, C. F.; Anselmo, M.; Müller, T. J. J.; Riva, R. *Chem.–Eur. J*. **2016**, *22*, 2020.
10. (a) Pomeranz, C. *Monatsh. Chem*. **1893**, *14*, 116. (b) Bischler, A.; Napieralski, B. *Ber. Dtsch. Chem. Ges*. **1893**, *26*, 190. (c) *Comprehensive Organic Name Reactions and Reagents*; Wang, Z., Ed.; Wiley-Interscience: New Jersey, 2010, p. 2206. (d) Doi, S.; Shirai, N.; Sato, Y. *J. Chem. Soc., Perkin Trans*. **1997**, *1*, 2217. (e) *Comprehensive Organic Name Reactions and Reagents*; Wang, Z., Ed.; Wiley-Interscience: New Jersey, 2010, p. 544. (f) Loones, K. T. J.; Maes, B. U. W.; Dommisse, R. A.; Lemiere, G. L. F. *Chem. Commun*. **2004**, 2466. (g) Sharon, A.; Pratap, R.; Maulik, P. R.; Ram, V. J. *Tetrahedron* **2005**, *61*, 3781.
11. Kopchuk, D. S.; Kovalev, I. S.; Khasanov, A. F.; Zyryanov, G. V.; Slepukhin, P. A.; Rusinov, V. L.; Chupakhin, O. N. *Mendeleev Commun*. **2013**, *23*, 142.
12. (a) Kopchuk, D. S.; Chepchugov, N. V.; Khasanov, A. F.; Kovalev, I. S.; Santra, S.; Nosova, E. V.; Zyryanov, G. V.; Majee, A.; Rusinov, V. L.; Chupakhin, O. N. *Tetrahedron Lett*. **2016**, *57*, 3862. (b) Kopchuk, D. S.; Nikonov, I. L.; Zyryanov, G. V.; Nosova, E. V.; Kovalev, I. S.; Slepukhin, P. A.; Rusinov, V. L.; Chupakhin, O. N. *Mendeleev Commun*. **2015**, *25*, 13. (c) Kopchuk, D. S.; Nikonov, I. L.; Zyryanov, G. V.; Kovalev, I. S.; Taniya, O. S.; Rusinov, V. L.; Chupakhin, O. N. *Russ. J. Org. Chem*. **2015**, *51*, 1170. [*Zh. Org. Khim.* **2015**, *51*, 1189.] (d) Nikonov, I. L.; Kopchuk, D. S.; Kovalev, I. S.; Zyryanov, G. V.; Khasanov, A. F.; Slepukhin, P. A.; Rusinov, V. L.; Chupakhin, O. N. *Tetrahedron Lett*. **2013**, *54*, 6427.
13. (a) Kopchuk, D. S.; Nikonov, I. L.; Zyryanov, G. V.; Kovalev, I. S.; Rusinov, V. L.; Chupakhin, O. N. *Chem. Heterocycl. Compd*. **2014**, *50*, 907. [*Khim. Geterotsikl. Soedin.* **2014**, 983.] (b) Kopchuk, D. S.; Krinochkin, A. P.; Khasanov, A. F.; Kovalev, I. S.; Slepukhin, P. A.; Starnovskaya, E. S.; Mukherjee, A.; Rahman, M.; Zyryanov, G. V.; Majee, A.; Rusinov, V. L.; Chupakhin, O. N.; Santra, S. *Synlett* **2018**, 483. (c) Kopchuk, D. S.; Nikonov, I. L.; Krinochkin, A. P.; Kovalev, I. S.; Zyryanov, G. V.; Rusinov, V. L.; Chupakhin, O. N. *Russ. J. Org. Chem*. **2017**, *53*, 959. [*Zh. Org. Khim.* **2017**, *53*, 942.]
14. Kopchuk, D. S.; Chepchugov, N. V.; Taniya, O. S.; Khasanov, A. F.; Giri, K.; Kovalev, I. S.; Santra, S.; Zyryanov, G. V.; Majee, A.; Rusinov, V. L.; Chupakhin, O. N. *Tetrahedron Lett*. **2016**, *57*, 5639.
15. Kopchuk, D. S.; Nikonov, I. L.; Khasanov, A. F.; Giri, K.; Santra, S.; Kovalev, I. S.; Nosova, E. V.; Gundala, S.; Venkatapuram, P.; Zyryanov, G. V.; Majee, A.; Chupakhin, O. N. *Org. Biomol. Chem*. **2018**, *16*, 5119.
16. Kopchuk, D. S.; Chepchugov, N. V.; Gorbunov, E. B.; Zyryanov, G. V.; Kovalev, I. S.; Nosova, E. V.; Slepukhin, P. A.; Rusinov, V. L.; Chupakhin, O. N. *J. Iran. Chem. Soc*. **2017**, *14*, 1507.
17. Gonsalves, A. M. d'A. R.; Pinho e Melo, T. M. V. D.; Gilchrist, T. L. *Tetrahedron* **1992**, *48*, 6821.
18. Dhar, R.; Hühnermann, W.; Kämpchen, T.; Overheu, W.; Seitz, G. *Chem. Ber*. **1983**, *116*, 97.
19. Himmelsbach, F.; Langkopf, E.; Eckhardt, M.; Maier, R.; Mark, M.; Tadayyon, M.; Lotz, R. WO Patent 2004/041820 A1.
20. Balog, J.; Riedl, Z.; Hajós, G.; Miskolczy, Z.; Biczók, L. *ARKIVOC* **2012**, (v), 109.
21. (a) *Metal Free C–H Functionalization of Aromatics*; Charushin, V. N.; Chupakhin, O. N., Eds.; Springer International Publishing: Cham, 2014, p. 283. (b) Chupakhin, O. N.;

Charushin, V. N. *Tetrahedron Lett*. **2016**, *57*, 2665. (c) Chupakhin, O. N.; Charushin, V. N. *Pure Appl. Chem*. **2017**, *89*, 1195. (d) Chupakhin, O. N.; Postovskii, I. Ya. *Russ. Chem. Rev.* **1976**, *45*, 454. [*Usp. Khim.* **1976**, *45*, 908.]
22. Konno, S.; Sagi, M.; Takaharu, E.; Fujimura, S.; Hayashi, K.; Yamanaka, H. *Chem. Pharm. Bull*. **1988**, *36*, 1721.
23. Krinochkin, A. P.; Kopchuk, D. S.; Kovalev, I. S.; Zyryanov, G. V.; Rusinov, V. L.; Chupakhin, O. N. *Russ. J. Org. Chem*. **2019**, *55*, 266. [*Zh. Org. Khim.* **2019**, *55*, 303.]
24. Kozhevnikov, D. N.; Kovalev, I. S.; Prokhorov, A. M.; Rusinov, V. L.; Chupakhin O. N. *Russ. Chem. Bull*., *Int. Ed.* **2003**, *52*, 1588. [*Izv. Akad. Nauk, Ser. Khim.* **2003**, 1504.]
25. Prokhorov, A. M.; Mąkosza, M.; Chupakhin O. N. *Tetrahedron Lett*. **2009**, *50*, 1444.
26. Kozhevnikov, D. N.; Kozhevnikov, V. N.; Kovalev, I. S.; Rusinov, V. L.; Chupakhin, O. N.; Aleksandrov, G. G. *Russ. J. Org. Chem*. **2002**, *38*, 744. [*Zh. Org. Khim.* **2002**, *38*, 780.]
27. Dubovtsev, A. Yu.; Dar'in, D. V.; Krasavin, M.; Kukushkin, V. Yu. *Eur. J. Org. Chem*. **2019**, 1856.
28. Saraswathi, T. V.; Srinivasan, V. R. *Tetrahedron* **1977**, *33*, 1043.
29. Kozhevnikov, V. N.; Shabunina, O. V.; Kopchuk, D. S.; Ustinova, M. M.; König B.; Kozhevnikov, D. N. *Tetrahedron* **2008**, *64*, 8963.
30. (a) Kopchuk, D. S.; Khasanov, A. F.; Kovalev, I. S.; Zyryanov, G. V.; Rusinov, V. L.; Chupakhin, O. N. *Mendeleev Commun*. **2013**, *23*, 209. (b) Kopchuk, D. S.; Khasanov, A. F.; Krinochkin, A. P.; Kovalev, I. S.; Zyryanov, G. V.; Rusinov, V. L.; Chupakhin, O. N. *Russ. J. Org. Chem*. **2016**, *52*, 1036. [*Zh. Org. Khim.* **2016**, *52*, 1041.] (c) Kopchuk, D. S.; Khasanov, A. F.; Chepchugov, N. V.; Kovalev, I. S.; Zyryanov, G. V.; Rusinov, V. L.; Chupakhin, O. N. *Russ. J. Org. Chem*. **2017**, *53*, 99. [*Zh. Org. Khim.* **2017**, *53*, 103.]
31. Sheldrick, G. M. *Acta Crystallogr.*, *Sect. A*: *Found. Crystallogr.* **2008**, *A64*, 112.