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Химия гетероциклических соединений

Oxidative cyclization of 5-aryl-1-benzyl-1,2,3-triazoles bearing electron-rich aromatic groups: *ortho*/*ortho* and *ortho*/*ipso* coupling

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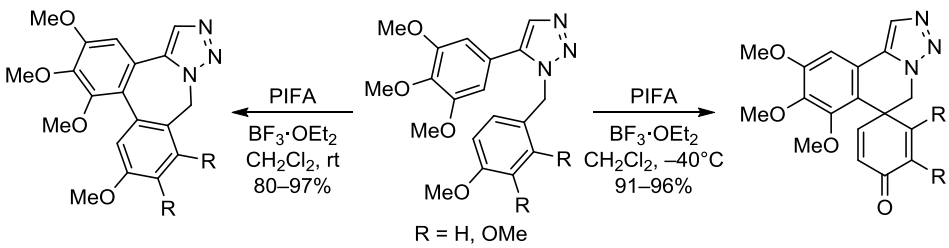


The intramolecular oxidative coupling of electron-rich aromatic groups in 5-(het)aryl-1-(het)arylalkyl-1*H*-1,2,3-triazoles was studied in detail. Under treatment with phenyliodoso bis(trifluoroacetate) and boron trifluoride etherate these substrates afforded products of either *ortho*/*ortho* or *ortho*/*ipso* coupling depending on the nature of aromatic groups and reaction conditions applied. It was found that for substrates which are capable for both types of coupling, *ortho*-/*ipso*-adducts are formed under kinetic control while *ortho*-/*ortho*-products are formed under thermodynamic control. The developed procedures allow preparation of complex polycyclic azaheterocycles from simple precursors in two steps only.

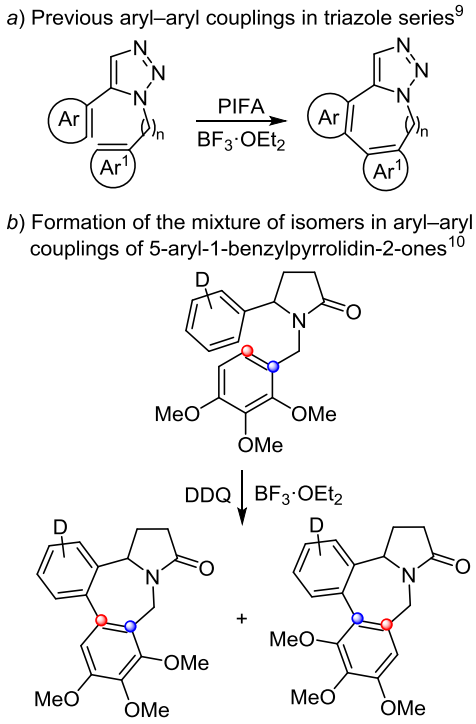
Keywords: 9*H*-dibenzo[*c*,*e*][1,2,3]triazolo[1,5-*a*]azepines, 3,3-disubstituted indoles, quinonoid compounds, 1,2,3-triazoles, intramolecular oxidative aryl–aryl coupling, *ipso* attack.

Carbon–carbon bond formation between two aromatic rings is one of the most important processes of organic chemistry, intensively studied since the early years of the 20th century when Ullmann reported copper-catalyzed coupling of two aryl halides producing symmetric biaryls.[1] Subsequently, thousands of papers devoted to aryl–aryl coupling were published with a particular focus on the bond formation between differently substituted aromatic rings.[2] In these processes, aryl halides (triflates, etc.) react with diverse substrates containing aryl–metal or aryl–metalloid bond producing biaryls. The importance of these studies was evident with the award of the Nobel Prize to Akira Suzuki and Ei-ichi Negishi in 2010 for their contribution to the development of aryl–aryl coupling.[3]

At the same time, the preliminary introduction of functional groups, involved in the process of aryl–aryl bond formation, places some limitations on the scope of these couplings. Conversely, C(Ar)–H/C(Ar)–H oxidative coupling does not have these constraints. As a result, this coupling, known as Scholl reaction,[4] attracted increasing attention during recent years,[5] diverse oxidants being used for the process initiation.[5–7] Nevertheless, the intermolecular Scholl reaction proceeds with only moderate chemo- and regioselectivity affording diverse side products in addition to the expected ones.[5b,6]

Oppositely, intramolecular Scholl reaction usually gives rise to products of the oxidative aryl–aryl coupling in good yields, chemo- and regioselectivity.[8] Proceeding from this basis, Dehaen et al. reported recently the $PhI(O_2CCF_3)_2$ (PIFA)/BF_3·OEt_2-induced intramolecular oxidative biaryl coupling of 5-aryl-1-(arylalkyl)-1,2,3-triazoles affording tetra- and pentacyclic compounds, which can be considered as structural analogs of allocolchicine (Scheme 1*a*).[9] Nevertheless, some of us (Boichenko et al.) have earlier

Scheme 1



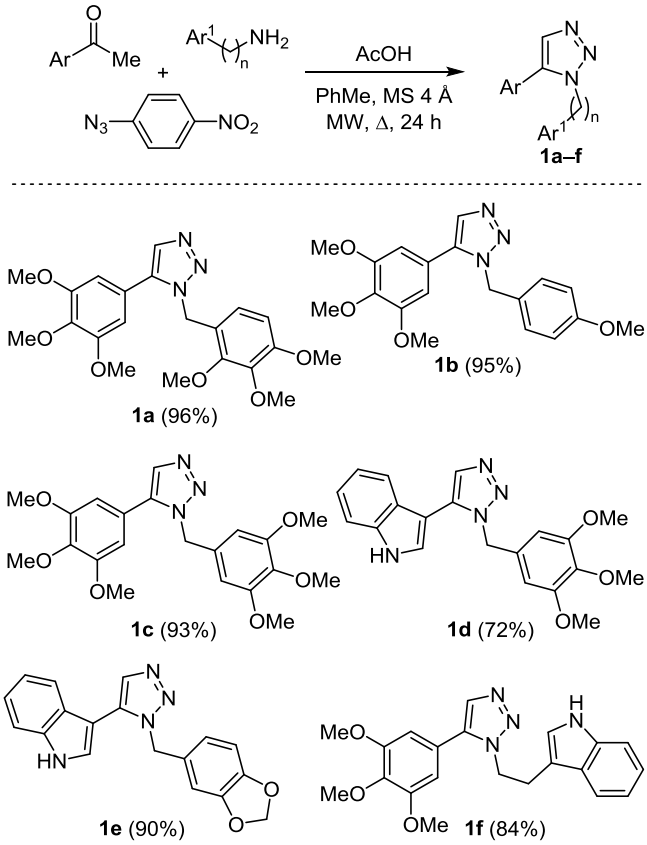
found that the related aryl–aryl coupling upon treatment of 5-aryl-1-benzylpyrrolidin-2-ones with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) and $BF_3 \cdot OEt_2$ can produce both the expected *ortho*/*ortho* coupling product and the isomeric polycycle, when the relative arrangement of electron-donating methoxy groups in one of two aromatic rings direct the electrophilic attack to *ipso* position (Scheme 1*b*).[10]

These distinctions can be resulting from the difference in the heterocycle, variations in the connected aryl groups, or the different oxidation systems applied. On the other hand, side products in the triazole series might not have been identified, as the aromatic substituents used were prone to *ortho*/*ortho*, but not *ortho*/*ipso* coupling. This stimulated us to combine our efforts for a more careful investigation of the oxidative aryl–aryl coupling in 5-aryl-1-(arylalkyl)triazoles.

The starting triazoles **1a**–**f** have been synthesized by the recently developed simple procedure from easily available acetophenones, arylalkylamines, and 4-nitrophenyl azide (Scheme 2).[11] The structure of compound **1a** was unambiguously proved by single crystal X-ray data (Fig. 1).

Then, we studied the reaction conditions for the oxidative coupling of two aryl groups in the synthesized substrates. For these experiments, we selected compound **1a** due to its structural similarity to the substrate that produced two types of products in the intramolecular oxidative aryl–aryl coupling of pyrrolidone-derived molecules.[10] We found that the rearranged isomer of the target compound (Scheme 1*b*) was not formed under all studied conditions. Nevertheless, in addition to the desired *ortho*/*ortho* coupling product **2a**, spiro compound **3a**, formed *via* *ortho*/*ipso* coupling, was also isolated (Scheme 3, Table 1).

Scheme 2



It is noteworthy that the combinations of DDQ and $BF_3 \cdot OEt_2$ as well as $FeCl_3$ and *m*-chloroperbenzoic acid (*m*-CPBA) are inefficient for the oxidative cyclization of substrate **1a** (Table 1, entries 1–3). However, upon treatment of substrate **1a** with PIFA and $BF_3 \cdot OEt_2$ at –40°C followed by warming up to room temperature the mixture of products **2a** and **3a** was formed in *ca*. 1:1 ratio (Table 1, entries 4, 5). The variation of the reaction temperature showed that *ortho*-/*ipso*-product **3a** is formed under the kinetic control; it was isolated in almost quantitative yield when reaction was performed at –40°C for 3 h (Table 1, entry 6). Compound **2a** is the product of thermodynamic

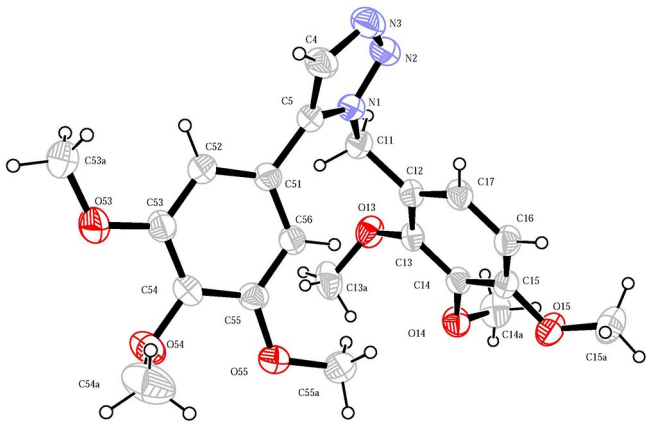


Figure 1. The single crystal X-ray structure of compound **1a** with non-hydrogen atoms represented as thermal vibration ellipsoids with a probability of 30%.

Scheme 3

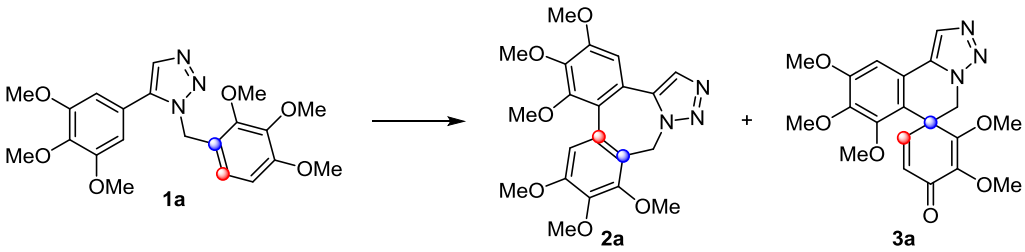


Table 1. Optimization of reaction conditions for oxidative cyclization of triazole **1a**

Entry	Solvent (concentration, M)	Oxidant (equiv)	Temperature, °C	Time, h	Isolated yield of product, %	
					2a	**3a**
1	PhCl (0.06)	DDQ/BF_3·Et_2O (1.2:12)	131	3	–*	
2	PhCl (0.06)	DDQ/BF_3·Et_2O (1.2:12)	131	0.5	–*	
3	CH_2Cl_2 (0.1)	*m*-CPBA/$FeCl_3$ (1:0.1)	20	3	–*	
4	CH_2Cl_2 (0.1)	PIFA/BF_3·Et_2O (1.1:3)	–40→20	3	46	46
5	CH_2Cl_2 (0.1)	PIFA/BF_3·Et_2O (1.1:3)	–40→20	0.75	45	44
6	CH_2Cl_2 (0.1)	PIFA/BF_3·Et_2O (1.1:3)	–40	3	–	96
7	CH_2Cl_2 (0.1)	PIFA/BF_3·Et_2O (1.1:3)	20	3	97	–
8	CH_2Cl_2 (0.1)	PIFA/BF_3·Et_2O (1.1:3)	83	3	85	–
9	PhCl (0.1)	PIFA/BF_3·Et_2O (1.1:3)	60	3	82	–
10	PhCl (0.1)	PIFA/BF_3·Et_2O (1.1:3)	120	3	79	–

* Oligomeric and polymeric products.

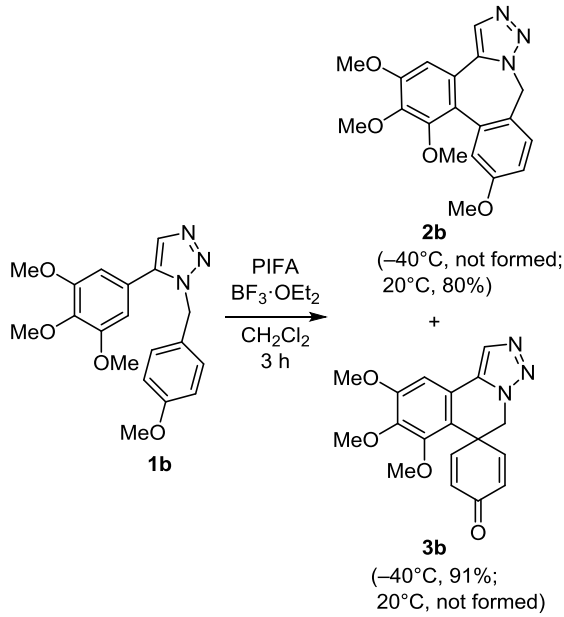
control; its best yield (97%) was obtained when the reaction was performed at room temperature (Table 1, entry 7). Further increase of the reaction temperature caused no change in the reaction chemoselectivity, but decreased the yield of compound **2a**.

Similarly, the treatment of compound **1b** with PIFA and BF_3·OEt_2 afforded the product of *ortho*/*ipso* coupling **3b** at –40°C and the *ortho*/*ortho* coupling product **2b** at room temperature (Scheme 4).

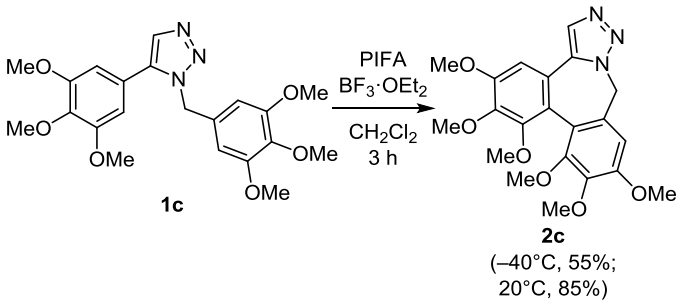
Nevertheless, compound **1c**, wherein substituents at both aryl groups direct the electrophilic attack to the *ortho* position, afforded a single product **2c** at both room temperature and –40°C in full accordance with the reported results (Scheme 5).[9] It is worth noting that the yield of compound **2c** was much lower than that of compounds **2a** or **2b**. It is presumably a result of the significant repulsion between the methoxy groups in the transition state; this effect was even larger in the oxidative cyclization of the corresponding 5-aryl-1-benzylpyrrolidin-2-one wherein the target product was not formed at all.[10]

Based on the obtained data, we decided to reinvestigate also the oxidative cyclization of indole-derived substrates **1d**–**f** considering the tendency of 3-substituted indoles to react with electrophiles primarily at C-3 position. Indeed,

Scheme 4

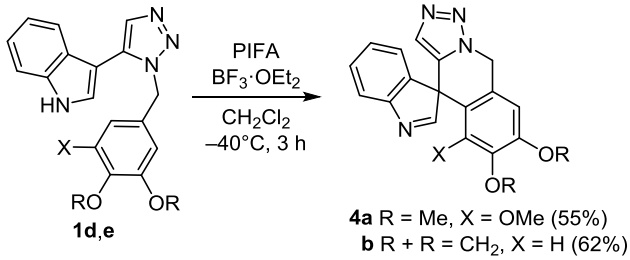


Scheme 5



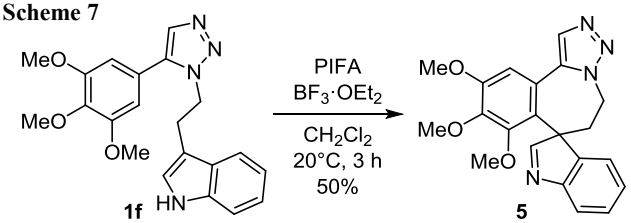
we found that 1-benzyl-5-(indol-3-yl)-1,2,3-triazoles **1d**,**e** afforded spiro compounds **4a**,**b** when they were treated with PIFA and BF_3·OEt_2 (Scheme 6). It is important to note that the structures of compounds **4a**,**b** were wrongly assigned in our previous paper as the C(2)-coupled isomer.[9]

Scheme 6



A similar behavior was found for substrates **1f** bearing 2-(indol-2-yl)ethyl group at the N-1 atom of the triazole ring. Its oxidation produced spiro compound **5** (Scheme 7).

Scheme 7



To conclude, intramolecular oxidative aryl–aryl coupling can produce either the expected *ortho*/*ortho* coupling products or products of *ortho*/*ipso* coupling depending on the substituents in two aromatic moieties and reaction conditions. The latter pathway can be realized when the aromatic group is prone to *ipso* attack by electrophilic species. Further investigations for better understanding of the mechanism and chemoselectivity of this coupling, as well as for identification of substrates which can produce *ortho*/*ipso* and *ipso*/*ipso* coupling products, are in progress.

Experimental

IR spectra were recorded on a Thermo Scientific Nicolet IR 200 FT-IR spectrometer in thin layer with the spectral resolution of 4 $см^{-1}$, the number of scans was 20, using ZnSe ATR accessory with an incidence angle of 45°. ^1H and ^{13}C NMR spectra (600 and 151 MHz, respectively) and two-dimensional ^1H–^{13}C HMBC and ^1H–^{13}C HSQC spectra were acquired on a Bruker Avance-600 spectrometer in $CDCl_3$ using the residual solvent signal as internal standard (7.26 ppm for ^1H nuclei, 77.1 ppm for ^{13}C nuclei). High-resolution mass spectra with electrospray ionization were recorded on an LTQ Orbitrap Elite instrument for samples in MeCN–H_2O solutions, using HCO_2Na–HCO_2H for calibration.

Triazoles **1c–f** were synthesized earlier.[11] Triazoles **1a**,**b** were prepared by the same procedure. All reagents used are commercially available unless otherwise noted. 2,3,4-Trimethoxybenzylamine was obtained in accordance with the described method.[12]

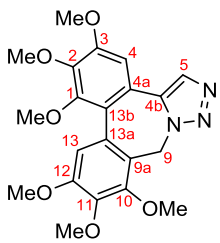
Synthesis of compounds 1a–f (General method). An appropriate primary amine (1.4 equiv), *p*-nitrophenyl azide (1 equiv), glacial AcOH (30 mol %), and molecular sieves 4 Å were added to a 1 M solution of a 1-arylethan-1-one (1 equiv) in PhMe. Next, the vial was placed in microwave reactor and reaction mixture was stirred at 100°C for 24 h. The product was purified by chromatography on silica gel (initially CH_2Cl_2, then petroleum ether – EtOAc mixture).

1-(2,3,4-Trimethoxybenzyl)-5-(3,4,5-trimethoxyphenyl)-1*H*-1,2,3-triazole (1a) was obtained from 1-(3,4,5-trimethoxyphenyl)ethan-1-one (297 mg, 1.4 mmol), 2,3,4-trimethoxybenzylamine (390 mg, 1.98 mmol), *p*-nitrophenyl azide (232 mg, 1.4 mmol), and AcOH (0.024 ml, 0.42 mmol) in PhMe (1.4 ml). Yield 558 mg (96%), light-yellow crystals, mp 137–140°C (CH_2Cl_2), R_f 0.53 (petroleum ether – EtOAc, 1:2). IR spectrum, ν, cm^{-1}: 3119, 3100, 3002, 2975, 2943, 2834, 2001, 1945, 1690, 1659, 1602, 1587, 1557, 1499, 1469, 1421, 1352, 1297, 1280, 1247, 1230, 1203, 1185, 1128, 1090, 1034, 1007. ^1H NMR spectrum, δ, ppm (*J*, Hz): 3.68 (3H, s, CH_3O); 3.69 (6H, s, $2CH_3O$); 3.76 (6H, s, $2CH_3O$); 3.80 (3H, s, CH_3O); 5.47 (2H, s, CH_2); 6.44 (2H, s, H Ar); 6.48 (1H, d, ^3J = 8.6, H Ar); 6.53 (1H, d, ^3J = 8.6, H Ar); 7.67 (1H, s, H Ar). ^{13}C NMR spectrum, δ, ppm: 46.8 (CH_2); 55.9 ($3CH_3O$); 60.5 (CH_3O); 60.6 (CH_3O); 60.7 (CH_3O); 105.9 (2C Ar); 107.2 (C Ar); 121.7 (C Ar); 122.1 (C Ar); 122.5 (C Ar); 132.8 (C Ar); 138.0 (C Ar); 138.7 (C Ar); 141.8 (C Ar); 150.5 (C Ar); 153.3 (2C Ar); 153.6 (C Ar). Found, *m*/*z*: 416.1816 $[M+H]^+$. $C_{21}H_{26}N_3O_6$. Calculated, *m*/*z*: 416.1816.

1-(4-Methoxybenzyl)-5-(3,4,5-trimethoxyphenyl)-1*H*-1,2,3-triazole (1b) was obtained from 1-(3,4,5-trimethoxyphenyl)ethan-1-one (200 mg, 0.95 mmol), 4-methoxybenzylamine (180 mg, 1.3 mmol), *p*-nitrophenyl azide (156 mg, 0.95 mmol), and AcOH (0.016 ml, 0.279 mmol) in PhMe (0.95 ml). Yield 321 mg (95%), dark-yellow viscous oil. The spectral data are in accordance with those reported previously.[13]

Synthesis of compounds 2a,b (General method). PIFA (1.1 equiv) and $BF_3·OEt_2$ (3 equiv) were added in one portion to a 0.1 M solution of compound **1a**,**b** (1 equiv) in dry CH_2Cl_2 at room temperature under argon atmosphere. The reaction mixture was stirred for 3 h and quenched by pouring into concentrated aqueous $NaHCO_3$ solution. The resulted mixture was extracted with CH_2Cl_2 (3 × 10 ml), the combined organic fractions were washed with brine and dried with Na_2SO_4. Then solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel (petroleum ether – EtOAc mixture).

1,2,3,10,11,12-Hexamethoxy-9*H*-dibenzo[*c*,*e*][1,2,3]-triazolo[1,5-*a*]azepine (2a) was obtained from triazole **1a** (208 mg, 0.5 mmol), PIFA (258 mg, 0.6 mmol), and $BF_3·Et_2O$ (0.2 ml, 1.6 mmol) in CH_2Cl_2 (8 ml). Yield 200 mg (97%), light-brown crystals, mp 156–157°C (CH_2Cl_2), R_f 0.45 (petroleum ether – EtOAc, 1:4). IR spectrum, ν, cm^{-1}: 3125, 3050, 3031, 2983, 2940, 2835, 1598, 1579, 1570, 1500, 1485, 1470, 1460, 1454, 1442, 1429, 1413, 1388, 1356, 1328, 1322, 1288, 1277, 1256, 1236, 1225, 1208, 1202, 1166, 1133, 1117, 1085, 1063, 1012. ^1H NMR spectrum, δ, ppm (*J*, Hz): 3.67 (3H, s, CH_3O); 3.83 (3H, s, CH_3O); 3.93 (3H, s, CH_3O); 3.96 (3H, s, CH_3O); 3.99 (3H, s, CH_3O); 4.00 (3H, s, CH_3O); 4.58 (1H, d, ^2J = 14.0, CH_2); 6.26 (1H, d, ^2J = 14.0, CH_2); 6.86 (1H, s, H-4); 6.99 (1H, s, H-13); 7.81 (1H, s, H-5). ^{13}C NMR spectrum, δ, ppm: 43.8 (C-9); 56.1 (12-CH_3O); 56.2 (2-CH_3O); 61.0 (11-CH_3O); 61.3 (1,3-CH_3O); 62.1 (10-CH_3O); 107.9 (C-4); 111.3 (C-13); 122.4 (C-13a); 123.2 (C-9a); 124.0 (C-4a); 129.4

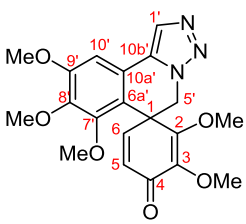


(C-13b); 131.4 (C-5); 136.1 (C-4b); 141.9 (C-11); 143.4 (C-3); 150.0 (C-10); 152.3 (C-1); 152.6 (C-12); 153.3 (C-2). Found, *m/z*: 414.1665 $[M+H]^+$. $C_{21}H_{24}N_3O_6$. Calculated, *m/z*: 414.1660.

1,2,3,12-Tetramethoxy-9*H*-dibenzo[*c,e*][1,2,3]triazolo-[1,5-*a*]azepine (2b) was obtained from triazole **1b** (96 mg, 0.27 mmol), PIFA (142 mg, 0.33 mmol), and $BF_3{\cdot}Et_2O$ (0.1 ml, 0.81 mmol) in CH_2Cl_2 (2.7 ml). Yield 76 mg (80%), orange crystals, mp 194–195°C (CH_2Cl_2), R_f 0.43 (petroleum ether – EtOAc, 1:4). IR spectrum, ν, cm^{-1}: 3140, 3125, 3076, 3041, 3001, 2974, 2921, 2550, 1738, 1684, 1607, 1596, 1575, 1506, 1484, 1461, 1437, 1410, 1393, 1352, 1321, 1289, 1282, 1264, 1240, 1233, 1218, 1197, 1184, 1168, 1134, 1116, 1075, 1033, 1020. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 3.67 (3H, s, CH_3O); 3.80 (3H, s, CH_3O); 3.96 (3H, s, CH_3O); 4.00 (3H, s, CH_3O); 4.96 (1H, d, ^2J = 14.0, CH_2); 5.62 (1H, d, ^2J = 14.0, CH_2); 6.86 (1H, s, H-4); 6.88 (1H, dd, ^3J = 8.4, ^4J = 2.7, H-11); 7.23 (1H, d, ^4J = 2.7, H-13); 7.37 (1H, d, ^3J = 8.4, H-10); 7.81 (1H, s, H-5). ^{13}C NMR spectrum, δ, ppm: 51.4 (C-9); 55.4 (12-CH_3O); 56.2 (2-CH_3O); 61.3 (1,3-CH_3O); 107.9 (C-4); 113.8 (C-11); 117.6 (C-13); 122.3 (C-13b); 124.2 (C-13a); 128.1 (C-4a); 129.2 (C-10); 131.6 (C-5); 134.8 (C-9a); 135.9 (C-4b); 143.5 (C-3); 152.5 (C-1); 153.44 (C-2); 159.1 (C-12). Found, *m/z*: 376.1273 $[M+Na]^+$. $C_{19}H_{19}N_3NaO_4$. Calculated, *m/z*: 376.1268.

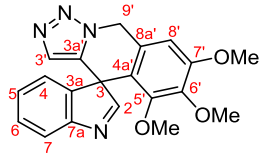
Synthesis of compounds 3–5 (General method). PIFA (1.2 equiv) and $BF_3{\cdot}OEt_2$ (3 equiv) were added dropwise to a 0.1 M solution of compound **1** (1 equiv) in dry CH_2Cl_2 at –40°C under argon atmosphere. The reaction mixture was stirred for 3 h at the same temperature and quenched by pouring into concentrated aqueous $NaHCO_3$ solution. The resulted mixture was extracted with CH_2Cl_2 (3 × 10 ml), combined organic fractions were washed with brine and dried with Na_2SO_4. Then solvent was removed under reduced pressure, residue was purified by chromatography on silica gel (petroleum ether – EtOAc mixture).

2,3,7',8',9'-Pentamethoxy-5'*H*-spiro[cyclohexane-1,6'-[1,2,3]triazolo[5,1-*a*]isoquinoline]-2,5-dien-4-one (3a) was obtained from triazole **1a** (208 mg, 0.5 mmol), PIFA (258 mg, 0.6 mmol), and $BF_3{\cdot}Et_2O$ (0.2 ml, 1.6 mmol) in CH_2Cl_2 (8 ml). Yield 192 mg (96%), black crystals, mp 206–208°C (CH_2Cl_2), R_f 0.26 (petroleum ether – EtOAc, 1:4). IR spectrum, ν, cm^{-1}: 3108, 3008, 2993, 2959, 2935, 2873, 2849, 1729, 1652, 1636, 1591, 1493, 1472, 1464, 1446, 1424, 1402, 1386, 1355, 1323, 1304, 1286, 1271, 1251, 1199, 1187, 1169, 1143, 1117, 1108, 1089, 1059, 1042, 1017, 1002. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 3.67 (3H, s, CH_3O); 3.82 (3H, s, CH_3O); 3.86 (3H, s, CH_3O); 3.94 (3H, s, CH_3O); 4.10 (3H, s, CH_3O); 4.48 (1H, d, ^2J = 13.0, CH_2); 4.72 (1H, d, ^2J = 13.0, CH_2); 6.18 (1H, d, ^3J = 9.9, H-5); 6.31 (1H, d, ^3J = 9.9, H-6); 6.95 (1H, s, H-10'); 7.93 (1H, s, H-1'). ^{13}C NMR spectrum, δ, ppm: 48.3 (C-1); 53.6 (C-5'); 56.3 (CH_3O); 60.7 (CH_3O); 60.8 (CH_3O); 60.9 (CH_3O); 61.2 (CH_3O); 104.3 (C-10'); 118.3 (C-10a'); 127.6 (C-5); 128.8 (C-1'); 130.9 (C-6a'); 132.8 (C-10b'); 137.9 (C-3); 142.8 (C-6); 143.7 (C-9'); 152.4 (C-7'); 154.3 (C-8'); 161.2 (C-2); 183.5 (C-4). Found, *m/z*: 422.1328 $[M+Na]^+$. $C_{20}H_{21}N_3NaO_6$. Calculated, *m/z*: 422.1323.



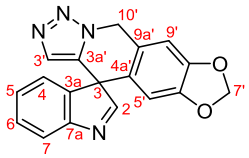
7',8',9'-Trimethoxy-5'*H*-spiro[cyclohexane-1,6'-[1,2,3]-triazolo[5,1-*a*]isoquinoline]-2,5-dien-4-one (3b) was obtained from triazole **1b** (120 mg, 0.34 mmol), PIFA (224 mg, 0.52 mmol), and $BF_3{\cdot}Et_2O$ (0.123 ml, 1 mmol) in CH_2Cl_2 (4 ml). Yield 105 mg (91%), orange crystals, mp 220–222°C (CH_2Cl_2), R_f 0.27 (petroleum ether – EtOAc, 1:4). IR spectrum, ν, cm^{-1}: 3128, 3108, 3057, 3037, 3015, 2981, 2937, 2885, 2855, 1699, 1662, 1627, 1601, 1572, 1490, 1471, 1455, 1425, 1402, 1350, 1291, 1273, 1250, 1226, 1215, 1194, 1183, 1126, 1115, 1084, 1067, 1042, 1018. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 3.64 (3H, s, CH_3O); 3.87 (3H, s, CH_3O); 3.96 (3H, s, CH_3O); 4.45 (2H, s, CH_2); 6.40 (2H, d, ^3J = 10.2, H-2,6 Ar); 6.89 (2H, d, ^3J = 10.2, H-3,5 Ar); 6.99 (1H, c, H-10); 7.98 (1H, c, H-1'). ^{13}C NMR spectrum, δ, ppm: 43.8 (C-1); 53.6 (C-5'); 56.4 (CH_3O); 60.6 (CH_3O); 61.0 (CH_3O); 104.7 (C-10'); 118.9 (C-10a'); 119.6 (C-6a'); 128.6 (C-2,6); 128.9 (C-1'); 132.9 (C-10b'); 144.0 (C-7'); 148.8 (C-3,5); 152.7 (C-8'); 154.5 (C-9'); 184.8 (C-4). Found, *m/z*: 340.1297 $[M+H]^+$. $C_{18}H_{18}N_3O_4$. Calculated, *m/z*: 340.1292.

5',6',7'-Trimethoxy-9'*H*-spiro[indole-3,4'-[1,2,3]tri-azolo[1,5-*b*]isoquinoline] (4a) was obtained from triazole **1d** (200 mg, 0.55 mmol), PIFA (310 mg, 0.72 mmol), and $BF_3{\cdot}Et_2O$ (0.2 ml, 1.62 mmol) in CH_2Cl_2 (4 ml). Yield 89 mg (45%), bright orange viscous oil, R_f 0.23 (petroleum ether – EtOAc, 1:2). IR spectrum, ν, cm^{-1}: 2995, 2973, 2940, 2839, 2827, 1730, 1683, 1607, 1587, 1553, 1535, 1500, 1456, 1432, 1414, 1361, 1341, 1281, 1249, 1199, 1149, 1127, 1105, 1090, 1077, 1043, 996. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 3.07 (3H, s, CH_3O); 3.71 (3H, s, CH_3O); 3.89 (3H, s, CH_3O); 5.74 (2H, ^2J = 17.5, CH_2); 6.71 (1H, s, H-8'); 6.93 (1H, d, ^3J = 7.4, H-4); 7.04 (1H, s, H-3'); 7.11–7.14 (1H, m, H-5); 7.34–7.37 (1H, m, H-6); 7.71 (1H, d, ^3J = 7.7, H-7); 7.99 (1H, s, H-2). ^{13}C NMR spectrum, δ, ppm: 47.1 (C-9'); 55.6 (CH_3O); 57.2 (C-3); 60.1 (CH_3O); 60.4 (CH_3O); 104.8 (C-8'); 114.4 (C-4a'); 121.5 (C-4,7); 125.2 (C-8a'); 127.0 (C-5); 128.6 (C-6); 128.9 (C-3'); 130.5 (C-3a'); 141.7 (C-6'); 143.6 (C-3a); 151.9 (C-5'); 154.2 (C-7'); 154.8 (C-7a); 171.9 (C-2). Found, *m/z*: 363.1452 $[M+H]^+$. $C_{20}H_{19}N_4O_3$. Calculated, *m/z*: 363.1452.

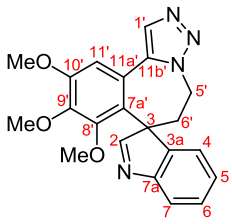


10'*H*-Spiro[indole-3,4'-[1,3]dioxolo[4,5-*g*][1,2,3]tri-azolo[1,5-*b*]isoquinoline] (4b) was obtained from triazole **1e** (100 mg, 0.314 mmol), PIFA (149 mg, 0.346 mmol), and $BF_3{\cdot}Et_2O$ (0.116 ml, 0.942 mmol) in CH_2Cl_2 (2 ml).

Yield 62 mg (62%), off-white solid, mp 208°C, R_f 0.20 (petroleum ether – EtOAc, 1:1). IR spectrum, ν, cm^{-1}: 3401, 2956, 2923, 2862, 1602, 1557, 1540, 1499, 1482, 1453, 1428, 1382, 1338, 1308, 1241, 1180, 1169, 1108, 1030, 993, 933, 852, 831, 798, 777, 750, 694, 659, 591, 561, 510, 480, 442, 414. ^{1}H NMR spectrum, δ, pm (*J*, Hz): 5.71 (1H, d, ^2J = 17.0, CH_2); 5.83 (1H, d, ^2J = 17.0, CH_2); 5.97 (1H, d, ^2J = 1.3, CH_2); 5.99 (1H, d, ^2J = 1.3, CH_2); 6.00 (1H, s, H Ar); 6.89 (1H, s, H Ar); 7.13 (1H, br. d, ^3J = 7.4, H Ar); 7.15 (1H, br. s, H Ar); 7.31–7.35 (1H, m, H Ar); 7.51–7.55 (1H, m, H Ar); 7.81 (1H, br. d, ^3J = 7.8, H Ar); 7.92 (1H, s, H Ar). ^{13}C NMR spectrum, δ, ppm: 48.4 (CH_2); 60.0 (C); 102.1 (CH_2); 105.8 (CH); 106.8 (CH); 121.4 (C); 122.3 (CH); 123.4 (C); 123.5 (CH); 128.2 (CH); 129.8 (CH); 130.0 (CH); 130.7 (C); 142.0 (C); 148.7 (C); 148.9 (C); 155.6 (C); 171.5 (CH=N). Found, *m*/*z*: 317.1031 $[M+H]^+$. $C_{18}H_{13}N_4O_2$. Calculated, *m*/*z*: 317.1032.



8',9',10'-Trimethoxy-5',6'-dihydrospiro[indole-3,7'-benzo-[*c*][1,2,3]triazolo[1,5-*a*]azepine] (5) was obtained from triazole **1f** (200 mg, 0.53 mmol), PIFA (270 mg, 0.63 mmol), and $BF_3{\cdot}Et_2O$ (0.2 ml, 1.62 mmol) in CH_2Cl_2 (4 ml). Yield 100 mg (50%), dark-orange viscous oil, R_f 0.34 (EtOAc). IR spectrum, ν, cm^{-1}: 3134, 3064, 2939, 2846, 1717, 1587, 1494, 1463, 1430, 1377, 1352, 1284, 1232, 1203, 1127, 1113, 1004, 975, 912. ^{1}H NMR spectrum, δ, pm (*J*, Hz): 1.80 (1H, ddd, ^2J = 15.2, ^3J = 7.1, ^3J = 1.7, 6'-CH_2); 2.40 (1H, ddd, ^2J = 15.2, ^3J = 9.7, ^3J = 2.1, 6'-CH_2); 3.02 (3H, s, CH_3O); 3.77 (3H, s, CH_3O); 3.94 (3H, s, CH_3O); 4.72 (1H, ddd, ^2J = 14.5, ^3J = 9.7, ^3J = 1.7, 5'-CH_2); 4.80 (1H, ddd, ^2J = 14.5, ^3J = 7.1, ^3J = 2.1, 5'-CH_2); 7.00 (1H, d, ^3J = 7.4, H-4); 7.06 (1H, s, H-11'); 7.19 (1H, dd, ^3J = 7.5, ^3J = 7.4, H-5); 7.40 (1H, dd, ^3J = 7.7, ^3J = 7.5, H-6); 7.75 (1H, d, ^3J = 7.7, H-7); 8.02 (1H, s, H-1'); 8.33 (1H, s, H-2). ^{13}C NMR spectrum, δ, ppm: 34.4 (C-6'); 46.9 (C-5'); 56.1 (CH_3O); 60.5 (CH_3O); 60.6 (CH_3O); 62.8 (C-3); 108.8 (C-11'); 121.4 (C-11a'); 121.5 (C-4,); 121.6 (C-7a'); 122.1 (C-7); 126.9 (C-5); 128.6 (C-6); 134.2 (C-1'); 136.8 (C-11b'); 143.0 (C-9'); 144.1 (C-3a); 153.1 (C-10'); 153.2 (C-8'); 153.7 (C-7a); 177.4 (C-2). Found, *m*/*z*: 377.1608 $[M+H]^+$. $C_{21}H_{21}N_4O_3$. Calculated, *m*/*z*: 377.1608.



X-ray structural analysis of compound 1a. Crystal of compound **1a** was grown from a solution in CH_2Cl_2 by slow evaporation of solvent at room temperature. The X-ray analysis was performed on a STOE STADIVARI PILATUS 100K single crystal diffractometer. The structure was solved by direct methods. All calculations were performed by using the SHELXT and SHELXL-15[14] program sets. The tables of atomic coordinates, bond lengths, valence and torsion angles, and the anisotropic temperature parameters for compound **1a** were deposited at the Cambridge Crystallographic Data Center (deposit CCDC 2048342).

Supplementary information file containing ^{1}H, ^{13}C NMR, ^{1}H–^{13}C HSQC, and ^{1}H–^{13}C HMBC spectra of the synthesized compounds is available at the journal website http://hgs.osi.lv.

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