ISSN 1070-4280, Russian Journal of Organic Chemistry, 2007, Vol. 43, No. 1, pp. 108–116. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © N.L. Racheva, S.N. Shurov, Z.G. Aliev, A.N. Maslivets, 2007, published in Zhurnal Organicheskoi Khimii, 2007, Vol. 43, No. 1, pp. 103–110.

Five-Membered 2,3-Dioxo Heterocycles: LI.* Reaction of 3-Aroyl-2,4-dihydro-1*H*-pyrrolo[2,1-c][1,4]benzoxazine-1,2,4-triones with 3-Amino-5,5-dimethylcyclohex-2-en-1-ones

N. L. Racheva[a], S. N. Shurov[a], Z. G. Aliev[b], and A. N. Maslivets[a]

[a] *Perm State University, ul. Bukireva 15, Perm, 614990 Russia*
e-mail: koh2@psu.ru

[b] *Institute of Chemical Physics Problem, Russian Academy of Sciences, Chernogolovka, Moscow oblast, Russia*

Received October 20, 2005

Abstract—3-Aroyl-2,4-dihydro-1*H*-pyrrolo[2,1-*c*][1,4]benzoxazine-1,2,4-triones react with N-unsubstituted and N-substituted 3-amino-5,5-dimethylcyclohex-2-en-1-ones to give 3'-aroyl-4'-hydroxy-1'-(*o*-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-triones. The molecular and crystalline structure of the 1-cyclohexyl-substituted derivative was studied by X-ray analysis.

DOI: 10.1134/S1070428007010149

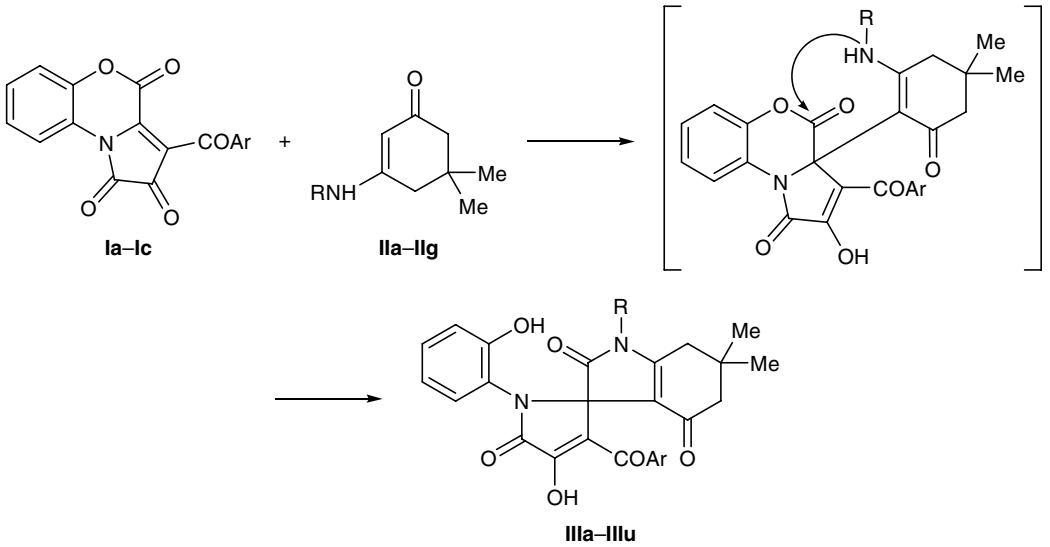
Monofunctional O- [2] and N-centered nucleophiles [3, 4] are known to reversibly add at the C^{3a} or C^{1} atom of 3-acyl-2,4-dihydro-1*H*-pyrrolo[2,1-*c*][1,4]benzoxazine-1,2,4-triones, while difunctional N,N- [5, 6] and S,N-nucleophiles [7], as well as the first representative of C,N-binucleophiles (3-amino-5,5-dimethylcyclohex-2-en-1-one having no substituent on the nitrogen atom) [8], attack in succession the C^{3a} carbon atom and carbonyl carbon atom in position *4*; the reactions with N,N- and S,N-binucleophiles are accompanied by cleavage of the oxazine and pyrrole rings at the C^{4}–O^{5} and N^{10}–C^{3a} bonds, respectively.

In continuation of our studies on nucleophilic transformations of hetareno[*a*]pyrrole-2,3-diones, in the present work we examined reactions of 3-aroyl-2,4-dihydro-1*H*-pyrrolo[2,1-*c*][1,4]benzoxazine-1,2,4-triones **Ia**–**Ic** with 1,3-C,N-binucleophiles, 3-amino-5,5-dimethylcyclohex-2-en-1-one (**IIa**) and its 3-alkylamino and 3-arylamino analogs **IIb**–**IIg**. Compounds **IIa**–**IIg** can be regarded as dimedone imines, and they exist as the corresponding enamino tautomers. These compounds were selected as 1,3-C,N-binucleophiles due to their accessibility from the preparative viewpoint [9] and the ease of variation of the substituent on the nitrogen atom. Molecules **IIa**–**IIg** possess two approximately equivalent nucleophilic centers, β-CH and NH groups, and the direction of primary attack by one of these on possible electrophilic centers in compounds **Ia**–**Ic** (C^{1}, C^{2}, or C^{3a}) should determine the product structure. With a view to estimate the effect of substituents in the substrate and reagent on the reaction course we used pyrrolobenzoxazinetriones **I** having electron-acceptor (bromine atom, **Ic**) and electron-donor (methoxy group, **Ib**) substituents in the *para* position of the 3-benzoyl group and enamines **II** having various substituents on the nitrogen atom.

The reactions were carried out with equimolar amounts of the reactants in anhydrous benzene at 79–80°C; after 1–1.5 min, the corresponding 3'-aroyl-4'-hydroxy-1'-(*o*-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-triones **IIIa**–**IIIu** were formed in high yield (Scheme 1). Compounds **IIIa**–**IIIu** were isolated as colorless or light yellow crystalline substances, which are poorly soluble in common organic solvents, readily soluble in DMF and DMSO, and insoluble in saturated hydrocarbons and water. They showed a positive color test (cherry color) for enolic or phenolic hydroxy group on treatment with an alcoholic solution of iron(III) chloride. The IR spectra of compounds **IIIa**–**IIIu** contain absorption bands due to stretching vibrations of the phenolic and enolic OH groups and NH group (two broadened bands in the regions 3360–3490 and 3160–3220 cm^{-1}), lactam carbonyl groups (1740–1770 and 1710–1740 cm^{-1}), and two enone carbonyl groups (a broad band at 1620–1640 cm^{-1}).

* For communication L, see [1].

Scheme 1.

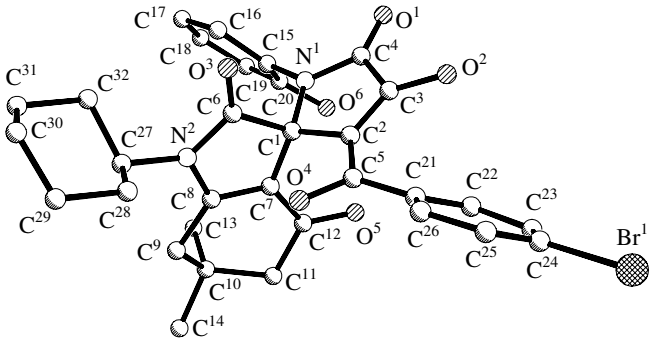


I, Ar = Ph (**a**), 4-$MeOC_6H_4$ (**b**), 4-BrC_6H_4 (**c**); **II**, R = H (**a**), $PhCH_2$ (**b**), *cyclo*-C_6H_{11} (**c**), CH_2=CH–CH_2 (**d**), Ph (**e**), 4-$MeOC_6H_4$ (**f**), 4-ClC_6H_4 (**g**); **III**, Ar = Ph, R = H (**a**), $PhCH_2$ (**d**), *cyclo*-C_6H_{11} (**g**), CH_2=CH–CH_2 (**j**), Ph (**m**), 4-$MeOC_6H_4$ (**p**), 4-ClC_6H_4 (**u**); Ar = 4-$MeOC_6H_4$, R = H (**b**), $PhCH_2$ (**e**), *cyclo*-C_6H_{11} (**h**), CH_2=CH–CH_2 (**k**), Ph (**n**), 4-$MeOC_6H_4$ (**q**), 4-ClC_6H_4 (**t**); Ar = 4-BrC_6H_4, R = H (**c**), $PhCH_2$ (**f**), *cyclo*-C_6H_{11} (**i**), CH_2=CH–CH_2 (**l**), Ph (**o**), 4-$MeOC_6H_4$ (**r**), 4-ClC_6H_4 (**u**).

Compounds **IIIa**–**IIIu** displayed in the ^{1}H NMR spectra (DMSO-d_6) signals from protons in the aromatic rings and substituents therein, two singlets from methyl protons in the dimedone fragment (δ 0.61–0.85 ppm), signals from two methylene groups in the dimedone fragment (δ 1.10–2.45 ppm), a doublet of doublets (*AB* system) from diastereotopic methylene protons in the benzyl group (compounds **IIId**–**IIIf**), signals from the cyclohexyl radical (**IIIg**–**IIIi**), a singlet from the phenolic hydroxy proton (δ 9.40–9.78 ppm), and a broadened singlet from the enolic OH group (δ 12.20–12.43 ppm).

The structure of product **IIIi** was proved by the X-ray diffraction data. Compound **IIIi** crystallized as a 1:1 solvate with ethyl acetate; the structure of its molecule is shown in figure. The double bonds in molecule **IIIi** are localized indicating the absence of appreciable conjugation. All bond lengths and bond angles almost do not differ from the corresponding standard values. Molecules **IIIi** in crystal are grouped around a screw axis (along the *b* axis of a unit cell), giving rise to infinite chains through fairly strong O^2–$H^2\cdots O^{5'}$ intermolecular hydrogen bonds. The distances $O^2\cdots O^{5'}$ and $H^2\cdots O^{5'}$ are 2.68 and 1.95 Å, respectively, and the angle at the hydrogen atom is 147°. Two intramolecular hydrogen bonds O^2–$H^2\cdots O^1$ (2.88 Å) and O^6–$H^6\cdots N^1$ (2.81 Å) are also possible. Ethyl acetate molecule is not involved in hydrogen bonding. The absolute configuration of the chiral center was determined as *S*. Presumably, crystallization of racemate from ethyl acetate gives two kinds of crystals, for the reaction is unlikely to be stereoselective.

A probable reaction scheme includes initial addition of enamine **IIa**–**IIg** at the C^{3a} carbon atom of pyrrolobenzoxazinetrione **Ia**–**Ic** and subsequent pyrrole ring closure via intramolecular attack by the amino group on the lactone carbonyl carbon atom in the oxazine ring and cleavage of the latter at the C^4–O^5 bond. Alkyl or aryl substitution of the nitrogen atom in enamines **II** almost does not affect the reaction course; we can only note appreciable reduction of the reaction rate with N-aryl-substituted compounds **IIe**–**IIg**. Analogous



Structure of the molecule of 3'-(4-bromobenzoyl)-1-cyclohexyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (**IIIi**) according to the X-ray diffraction data.

effect is produced by introduction of a methoxy group into the *para* position of the benzoyl substituent in pyrrolobenzoxazinetrione **I**, but the reaction direction does not change. The described transformation is a rare example of regioselective construction of a spiroheterocyclic system with variable substitution pattern.

Using the AM1 semiempirical SCF MO LCAO method [10], we calculated the enthalpies of formation (ΔH_f) of possible intermediates in the reaction of compound **Ia** with **IIa** (Schemes 2, 3), as well as their geometric and electronic parameters [10]. Our choice of the calculation procedure was based on the fact that just the AM1 method ensured the best agreement between the calculated and experimental bond lengths and bond angles in molecule **IIIi** (as compared to other semiempirical approximations).

Spiro compound **IIIa** can be formed along two paths, *a* (Scheme 2) and *b* (Scheme 3). Path *a* implies attack on the C^{3a} atom in **Ia** by C^2 of enamine **IIa** with formation of zwitterionic intermediate **Int1A** which can be stabilized via proton transfer from C^2 of the enamine fragment to C^3 or C^2=O or PhC=O oxygen atom. Neutral adducts **Int2A**, **Int2'A**, and **Int2''A** are then converted into intermediates **Int3A**, **Int3'A**, and **Int3''A**, respectively, as a result of intramolecular nucleophilic attack on the lactone carbonyl by the nitrogen atom of the enaminoketone fragment. Proton transfer from the oxygen atom of the hydroxy group to the endocyclic oxygen atom is accompanied by cleavage of the C^4–O^5 bond, leading to the final product, spiro[indole-3,2'-pyrrole] **IIIa**.

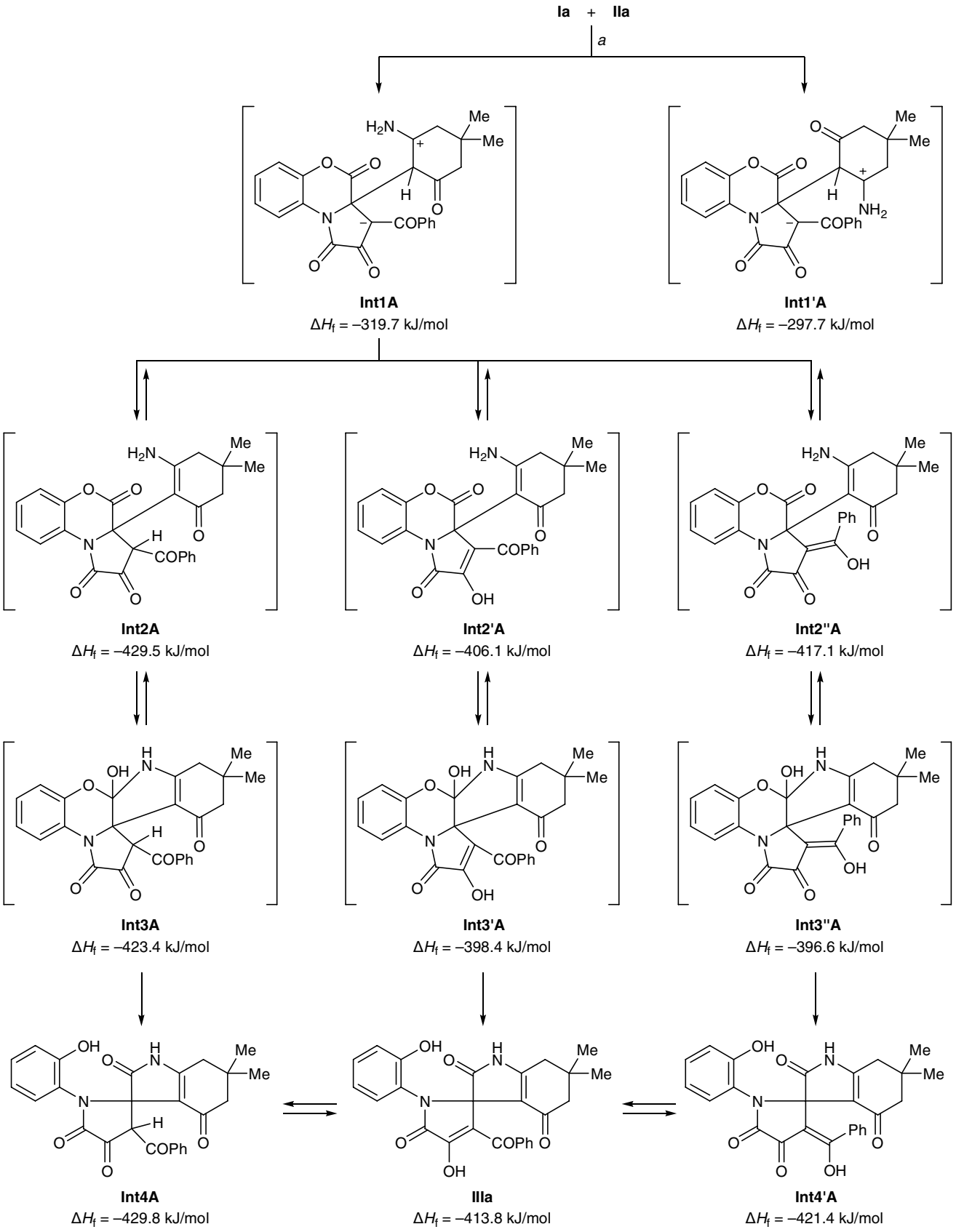
An alternative path (*b*, Scheme 3) includes initial attack by the nitrogen atom of enamine **IIa** on the lactone carbonyl carbon atom of compound **Ia** with formation of zwitterionic adduct **Int1B**. The subsequent proton transfer from the nitrogen atom to oxygen should give neutral intermediate **Int2B** which can be converted into **Int3A** through **Int3B**.

According to the calculations, all intermediates along path *a* correspond to minima on the potential energy surfaces (no negative Hessian eigenvalues were obtained for these structures). Intermediate **Int1** can exist as two stable stereoisomers **Int1A** and **Int1'A**. Intermediate **Int1A** is characterized by spatially close arrangement of the amino group and lactone carbonyl, while the lactone carbonyl in **Int1'A** is close to the carbonyl group of the enaminoketone fragment. The C^{3a}–$C^{2'}$ bond length in zwitterion **Int1A** is 1.597 Å. The formation of a new C–C bond changes the geometric parameters and electron density distribution in the heterocyclic fragment, the strongest variations being observed in the vicinity of the reaction center. The C^{3a}–C^3 bond becomes longer by 0.131 Å, and the C^{3a}–C^4 and C^{3a}–N bonds extend by 0.059 and 0.054 Å, respectively. The C^2–C^3 and C^3–C(O) bonds shorten by 0.057 and 0.048 Å. Some extension of the C^3=O and PhC=O carbonyl bonds is also observed (by 0.015 and 0.024 Å, respectively). Variation of the geometric parameters leads to variation of charges on atoms. The negative charge on C^3 increases by 0.355 a.u. and reaches –0.505 a.u. The charge on the benzoyl oxygen atom becomes equal to –0.466 a.u. (the gain is 0.216 a.u.); $q(C^3{=}O)$ = –0.305 a.u. (Δq = 0.129 a.u.), $q(C^4{=}O)$ = –0.317 a.u. (Δq = 0.083 a.u.), $q(C^2{=}O)$ = –0.267 a.u. (Δq = 0.037 a.u.), q(N) = –0.278 a.u. (Δq = 0.040 a.u.). The geometric parameters and charges on atoms in the enaminoketone fragment also change. The $C^{3'}$–N bond shortens from 1.385 to 1.323 Å, while the $C^{2'}$–$C^{3'}$ bond length increases from 1.364 to 1.504 Å. The negative charge on the nitrogen atom decreases from –0.353 to –0.186 a.u. (i.e., it acquires electron-donor properties), and the charge on C^2 decreases from –0.358 to –0.205 a.u. The $C^{3'}$ atom becomes more electron-deficient: its positive charge increases from 0.101 to 0.281 a.u.

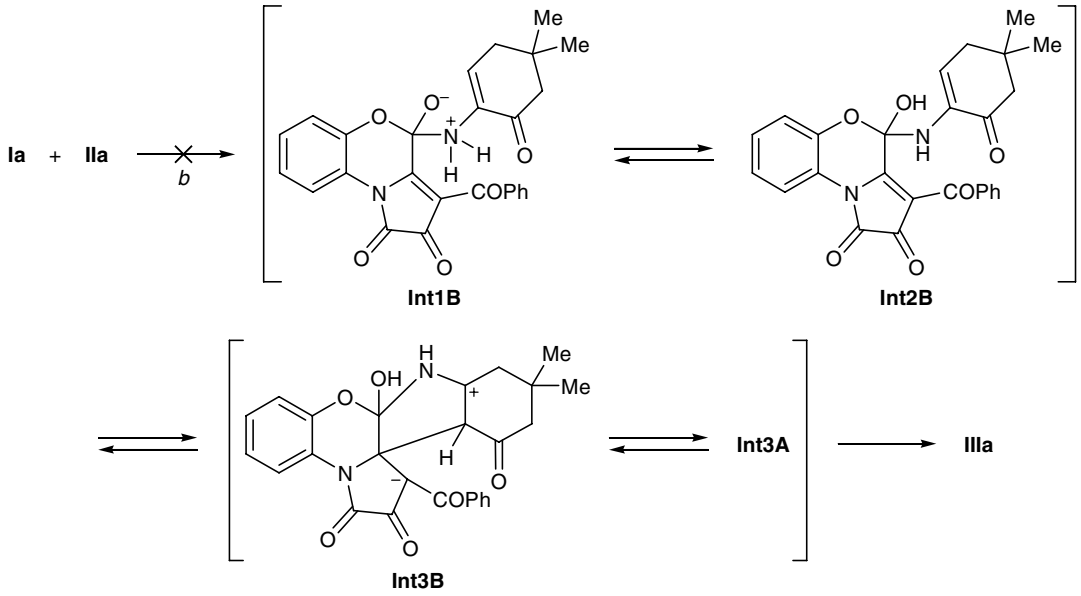
Zwitterionic species **Int1A** can be stabilized via proton migration from C^2 of the enaminoketone fragment to C^3 or carbonyl oxygen atoms in the pyrroloxazine fragment to give neutral intermediate **Int2A**, **Int2'A**, or **Int2''A**. This transformation is favorable from the thermodynamic viewpoint, as follows from comparison of the corresponding ΔH_f values. Intermediates **Int2A** and **Int2'A** are similar in stability, and **Int2''A** is slightly less stable. The transformation of **Int2** into **Int3** involves nucleophilic attack on the lactone carbonyl carbon atom with formation of C^4–N bond and proton transfer from the nitrogen atom to oxygen. This transformation is favored by spatial proximity of the reaction centers to each other. The interatomic distance $C^4 \cdots N$ in **Int2A** is 3.01 Å, and the corresponding distances in **Int2'A** and **Int2''A** are 2.847 and 2.804 Å, respectively. The total charges on the nitrogen atom in **Int2A**, **Int2'A**, and **Int2''A** are –0.355, –0.334, and –0.397 a.u., and on C^4, 0.297, 0.303, and 0.277 a.u., respectively. The oxygen atom in the lactone carbonyl group of the above intermediates has a larger negative charge than that on O^5; therefore, proton transfer to the former is more probable.

The enthalpies of formation (ΔH_f) of intermediates **Int3A** are lower in absolute value, so that they should be less stable than their precursors. Proton transfer from the hydroxy group to the endocyclic oxygen atom

Scheme 2.


Ia + IIa
a
Int1A
ΔHf = –319.7 kJ/mol
Int1'A
ΔHf = –297.7 kJ/mol
Int2A
ΔHf = –429.5 kJ/mol
Int2'A
ΔHf = –406.1 kJ/mol
Int2''A
ΔHf = –417.1 kJ/mol
Int3A
ΔHf = –423.4 kJ/mol
Int3'A
ΔHf = –398.4 kJ/mol
Int3''A
ΔHf = –396.6 kJ/mol
Int4A
ΔHf = –429.8 kJ/mol
IIIa
ΔHf = –413.8 kJ/mol
Int4'A
ΔHf = –421.4 kJ/mol

Scheme 3.



in intermediates **Int3A** is irreversible and is accompanied by cleavage of the C^4–O^5 bond, leading to spiro[indole-3,2'-pyrrole] **IIIa**. The product can exist as ketone tautomer **Int4A** or enol **IIIa** or **Int4'A**. In keeping with the calculated enthalpies of formation, tautomers **Int4A** and **Int4'A** are more stable; however, the calculations refer to an isolated molecule in the gas phase, and the stability order under these conditions may be just the same. In going to solution or crystalline phase, factors stabilizing the enol form, e.g., intermolecular hydrogen bonding, could appear; undoubtedly, these factors cannot be taken into account in the calculations for isolated molecules.

Path *b* seems to be less probable. Geometry optimization of zwitterionic structure **Int1B** led to its "dissociation" into initial molecules **Ia** and **IIa**.

EXPERIMENTAL

The IR spectra were recorded on a UR-20 spectrometer from samples dispersed in mineral oil. The ^{1}H NMR spectra were measured from solutions in DMSO-d_6 on a Bruker WP-400 instrument at 400 MHz relative to TMS as internal reference. The mass spectra (electron impact, 70 eV) were obtained on an MKh-1320 mass spectrometer. The purity of the products was checked by TLC on Silufol plates using ethyl acetate or ethyl acetate–benzene (1:5) as eluent; development with iodine vapor.

X-Ray diffraction study of compound IIIi. Rhombic crystals; $C_{32}H_{30}BrN_2O_6 \cdot C_4H_8O_2$; unit cell parameters: a = 10.350(2), b = 21.551(4), c = 15.288(3) Å; V = 3410.0(11) Å^3; M 706.59; d_{calc} = 1.376 g/cm^3; Z = 4; space group $P2_12_12_1$. The intensities of experimental reflections were measured on a KM-4 (KUMA DIFFRACTION) automatic four-circle diffractometer (χ-geometry, ω/2Θ scanning, monochromatized MoK_α irradiation, $2\Theta \leq 50.06°$). Total of 3834 reflections were measured, 557 of which were Friedel pairs. No correction for absorption was introduced (μ = 0.159 mm^{-1}). The structure was solved by the direct method using SIR92 program [11], followed by a series of calculations of the electron density maps. The positions of hydrogen atoms were set from the geometry considerations. The structure was refined by the full-matrix least-squares procedure in anisotropic approximation using SHELXL-97 software [12]; the final divergence factors were R_1 = 0.0486, wR_2 = 0.1165 [from 1376 reflections with $I \geq 2\sigma(I)$] and R_1 = 0.1844, wR_2 = 0.1385 (from all independent reflections); GooF 0.879. The absolute configuration of molecule **IIIi** was determined with a sufficient reliability; the absolute structure parameter was x = 0.03(2), while for the inverted structure x = 0.55(2); the uncertainty factor was R_1 = 0.0594 against 0.0486.

3'-Benzoyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIa). A solution of 1.0 mmol of compound **Ia** and 1.0 mmol of enamine **IIa** in 10 ml of anhydrous benzene was heated for 1 min under reflux. The mixture was cooled, and the

precipitate was filtered off. Yield 84%, mp 229–230°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3300 br, 3180 br (OH, NH); 1760, 1702 (C^2=O, $C^{5'}$=O); 1665, 1640 (C^4=O, PhCO). ^{1}H NMR spectrum, δ, ppm: 0.73 s (3H, Me), 0.87 s (3H, Me), 1.99 s (2H, 7-H), 2.21 d.d and 2.35 d.d (1H each, 5-H, *J* = 18.1 Hz), 6.75–7.69 m (9H, H_{arom}), 9.41 s (1H, OH, phenol), 10.87 s (1H, NH), 12.20 br.s (1H, OH, enol). Found, %: C 68.09; H 4.86; N 6.10. $C_{26}H_{22}N_2O_6$. Calculated, %: C 68.11; H 4.84; N 6.11.

Compounds **IIIb–IIIu** were synthesized in a similar way.

4'-Hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIb). Yield 81%, mp 202–203°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3280 br, 3150 br (OH, NH); 1755, 1730 (C^2=O, $C^{5'}$=O); 1645 br (C^4=O, C_6H_4CO). ^{1}H NMR spectrum, δ, ppm: 0.72 s (3H, Me), 0.86 s (3H, Me), 1.99 s (2H, 7-H), 2.20 d.d and 2.35 d.d (1H each, 5-H, *J* = 18.1 Hz), 3.84 s (3H, MeO), 6.73–7.73 m (8H, H_{arom}), 9.35 s (1H, OH, phenol), 10.84 s (1H, NH), 12.00 br.s (1H, OH, enol). Found, %: C 66.41; H 4.92; N 5.74. $C_{27}H_{24}N_2O_7$. Calculated, %: C 66.39; H 4.95; N 5.73.

3'-(4-Bromobenzoyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIc). Yield 80%, mp 210–214°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3430 br, 3060 br (OH, NH); 1755, 1735 (C^2=O, $C^{5'}$=O); 1645 br (C^4=O; C_6H_4CO). ^{1}H NMR spectrum, δ, ppm: 0.74 s (3H, Me), 0.86 s (3H, Me), 1.99 s (2H, 7-H), 2.21 d.d and 2.35 d.d (1H each, 5-H, *J* = 18.2 Hz), 6.74–7.72 m (8H, H_{arom}), 9.43 s (1H, OH, phenol), 10.88 s (1H, NH), 12.40 br.s (1H, OH, enol). Found, %: C 58.09; H 3.96; N 5.22. $C_{26}H_{21}BrN_2O_6$. Calculated, %: C 58.11; H 3.94; N 5.21.

3'-Benzoyl-1-benzyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIId). Yield 87%, mp 231–232°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3490 br, 3300 br (OH); 1724 br (C^2=O, $C^{5'}$=O); 1630 br (C^4=O, PhCO). ^{1}H NMR spectrum, δ, ppm: 0.73 s (3H, Me), 0.82 s (3H, Me), 2.00 d.d and 2.09 d.d (1H each, 7-H, *J* = 16.1 Hz), 2.04 d.d and 2.43 d.d (1H each, 5-H, *J* = 18.0 Hz), 4.71 d.d and 4.92 d.d (1H each, C**H**$_2$Ph, *J* = 16.5 Hz), 6.73–7.72 m (14H, H_{arom}), 9.59 s (1H, OH, phenol), 12.38 br.s (1H, OH, enol). Found, %: C 72.27; H 5.12; N 5.09. $C_{33}H_{28}N_2O_6$. Calculated, %: C 72.25; H 5.14; N 5.11.

1-Benzyl-4'-hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIe). Yield 85%, mp 214–216°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3480 br, 3300 br (OH); 1755, 1719 (C^2=O, $C^{5'}$=O); 1620 br (C^4=O, C_6H_4CO). ^{1}H NMR spectrum, δ, ppm: 0.72 s (3H, Me), 0.80 s (3H, Me), 1.98 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.03 d.d and 2.42 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.85 s (3H, OMe), 4.70 d.d and 4.92 d.d (2H, C**H**$_2$Ph, *J* = 16.5 Hz), 6.73–7.75 m (13H, H_{arom}), 9.53 s (1H, OH, phenol), 12.16 br.s (1H, OH, enol). ^{13}C NMR spectrum (DMSO-d_6), δ_C, ppm: 190.01 (C^4); 187.45 (C_6H_4**C**O); 174.65, 165.81, 162.97, 154.79, 151.09 (C^2, **C**OMe, $C^{7a'}$, C^5, $C^{4'}$); 136.09–109.57 (C_{arom}), 68.97 (C_{spiro}); 55.49 (CH_3O); 50.39 (CH_2); 43.09 (C^5); 35.19 (C^7); 27.60 (CH_3); 33.52 (C^6). Found, %: C 70.56; H 5.25; N 4.86. $C_{34}H_{30}N_2O_7$. Calculated, %: C 70.58; H 5.23; N 4.84.

1-Benzyl-3'-(4-bromobenzoyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIf). Yield 83%, mp 241–242°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3520 br, 3170 br (OH); 1748, 1718 (C^2=O, $C^{5'}$=O); 1650, 1615 br (C^4=O, C_6H_4CO). ^{1}H NMR spectrum, δ, ppm: 0.73 s (3H, Me), 0.81 s (3H, Me), 2.00 d.d and 2.09 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.05 d.d and 2.43 d.d (1H each, 5-H, *J* = 18.2 Hz), 4.71 d.d and 4.90 d.d (1H each, C**H**$_2$Ph, *J* = 16.5 Hz), 6.73–7.75 m (13H, H_{arom}), 9.60 s (1H, OH, phenol), 12.55 br.s (1H, OH, enol). Found, %: C 63.19; H 4.32; N 4.44. $C_{33}H_{27}BrN_2O_6$. Calculated, %: C 63.17; H 4.34; N 4.46.

3'-Benzoyl-1-cyclohexyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIg). Yield 82%, mp 215–217°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3410 br, 3210 br (OH); 1738 (C^2=O, $C^{5'}$=O); 1640, 1620 br (C^4=O, PhCO). ^{1}H NMR spectrum, δ, ppm: 0.70 s (3H, Me), 0.89 s (3H, Me), 1.10–1.98 m (10H, CH_2, cyclohexyl), 1.95 d.d and 2.00 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.43 d.d and 2.53 d.d (1H each, 5-H, *J* = 18.7 Hz), 3.67 m (1H, 1-CH), 6.71–7.70 m (9H, H_{arom}), 9.37 s (1H, OH, phenol), 12.17 br.s (1H, OH, enol). Found, %: C 71.11; H 5.95; N 5.17. $C_{32}H_{32}N_2O_6$. Calculated, %: C 71.09; H 5.97; N 5.18.

1-Cyclohexyl-4'-hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIh). Yield 80%, mp 219–220°C (decomp., from

ethyl acetate). IR spectrum, ν, cm^{-1}: 3445 br, 3050 br (OH); 1745, 1725 (C^2=O, $C^{5'}$=O); 1655, 1620 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.68 s (3H, Me), 0.88 s (3H, Me), 1.12–1.99 m (10H, CH_2, cyclohexyl), 1.93 d.d and 1.99 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.42 d.d and 2.53 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.66 m (1H, 1-CH), 3.84 s (3H, OMe), 6.71–7.71 m (8H, H_{arom}), 9.30 s (1H, OH, phenol), 11.95 br.s (1H, OH, enol). Found, %: C 69.56; H 5.86; N 4.90. $C_{33}H_{33}N_2O_7$. Calculated, %: C 69.58; H 5.84; N 4.92.

3'-(4-Bromobenzoyl)-1-cyclohexyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIi). Yield 80%, mp 258–261°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3460 br, 3040 br (OH); 1750, 1724 (C^2=O, $C^{5'}$=O); 1660, 1624 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.70 s (3H, Me), 0.89 s (3H, Me), 1.13–1.99 m (1H, CH_2, cyclohexyl), 1.95 d.d and 2.00 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.43 d.d and 2.53 d.d (1H each, 5-H, *J* = 18.8 Hz), 3.66 m (1H, 1-CH), 6.70–7.75 m (8H, H_{arom}), 9.41 s (1H, OH, phenol), 12.38 br.s (1H, OH, enol). Found, %: C 62.12; H 4.87; N 4.55. $C_{32}H_{30}BrN_2O_6$. Calculated, %: C 62.14; H 4.89; N 4.53.

1-Allyl-3'-benzoyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIj). Yield 85%, mp 220–221°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3350 br, 3200 br (OH); 1752, 1701 (C^2=O, $C^{5'}$=O); 1660, 1615 br (C^4=O, PhCO). ^1H NMR spectrum, δ, ppm: 0.76 s (3H, Me), 0.87 s (3H, Me), 2.01 d.d and 2.06 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.30 d.d and 2.47 d.d (1H each, 5-H, *J* = 18.0 Hz), 4.17 m (2H, 1-CH_2), 4.79 d (1H, *trans*-CH_2=, *J* = 17.2 Hz), 5.00 d (1H, *cis*-CH_2=, *J* = 10.8 Hz), 5.75 m (1H, CH=), 6.72–7.70 m (9H, H_{arom}), 9.49 s (1H, OH, phenol), 12.30 br.s (1H, OH, enol). Found, %: C 69.85; H 5.28; N 5.59. $C_{29}H_{26}N_2O_6$. Calculated, %: C 69.87; H 5.26; N 5.62.

1-Allyl-4'-hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIk). Yield 88%, mp 217–219°C (decomp., from ethyl acetate–dichloroetane). IR spectrum, ν, cm^{-1}: 3160 br (OH); 1755, 1704 (C^2=O, $C^{5'}$=O); 1660, 1619 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.75 s (3H, Me), 0.86 s (3H, Me), 2.00 d.d and 2.04 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.28 d.d and 2.47 d.d (1H each, 5-H, *J* = 18.5 Hz), 3.84 s (3H, OMe), 4.17 m (2H, 1-CH_2), 4.78 d (1H, *trans*-CH_2=, *J* = 18.1 Hz), 4.99 d (1H, *cis*-CH_2=, *J* = 10.9 Hz), 5.75 m (1H, CH=), 6.73–7.72 m (8H, H_{arom}), 9.46 s (1H, OH, phenol), 12.10 br.s (1H, OH, enol). Found, %: C 68.19; H 5.33; N 5.31. $C_{30}H_{28}N_2O_7$. Calculated, %: C 68.17; H 5.34; N 5.29.

1-Allyl-3'-(4-bromobenzoyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIl). Yield 88%, mp 224–225°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3430 br, 3260 br (OH); 1731 (C^2=O, $C^{5'}$=O); 1639 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.76 s (3H, Me), 0.87 s (3H, Me), 2.00 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.4 Hz), 2.30 d.d and 2.48 d.d (1H each, 5-H, *J* = 18.5 Hz), 4.17 m (2H, 1-CH_2), 4.79 d (1H, *trans*-CH_2=, *J* = 18.0 Hz), 5.00 d (1H, *cis*-CH_2=, *J* = 10.9 Hz), 5.74 m (1H, CH=), 6.73–7.72 m (8H, H_{arom}), 9.53 s (1H, OH, phenol), 12.58 br.s (1H, OH, enol). Found, %: C 60.30; H 4.38; N 4.83. $C_{29}H_{25}BrN_2O_6$. Calculated, %: C 60.32; H 4.36; N 4.85.

3'-Benzoyl-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-1-phenyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIm). Yield 88%, mp 204–205°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3400 br, 3040 br (OH); 1750, 1720 (C^2=O, $C^{5'}$=O); 1660, 1625 br (C^4=O, PhCO). ^1H NMR spectrum, δ, ppm: 0.59 s (3H, Me), 0.82 s (3H, Me), 1.97 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.1 Hz), 2.08 d.d and 2.33 d.d (1H each, 5-H, *J* = 18.0 Hz), 6.80–7.73 m (14H, H_{arom}), 9.75 s (1H, OH, phenol), 12.44 br.s (1H, OH, enol). Found, %: C 71.87; H 4.88; N 5.26. $C_{32}H_{26}N_2O_6$. Calculated, %: C 71.89; H 4.90; N 5.24.

4'-Hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-1-phenyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIn). Yield 86%, mp 232–234°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3450 br, 3040 br (OH); 1750, 1724 (C^2=O, $C^{5'}$=O); 1660, 1620 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.58 s (3H, Me), 0.81 s (3H, Me), 1.95 d.d and 2.04 d.d (1H each, 7-H, *J* = 16.1 Hz), 2.08 d.d and 2.33 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.85 s (3H, OMe), 6.79–7.78 m (13H, H_{arom}), 9.71 s (1H, OH, phenol), 12.22 br.s (1H, OH, enol). Found, %: C 70.22; H 4.97; N 4.94. $C_{33}H_{28}N_2O_7$. Calculated, %: C 70.20; H 4.99; N 4.96.

3'-(4-Bromobenzoyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-1-phenyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIo).

Yield 89%, mp 215–218°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3420 br, 3090 br (OH); 1755, 1723 (C^2=O, $C^{5'}$=O); 1630 br, 1615 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.59 s (3H, Me), 0.82 s (3H, Me), 1.97 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.09 d.d and 2.34 d.d (1H each, 5-H, *J* = 18.4 Hz), 6.79–7.75 m (13H, H_{arom}), 9.77 s (1H, OH, phenol), 12.60 br.s (1H, OH, enol). Found, %: C 62.63; H 4.09; N 5.59. $C_{32}H_{25}BrN_2O_6$. Calculated, %: C 62.65; H 4.11; N 4.57.

3'-Benzoyl-4'-hydroxy-1'-(2-hydroxyphenyl)-1-(4-methoxyphenyl)-6,6-dimethyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIp). Yield 82%, mp 227–228°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3240 br (OH); 1750, 1708 (C^2=O, $C^{5'}$=O); 1640 br, 1623 br (C^4=O, PhCO). ^1H NMR spectrum, δ, ppm: 0.60 s (3H, Me), 0.81 s (3H, Me), 1.97 d.d and 2.05 d.d (1H each, 7-H, *J* = 16.1 Hz), 2.05 d.d and 2.28 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.82 s (3H, OMe), 6.80–7.78 m (13H, H_{arom}), 9.74 s (1H, OH, phenol), 12.41 br.s (1H, OH, enol). Found, %: C 70.18; H 4.97; N 4.98. $C_{33}H_{28}N_2O_7$. Calculated, %: C 70.20; H 4.99; N 4.96.

4'-Hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-1-(4-methoxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIq). Yield 83%, mp 213–215°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3385 br, 3200 br (OH); 1730 (C^2=O, $C^{5'}$=O); 1660, 1625 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.58 s (3H, Me), 0.80 s (3H, Me), 1.94 d.d and 2.03 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.04 d.d and 2.27 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.82 s (3H, OMe), 3.85 s (3H, OMe), 6.79–7.80 m (12H, H_{arom}), 9.66 s (1H, OH, phenol), 12.20 br.s (1H, OH, enol). Found, %: C 68.66; H 5.11; N 4.74. $C_{34}H_{30}N_2O_8$. Calculated, %: C 68.68; H 5.09; N 4.71.

3'-(4-Bromobenzoyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-1-(4-methoxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIr). Yield 80%, mp 225–226°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3390 br, 3100 br (OH); 1740, 1720 (C^2=O, $C^{5'}$=O); 1639, 1618 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.59 s (3H, Me), 0.82 s (3H, Me), 1.96 d.d and 2.04 d.d (1H each, 7-H, *J* = 16.1 Hz), 2.05 d.d and 2.29 d.d (1H each, 5-H, *J* = 18.4 Hz), 3.82 s (3H, OMe), 6.78–7.78 m (12H, H_{arom}), 9.75 s (1H, OH, phenol), 12.62 br.s (1H, OH, enol). Found, %: C 61.57; H 4.21; N 4.33. $C_{33}H_{27}BrN_2O_7$. Calculated, %: C 61.59; H 4.23; N 4.35.

3'-Benzoyl-1-(4-chlorophenyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro-[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIs). Yield 88%, mp 213–214°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3295 br (OH); 1720, 1702 (C^2=O, $C^{5'}$=O); 1626 br (C^4=O, PhCO). ^1H NMR spectrum, δ, ppm: 0.57 s (3H, Me), 0.82 s (3H, Me), 1.96 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.12 d.d and 2.36 d.d (1H each, 5-H, *J* = 18.0 Hz), 6.79–7.72 m (13H, H_{arom}), 9.80 s (1H, OH, phenol), 12.50 br.s (1H, OH, enol). Found, %: C 67.52; H 4.41; N 4.90. $C_{32}H_{25}ClN_2O_6$. Calculated, %: C 67.55; H 4.43; N 4.92.

1-(4-Chlorophenyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-3'-(4-methoxybenzoyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIt). Yield 87%, mp 189–192°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3200 br (OH); 1756, 1710 (C^2=O, $C^{5'}$=O); 1640, 1610 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.56 s (3H, Me), 0.80 s (3H, Me), 1.94 d.d and 2.04 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.12 d.d and 2.35 d.d (1H each, 5-H, *J* = 18.0 Hz), 3.85 s (3H, OMe), 6.78–7.75 m (12H, H_{arom}), 9.76 s (1H, OH, phenol), 12.28 br.s (1H, OH, enol). Found, %: C 66.19; H 4.57; N 4.66. $C_{33}H_{27}ClN_2O_7$. Calculated, %: C 66.17; H 4.54; N 4.68.

3'-(4-Bromobenzoyl)-1-(4-chlorophenyl)-4'-hydroxy-1'-(2-hydroxyphenyl)-6,6-dimethyl-6,7-dihydrospiro[indole-3,2'-pyrrole]-2,4,5'(1*H*,1'*H*,5*H*)-trione (IIIu). Yield 89%, mp 220–222°C (decomp., from ethyl acetate). IR spectrum, ν, cm^{-1}: 3070 br (OH); 1754, 1721 (C^2=O, $C^{5'}$=O); 1639, 1615 br (C^4=O, C_6H_4CO). ^1H NMR spectrum, δ, ppm: 0.57 s (3H, Me), 0.82 s (3H, Me), 1.96 d.d and 2.07 d.d (1H each, 7-H, *J* = 16.0 Hz), 2.13 d.d and 2.38 d.d (1H each, 5-H, *J* = 18.0 Hz), 6.87–7.98 m (12H, H_{arom}), 9.84 s (1H, OH, phenol), 12.62 br.s (1H, OH, enol). Found, %: C 59.30; H 3.72; N 4.30. $C_{32}H_{24}BrClN_2O_6$. Calculated, %: C 59.32; H 3.73; N 4.32.

This study was performed under financial support by the Russian Foundation for Basic Research (project no. 04-03-96033).

REFERENCES

1. Bozdyreva, K.S., Smirnova, I.V., and Maslivets, A.N., *Russ. J. Org. Chem.*, 2005, vol. 41, p. 1081.
2. Maslivets, A.N., Mashevskaya, I.V., Krasnykh, O.P., Shurov, S.N., and Andreichikov, Yu.S., *Zh. Org. Khim.*, 1992, vol. 28, p. 2545.

3. Maslivets, A.N., Mashevskaya, I.V., and Andreichikov, Yu.S., *Zh. Org. Khim.*, 1993, vol. 29, p. 2056.
4. Mashevskaya, I.V., Kol'tsova, S.V., Voronina, E.V., Odegova, A.N., and Maslivets, A.N., *Khim.-Farm. Zh.*, 2001, vol. 35, p. 19.
5. Maslivets, A.N., Mashevskaya, I.V., and Andreichikov, Yu.S., *Russ. J. Org. Chem.*, 1995, vol. 31, p. 569.
6. Tolmacheva, I.A., Mashevskaya, I.V., and Maslivets, A.N., *Russ. J. Org. Chem.*, 2001, vol. 37, p. 596.
7. Mashevskaya, I.V., Kol'tsova, S.V., and Maslivets, A.N., *Khim. Geterotsikl. Soedin.*, 2001, p. 705.
8. Mashevskaya, I.V., Duvalov, A.V., Tolmacheva, I.V., Aliev, Z.G., and Maslivets, A.N., *Russ. J. Org. Chem.*, 2004, vol. 40, p. 1359.
9. Jirkovsky, I., *Can. J. Chem.*, 1974, vol. 52, p. 55.
10. Dewar, M.J.S., Zoebisch, E.G., Healy, E.F., and Stewart, J.J.P., *J. Am. Chem. Soc.*, 1985, vol. 107, p. 3902.
11. Altomare, A., Cascarano, G., Giacovazzo, C., and Gualardi, A., *J. Appl. Crystallogr.*, 1993, vol. 26, p. 343.
12. Sheldrick, G.M., *SHELX-97. Programs for Crystal Structure Analysis*, Göttingen: Univ. of Göttingen, 1998, p. 2332.