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Synthesis of New Aryl(hetaryl)vinyl-Substituted Benzo[*f*]quinolines and 4,7-Phenanthrolines

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Abstract—Previously unknown 1-[2-aryl(quinolin-2-yl)ethenyl]-3-[aryl(quinolin-2-yl)]benzo[*f*]quinolines and 3-aryl-1-(2-arylethenyl)-4,7-phenanthrolines were synthesized by reactions of 1-methylbenzo[*f*]quinolines and 1-methyl-4,7-phenanthrolines with substituted *N*-benzylideneanilines and *N*-(quinolin-2-ylmethylidene)aniline on heating in dimethylformamide in the presence of potassium hydroxide.

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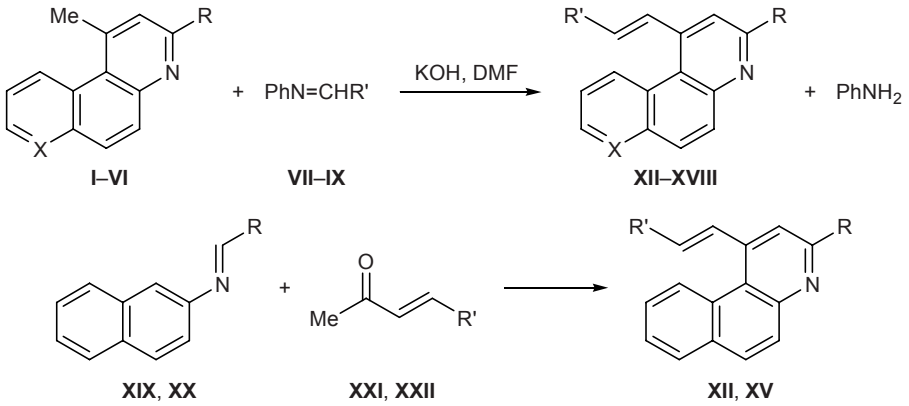
Fused nitrogen-containing heterocycles with arylvinyl or styryl substituents are used as photosensitizers, cyanine dyes, and medicines [1–5]. Compounds containing a styrylquinoline fragment attract specific attention due to strong antibacterial, fungicidal, and antitumor activity of some representatives [5–7]. The synthesis of styryl-substituted benzo[*f*]quinolines and 4,7-phenanthrolines was reported in several publications [3, 8, 9]; however, the described procedures were not always satisfactory. For example, the procedure based on the reaction of methyl-substituted benzo[*f*]-quinolines with aromatic aldehydes [8] cannot be applied to preparation of hetarylvinyl derivatives, for initial 1-methyl-3-quinolylbenzo[*f*]quinolines (as free bases) do not react with aldehydes, while the corresponding quaternary salts (in which the methyl group is activated) undergo decomposition under the proposed conditions. Catalytic condensation of *N*-arylmethylidenenaphthalen-2-amines with substituted benzylideneacetones (4-arylbut-3-en-2-ones), developed for the synthesis of styryl-substituted benzo[*f*]quinolines [9], is also ineffective as applied to reactions with quinolyl-substituted Schiff bases. Steric hindrances created by the bulky quinoline fragment hamper the reaction of Schiff base with unsaturated ketone, and the yield of the target product decreases. In this case, hydrolysis of the initial Schiff base and polymerization of the carbonyl component become predominating reaction pathways which lead to the formation of unidentifiable tarry products.

We were the first to synthesize new aryl(hetaryl)-vinyl-substituted benzo[*f*]quinolines and 4,7-phenanthrolines by reactions of 1-methylbenzo[*f*]quinolines and 1-methyl-4,7-phenanthrolines **I**–**VI** with Schiff bases **VII**–**XI** derived from aniline. Schiff bases **I**–**VI** were selected as source of aryl(hetaryl)methylidene fragment, taking into account similarity between the π-electron systems of the carbonyl and C=N groups, so that Schiff bases were considered to be heteroanalogs of carbonyl compounds.

1-Methylbenzo[*f*]quinolines **I**–**III** and 1-methyl-4,7-phenanthrolines **IV**–**VI** were synthesized by condensation of *N*-[aryl(quinolin-2-yl)methylidene]naphthalen-2-amines and *N*-(arylmethylidene)quinolin-6-amines, respectively with acetone [8]. Benzo[*f*]quinolines **I**–**III** were brought into reactions with *N*-benzylideneaniline (**VII**), *N*-(quinolin-2-ylmethylidene)-aniline (**VIII**), and *N*-(4-nitrobenzylidene)aniline (**IX**). Analogous reactions of 3-aryl-1-methyl-4,7-phenanthrolines **IV**–**VI** were performed with *N*-(4-nitrobenzylidene)aniline (**IX**), *N*-(4-bromobenzylidene)aniline (**X**), and *N*-(4-hydroxybenzylidene)aniline (**XI**) (Scheme 1). The reactions were carried out by heating equimolar amounts of compound **I**–**VI** and Schiff base **VII**–**XI** in dimethylformamide in the presence of excess potassium hydroxide. As a result, we isolated 38–61% of the corresponding 1-[2-aryl(quinolin-2-yl)-ethenyl]-3-[aryl(quinolin-2-yl)benzo[*f*]quinolines **XII**–**XV** and 1-(2-arylethenyl)-3-aryl-4,7-phenanthrolines **XVI**–**XVIII**. The substituents R and R′ almost did not

Scheme 1.



I–**III**, **XII**–**XV**, X = CH; **IV**–**VI**, **XVI**–**XVIII**, X = N; **I**, **XII**, **XIX**, R = Ph; **II**, **XIII**, **XIV**, R = quinolin-2-yl; **III**, **IV**, **XV**, **XVI**, **XX**, R = 4-$O_2NC_6H_4$; **V**, **XVII**, R = 4-BrC_6H_4; **VI**, **XVIII**, R = 2-HOC_6H_4; **VII**, **XIII**, R′ = Ph; **VIII**, **XII**, **XIV**, **XXI**, R′ = quinolin-2-yl; **IX**, **XV**, **XVI**, **XXII**, R′ = 4-$O_2NC_6H_4$; **X**, **XVII**, R′ = 4-BrC_6H_4; **XI**, **XVIII**, R′ = 2-HOC_6H_4.

affect the yield of the target products. The poor yield of 1-[2-(2-hydroxyphenyl)ethenyl]-3-(2-hydroxyphenyl)-4,7-phenanthroline (**XVIII**, 38%) is likely to be related to steric effect of the *ortho*-hydroxy group in the benzene ring of Schiff base **XI**.

It should be noted that we succeeded in synthesizing only 1-[2-(quinolin-2-yl)ethenyl]-3-phenylbenzo[*f*]quinoline (**XII**) and 1-[2-(4-nitrophenyl)ethenyl]-3-(4-nitrophenyl)benzo[*f*]quinoline (**XV**) by an alternative method, condensation of *N*-benzylidenenaphthalen-2-amine (**XIX**) and *N*-(4-nitrobenzylidene)naphthalen-2-amine (**XX**), respectively, with 4-(quinolin-2-yl)but-3-en-2-one (**XXI**) and 4-(4-nitrophenyl)but-3-en-2-one (**XXII**). However, the yields of **XIII** and **XV** were lower (42–54%) than in the reactions of **I** and **III** with the corresponding Schiff bases.

The structure of newly synthesized compounds **XII**–**XVIII** was confirmed by elemental analysis and IR, UV, and ^{1}H NMR spectra. The IR spectra of benzo[*f*]quinoline and 4,7-phenanthroline derivatives **XII**–**XVIII** contain absorption bands at 3080–3000, 1595–1575, and 1480–1450 cm^{-1}, which are typical of stretching and bending vibrations of C–H and C–C bonds in the azaphenanthrene ring system. Stretching vibrations of the exocyclic C=C bond give rise to absorption at 1630–1600 cm^{-1}, and stretching and bending vibrations of the corresponding =C–H bonds appear at 2990–2920 and 1300–1295 and 990–975 cm^{-1}, respectively. Nitro derivatives **XV** and **XVII** displayed strong absorption bands due to stretching vibrations of the nitro group (1590–1585 and 1355–1340 cm^{-1}).

The electronic absorption spectra of **XII**–**XVIII** are typical of benzo[*f*]quinolines and 4,7-phenanthrolines [8, 10]. The spectra contain three bands in the UV region: β (257–265 nm), *r* (271–303 nm), and α (330–378 nm). The β and *r* bands are displaced toward longer wavelengths relative to the corresponding bands in the spectra of the initial methyl-substituted compounds [8, 10], and the intensity of the α-band strongly increases. This pattern results from extension of the conjugated bond system due to introduction of additional chromophore (ethenyl group conjugated with the aromatic substituent R′). Apart from absorption bands belonging to the benzo[*f*]quinoline core, quinolyl-substituted derivatives **XIII** and **XIV** showed three fairly strong maxima at λ 316–320, 329–330, and 344–345 nm, which should be attributed to the quinolyl substituent [11].

In the mass spectra of **XII**–**XVIII**, the most abundant were the corresponding molecular ions $[M]^+$. Their fragmentation involved expulsion of neutral HCN molecules at different decomposition steps, which is typical of fused nitrogen-containing heterocycles. The mass spectra of **XII** and **XV**–**XVIII** contained medium-intensity peaks from the $[M - R]^+$ ions (I_{rel} = 22–31%). The presence of $[M - NO]^+$ and $[M - NO_2]^+$ ion peaks confirmed the structure of nitro-substituted compounds **XV** and **XVI**. The intensity ratio in the molecular ion cluster, as well as the presence of $[M - Br]^+$ ion peak, was consistent with the presence of a bromine atom in molecule **XVII**.

The ^{1}H NMR spectra of **XII**–**XVIII** were interpreted using the data reported previously for 1-methyl-3-arylbenzo[*f*]quinolines and 3-aryl-1-phenyl-4,7-phenanthrolines [10, 12]. Ethenyl derivatives **XII**–**XVIII** displayed two doublets from protons at the

exocyclic double bond in the region δ 7.54–7.80 (**XII**–**XV**) or 8.07–8.30 ppm (**XVI**–**XVIII**). The coupling constant ^3J is equal to 15.6–16.2 Hz, indicating *trans* orientation of these protons. Arylvinyl-substituted 4,7-phenanthrolines **XVI**–**XVIII** are poorly soluble in organic solvents; therefore, their ^{1}H NMR spectra were recorded from solutions in CF_3COOD, and all signals were displaced downfield relative to the corresponding signals of their analogs whose spectra were measured in $CDCl_3$ [12]. The downfield shift results from protonation of the ring nitrogen atoms by strong acid. The effects of bromine atom and hydroxy and nitro groups extends primarily to protons in the phenyl ring containing these substituents. On the other hand, the 2-H and 10-H signals of *ortho*-hydroxyphenyl-substituted phenanthroline **XVIII** are displaced appreciably downfield, as compared to analogous compounds **XVI** and **XVII**. The 2-H proton is deshielded due to electron-withdrawing effect of the oxygen atom in the hydroxy group in the 3-phenyl substituent. Steric effect of the *ortho*-hydroxy group forces the 2-hydroxyarylvinyl fragment out from conjugation with the phenanthroline core, so that the 10-H proton is shielded to a lesser extent.

EXPERIMENTAL

The UV spectra were recorded on a Specord UV-Vis spectrophotometer from solutions in ethanol with a concentration c of 10^{-4} M. The IR spectra were measured in KBr on a Nicolet Protégé-460 spectrometer with Fourier transform. The NMR spectra were obtained on Bruker AC-500 (500 MHz) and Tesla BS-567 instruments (100 MHz) using $CDCl_3$ and CF_3COOD as solvents and tetramethylsilane as internal reference. The mass spectra (electron impact, 70 eV) were run on a Finnigan MAT Incos 50 spectrometer and on a Hewlett–Packard 5890/5972 GC–MS system (HP-5MS capillary column, 30 m × 0.25 mm, film thickness 0.25 μm; injector temperature 250°C). The melting points were determined using a Kofler hot stage.

Initial 1-methylbenzo[*f*]quinolines **I**–**III** and 1-methyl-4,7-phenanthrolines **IV**–**VI** were synthesized according to the procedure reported in [8].

1-[2-Aryl(quinolin-2-yl)ethenyl]-3-[aryl(quinolin-2-yl)]benzo[*f*]quinolines XII–XV and 3-aryl-1-(2-arylethenyl)-4,7-phenanthrolines XVI–XVIII (*general procedure*). *a*. A mixture of 5 mmol of compound **I**–**VI**, 5 mmol of Schiff base **VII**–**XI**, and 50 mmol of powdered potassium hydroxide in 40 ml of dimethylformamide was heated to 80–90°C under vigorous stirring and was stirred for 1.5–2.0 h at that temperature. The mixture was cooled to room temperature, and 50 ml of water and 35 ml of 10% hydrochloric acid were added. The precipitate was filtered off, washed with water until neutral washings and with methanol, and recrystallized from propan-2-ol–toluene (1 : 2) (**XII**–**XIV**) or DMF (**XV**–**XVIII**).

b. A mixture of 5 mmol of *N*-benzylidenenaphthalen-2-amine (**XIX**) or *N*-(4-nitrobenzylidene)naphthalen-2-amine (**XX**) and 5 mmol of 4-(quinolin-2-yl)but-3-en-2-one (**XXI**) or 4-(4-nitrophenyl)but-3-en-2-one (**XXII**), respectively, in 10 ml of ethanol containing 1 ml of concentrated hydrochloric acid was heated for 1 h in a sealed ampule. The precipitate was filtered off, treated with aqueous ammonia, washed with water, and recrystallized from propan-2-ol–toluene (**XII**) or dimethylformamide (**XV**).

3-Phenyl-1-[2-(quinolin-2-yl)ethenyl]benzo[*f*]quinoline (XII). Yield 46% (*a*), 42% (*b*), mp 172–173°C. UV spectrum, λ_{max}, nm (logε): 260 (4.69), 271 (4.72), 338 (4.40). ^{1}H NMR spectrum, δ, ppm: 7.19–8.63 m and 8.82 m (18H, H_{arom}), 7.62 d and 7.80 d (2H, CH=CH, ^3J = 15.8 Hz). Found, %: C 88.02; H 4.73; N 6.51. $C_{30}H_{20}N_2$. Calculated, %: C 88.24; H 4.90; N 6.86.

1-(2-Phenylethenyl)-3-(quinolin-2-yl)benzo[*f*]quinoline (XIII). Yield 58%, mp 209–210°C. UV spectrum, λ_{max}, nm (logε): 257 (4.63), 287 (4.64), 316 (4.62), 329 (4.53), 344 (4.45), 374 (3.88). ^{1}H NMR spectrum, δ, ppm: 7.24–8.81 m (20H, H_{arom}, CH=CH). Found, %: C 87.93; H 4.69; N 6.67. $C_{30}H_{20}N_2$. Calculated, %: C 88.24; H 4.90; N 6.86.

3-(Quinolin-2-yl)-1-[2-(quinolin-2-yl)ethenyl]benzo[*f*]quinoline (XIV). Yield 61%, mp 199–200°C. UV spectrum, λ_{max}, nm (logε): 265 (4.76), 285 (4.79), 315 (4.59), 330 (4.62), 345 (4.60), 378 (4.06). ^{1}H NMR spectrum, δ, ppm: 7.29–8.84 m (21H, 19H_{arom}, CH=CH). Found, %: C 85.24; H 4.63; N 9.41. $C_{31}H_{21}N_3$. Calculated, %: C 85.52; H 4.83; N 9.66.

3-(4-Nitrophenyl)-1-[2-(4-nitrophenyl)ethenyl]benzo[*f*]quinoline (XV). Yield 60% (*a*), 54% (*b*), mp 299–300°C. UV spectrum, λ_{max}, nm (logε): 265 (4.56), 299 (4.62), 342 (4.43). ^{1}H NMR spectrum, δ, ppm: 7.34 m, 7.42 d, 7.79 m, 8.04 d, 8.12 d (15H, H_{arom}, ^3J = 8.8 Hz); 7.54 d, 7.72 d (2H, CH=CH, ^3J = 15.6 Hz). Found, %: C 72.22; H 3.73; N 9.29. $C_{27}H_{17}N_3O_4$. Calculated, %: C 72.48; H 3.80; N 9.40.

3-(4-Nitrophenyl)-1-[2-(4-nitrophenyl)ethenyl]-4,7-phenanthroline (XVI). Yield 49%, mp 336–337°C. UV spectrum, λ_{max}, nm (log ε): 250 (4.48), 303 (4.49), 330 (4.32). ^{1}H NMR spectrum, δ, ppm: 8.00 d, 8.40 d, 8.63 d (8H, H_{arom}, ^3J = 8.3 Hz); 8.07 d, 8.30 d (2H, CH=CH, ^3J = 16.1 Hz); 8.47 d.d (1H, 9-H, ^3J = 8.8, ^4J = 4.4 Hz); 8.84 s (1H, 2-H); 9.02 d, 9.09 d (2H, 5-H, 6-H, ^3J = 9.1 Hz); 9.48 d (1H, 8-H, ^3J = 4.4 Hz); 10.32 d (1H, 10-H, ^3J = 8.8 Hz). Found, %: C 69.50; H 3.42; N 12.39. $C_{26}H_{16}N_4O_4$. Calculated, %: C 69.64; H 3.57; N 12.50.

3-(4-Bromophenyl)-1-[2-(4-bromophenyl)ethenyl]-4,7-phenanthroline (XVII). Yield 52%, mp 262–263°C. UV spectrum, λ_{max}, nm (log ε): 232 (4.41), 256 (4.43), 296 (4.53), 338 (4.30). ^{1}H NMR spectrum, δ, ppm: 7.64 d, 7.78 d, 7.98 d, 8.08 m (10H, H_{arom}, ^3J = 8.4, CH=CH, ^3J = 16.0 Hz); 8.48 d.d (1H, 9-H, ^3J = 8.0, ^4J = 4.8 Hz); 8.70 s (1H, 2-H); 8.96 d, 9.00 d (2H, 5-H, 6-H, ^3J = 9.1 Hz); 9.40 d (1H, 8-H, ^3J = 4.8 Hz); 10.28 d (1H, 10-H, ^3J = 8.0 Hz). Found, %: C 60.45; H 2.89; Br 30.73; N 5.26. $C_{26}H_{16}Br_2N_2$. Calculated, %: C 60.47; H 3.10; Br 31.01; N 5.43.

3-(2-Hydroxyphenyl)-1-[2-(2-hydroxyphenyl)ethenyl]-4,7-phenanthroline (XVIII). Yield 38%, mp 297–298°C. UV spectrum, λ_{max}, nm (log ε): 260 (4.53), 294 (4.55), 340 (4.46). ^{1}H NMR spectrum, δ, ppm: 7.10 d, 7.19 t, 7.38 d, 7.40 m, 7.46 d, 7.71 d, 7.77 t, 8.29 d (8H, H_{arom}, ^3J = 8.0 Hz); 8.23 d, 8.33 d (2H, CH=CH, ^3J = 16.2 Hz); 8.47 d.d (1H, 9-H, ^3J = 7.9, ^4J = 4.1 Hz); 8.83 d, 8.87 d (2H, 5-H, 6-H, ^3J = 9.3 Hz); 8.96 s (1H, 2-H); 9.40 d (1H, 8-H, ^3J = 4.1 Hz); 10.57 d (1H, 10-H, ^3J = 7.9 Hz). Found, %: C 79.85; H 4.43; N 6.94. $C_{26}H_{18}N_2O_2$. Calculated, %: C 80.00; H 4.62; N 7.18.

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