A Platinum Open Access Journal for Organic Chemistry

Paper

Free to Authors and Readers

DOAJ Seal

Arkivoc **2022**, part ii, 0-0
to be inserted by editorial office

Synthesis of substituted 1,3-oxazino[5,4,3-*ij*]quinolin-1,3-diones by the oxidation of various pyrrolo[3,2,1-*ij*]quinoline-1,2-diones with *m*-chloroperbenzoic acid

Svetlana M. Medvedeva,[a] Alexey V. Movchan,[a] Oleg E. Sidorenko,[a] Alexander S. Shestakov,[a] Irina V. Ledenyova,[a] Igor V. Zavarzin,[b] and Khidmet S. Shikhaliev*[a]

[a]*Voronezh State University, Universitetskaya pl. 1, Voronezh, 394006, Russia*
[b]*N.D. Zelinsky Institute of Organic Chemistry, Russian Academy of Sciences, Leninsky pr., 47, Moscow 119991, Russia*
Email: chocd261@chem.vsu.ru

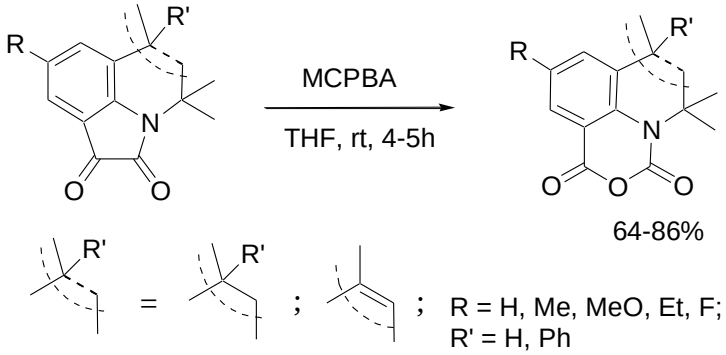
This paper is dedicated to the successful career of Professor Girolamo Cirrincione in the field of research on nitrogen heterocyclic systems of pharmaceutical interest

Received mm-dd-yyyy **Accepted Manuscript** mm-dd-yyyy **Published on line** mm-dd-yyyy

Dates to be inserted by editorial office

Abstract

When various pyrrolo[3,2,1-*ij*]quinoline-1,2-diones were oxidized with *m*-chloroperbenzoic acid, 1,3-oxazino[5,4,3-*ij*]quinolin-1,3-diones were obtained in good yields (64–86%) and characterized by spectral methods. Recyclization/rearrangement of the pyrroldione fragment of pyrrolo[3,2,1-*ij*]quinoline-1,2-diones, regardless of the presence and electronic nature of the substituent in the aromatic part, the presence of a bulky phenyl group or a multiple bond in the heterocyclic fragment, proceeds selectively with the formation of a 1,3-oxazine cycle, rather than an isomeric 1,4-oxazine ring. This outcome corresponds to the data acquired from quantum mechanical calculations.



Keywords: Pyrrolo[3,2,1-*ij*]quinoline-1,2-dione, oxidation, *m*-chloroperbenzoic acid, 1,3-oxazino[5,4,3-*ij*]quinolin-1,3-dione, 1,4-oxazino[2,3,4-*ij*]quinoline-2,3-dione, oxidative recyclization/rearrangement.

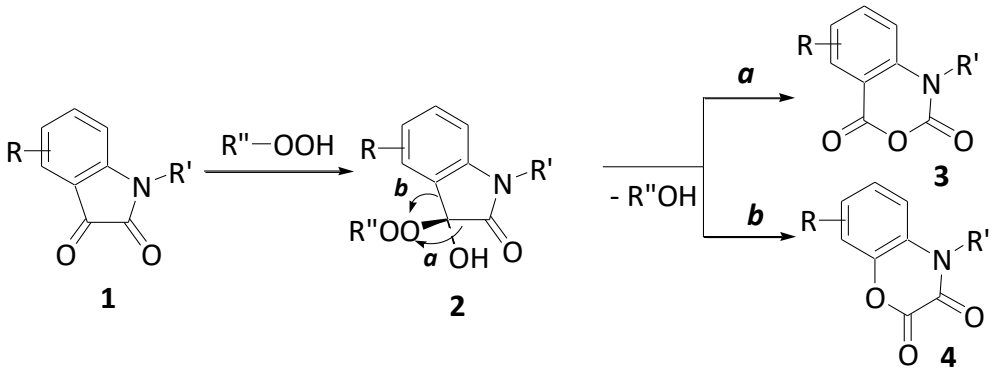
Introduction

Annulated oxazines (with heteroatoms in positions 1,3- and 1,4-) are widely used as starting compounds for the preparation of various acyclic and heterocyclic systems, the synthesis of which is frequently impossible by multi-step or other methods.[1-8] In addition, they are of interest to biochemists and pharmacologists.[1-3,5,8] Among them, compounds have been found that exhibit a wide range of pharmacological activity, including antibacterial,[9-11] anticoagulant,[5,8,11] anti-inflammatory,[12,13] cardiovascular,[14] antidepressant[11,15,16] and antitumor properties. [1,2,17,18]

At the same time, among tricyclic compounds in which a hydroquinoline cycle is annulleted at the *i* and *j* positions with carbo- or hetero-cycles, biologically active substances have also been found, including those exhibiting anticoagulant activity.[19-21] In particular, partially hydrogenated oxazinoquinolines exhibit various types of biological activity. As bioactive examples, substituted 1,4-oxazino[2,3,4-*ij*]quinolines are used in medicine as effective bactericidal agents (ofloxacin and its analogs).[22-24] Some derivatives of these compounds have a high selective affinity for cannabinoid CB2 receptors (without having psychoactive properties) and can be used to reduce inflammatory activity and neuropathic pain.[25] 1,3-Oxazino[5,4,3-*ij*]quinolines also exhibit antibacterial activity.[26.27]

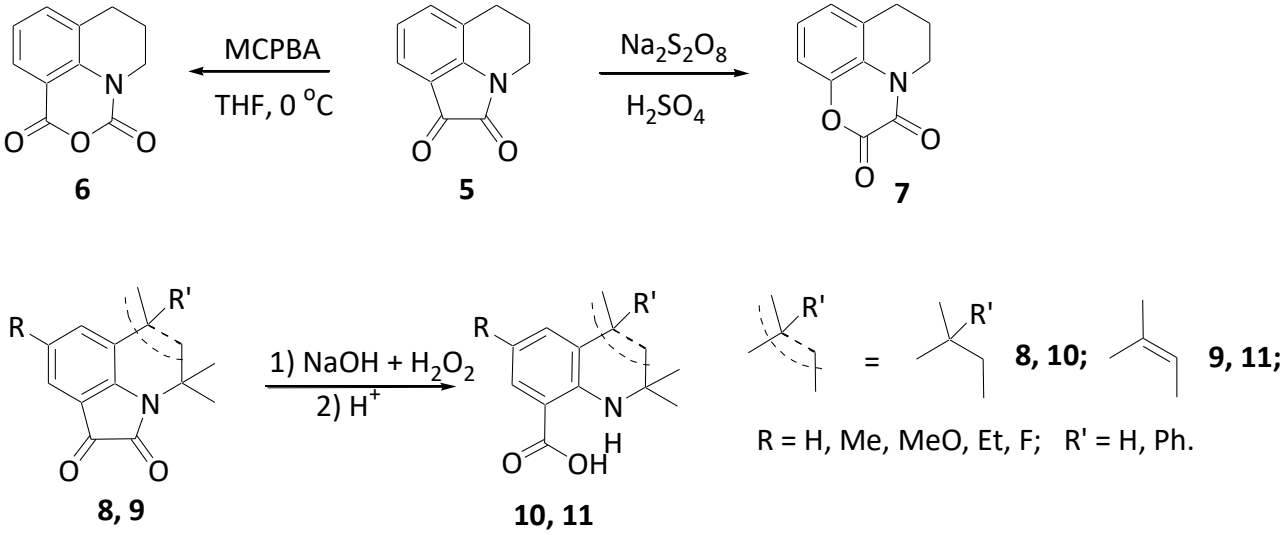
In this regard, the synthesis of new derivatives in the series of 1,3-oxazino[5,4,3-*ij*]quinolines or isomeric 1,4-oxazino[2,3,4-*ij*]quinolines is relevant. One of the methods for constructing these systems is an approach involving the addition of oxazine fragments to the hydroquinoline cycle.

The literature describes the syntheses of 1,3-oxazinoquinolinediones, a problem being that these approaches lead to the formation of products with low yields. These syntheses are also often difficult to apply due to their complexity: they are either multi-stage in nature or use toxic reagents (such as phosgene, CS_2 or CO).[28-30] For the synthesis of 1,4-oxazinoquinolinedione, the only way involves the reaction of 8-hydroxy-1,2,3,4-tetrahydroquinoline with oxalyl chloride.[31] At the same time, recyclizations/rearrangements of the pyrroledione fragment of substituted isatins (1-*H*-indole-2,3-diones) **1** into the 1,3- or 1,4-oxazine ring have been known for a long time (Scheme 1). In this case, the oxidative transformations of the pyrrole ring of intermediate products **2** probably proceed through the Baeyer-Villiger reaction along pathways ***a*** or ***b***, respectively, depending on the reaction conditions and the oxidant.[32-34] However, there is conflicting information on the structure of the oxidation products of substituted isatins with *m*-chloroperbenzoic acid (MCPBA), the products have been assigned the structures of 1,3-oxazine-2,4-diones (isatoic anhydrides)[33-35] **3** and 1,4-oxazine-2,3-diones[36,37] **4** (Scheme 1). Moreover, sufficiently convincing evidence has been presented that the reaction proceeds selectively with the formation of isatoic anhydrides **3**,[33] or 1,4-oxazines **4**.[36] In the latter case, the choice of the reaction route along pathway ***b*** is explained by the presence of electron-donating substituents on the aromatic ring.[36]



Scheme 1. Reaction of substituted isatins with *m*-chloroperbenzoic acid.

Earlier, based on oxidative transformations of the tricyclic analogue of isatin - pyrrolo[3,2,1-*ij*]quinoline-1,2-dione (**5**) under the action of peracids, we synthesized 1,3-oxazino[5,4,3-*ij*]quinoline-1,3-dione (**6**) and its isomer - 1,4-oxazino[2,3,4-*ij*]quinoline-2,3-dione (**7**) (Scheme 2).[38] Previously, we also showed that various substituted pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **8** and **9**, as well as isatin, undergo opening of the pyrroledione fragment and subsequent decarboxylation under the action of hydrogen peroxide in an alkaline medium, with the subsequent formation hydroquinoline-8-carboxylic acids **10** and **11**, respectively (Scheme 2).[39] In addition, the presence of a *gem*-dimethyl fragment in the *ortho* position from the nodal nitrogen did not sterically hinder this decyclization.



Scheme 2. Oxidative transformations of pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **5**, **8** and **9**.

In order to obtain new oxazinohydroquinolines, and to establish their structure, in this work we carried out the oxidation of 4,4,6-trimethyl-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **9** and their hydrogenated analogs, 4,4,6-trimethyl-5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **8**, with *m*-chloroperbenzoic acid.

Results and Discussion

8-*R*-4,4,6-trimethyl-5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones (**8a-e)**, 4,4,6-trimethyl-6-phenyl-5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-dione (**8f)**, 8-R-4,4,6-trimethyl-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones (**9a-e**) were prepared according to the Stolle method,[40] which we had previously modified[41,42] by reacting the hydrochlorides of the corresponding starting substituted hydroquinolines with oxalyl chloride (without using Lewis acids as catalysts, which are required for cyclization in the classical version of the reaction). In a previous paper[38] we developed optimal conditions for the selective oxidation of pyrrolo[3,2,1-*ij*]quinoline-1,2-dione **5** in THF, leading to the formation of 1,3-oxazinoquinolinedione **6**. This process involved a solution of *m*-chloroperbenzoic acid in THF being added in small portions at a temperature of -2-3 °C, after which the reaction mixture was kept at room temperature for 4-5 hours. In this paper, we have studied the oxidation of pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **9a-e** and **8a-f** without substituents and having acceptor fluorine atoms or various electron-donating substituents on the benzene ring, including compound **8f** containing two substituents (methyl and phenyl group) in the *para* position relative to the nitrogen atom in the hydropyridine fragment. The oxidation of all pyrroloquinolinediones **8** by this method proceeded smoothly (regardless of the presence and electronic nature of the substituents on the aromatic part or the presence of a bulky phenyl group in the heterocyclic fragment). After 3 hours, the reaction mixture began to change color from orange to light yellow, which allowed visual analysis of the reaction progress. Within 4-5 hours the reaction was deemed complete, and the reaction products precipitated after removal of excess solvent on a rotary evaporator. After purification from the mixture of *m*-chlorobenzoic acid by recrystallization from CCl_4, the products yields were 64–86%. Using a combination of ^{1}H NMR and ^{13}C NMR spectroscopy and mass spectrometry data, the reaction products could be assigned the structures, 9-R-7-R'-5,5,7-trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones **10a-f**.

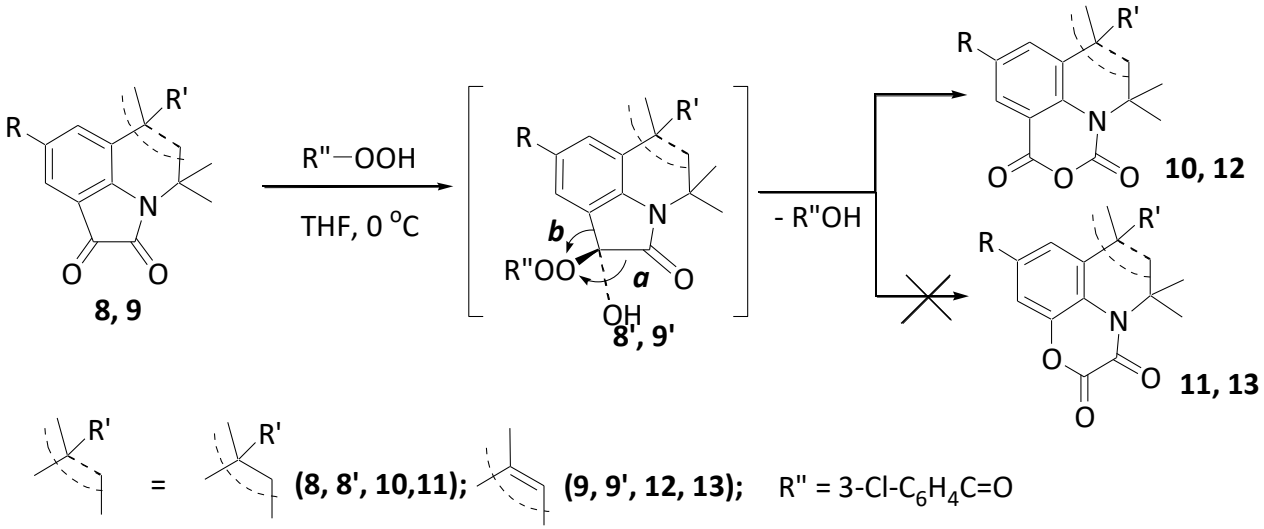
The structure of the compounds obtained, **10a-f**, was unambiguously confirmed by ^{1}H and ^{13}C NMR spectroscopy and mass spectrometry. In the ^{1}H NMR spectra of all 1,3-oxazinoquinolines **10**, the proton signals of the *gem*-dimethyl groups and other substituents at positions 7 and 9 of the hydroquinoline fragments appear in the corresponding regions.[39,41,42]. It should be noted that in the aromatic areas of the spectra, the signals of some protons of the hydroquinoline cycles were shifted quite downfield - up to 8.0 ppm, which we observed earlier in previous research.[38] This shift can be associated with the presence of an intramolecular hydrogen bond between a proton and an adjacent carbonyl group in the 1,3-oxazine ring.[33] The presence of a characteristic signal of an aromatic carbon atom at 158-160 ppm in the ^{13}C NMR spectra of the obtained compounds **10** and the absence of peaks in the region of 150-152 ppm indicated that the aromatic ring is associated with a carbonyl carbon,[33,38] but not with an oxygen atom.[36,38]

In the mass spectra (EI) of oxazinoquinoline-1,3-diones **10a-f**, peaks of molecular radical ions of low intensity (I_{rel} = 10 - 21%,) were observed. The maximum intensity and (I_{rel} = 100%) were possessed by the ions formed during the elimination of a CO_2 molecule and a methyl radical from the molecular radical ions. Elimination of the latter is characteristic of the decomposition of molecular ions of hydroquinoline derivatives with a *gem*-dimethyl group in the second position.[43] The decay of a molecular radical ion with the release of a CO_2 molecule additionally confirmed the structure of 1,3-oxazinoquinolines **10**, ascribed to the obtained compounds, rather than 1,4-oxazinoquinolines **11**, the decomposition of which should occur with the successive release of two CO molecules.[38]

In terms of the reaction mechanism, presumably, at the first stage of the process, the peracid is added to the carbon atom of the carbonyl group with the formation of intermediates **8'a–f**, the subsequent

recyclization/rearrangement of which, due to the opening of the pyrrole ring (by bond ***a***), leads to the formation of compounds **10** (Scheme 3). It should be noted that in the case of pyrroloquinolinediones **8**, we failed to direct the reaction along the route involving the opening of bond ***b***, according to the method described[36] for the preparation of 1,4-oxazines. Oxidation of pyrroloquinolinediones **8** by this method, when the entire amount of *m*-chloroperbenzoic acid was added at once at room temperature (even in the presence of electron donor groups in the hydroquinoline fragment of these compounds), did not lead to the expected 7-R-9-R'-5,5,7-trimethyl-6,7-dihydro-5*H*-[1,4]oxazino[2,3,4-*ij*]quinoline-2,3-diones **11a-f**. As a result, using this technique, we obtained products that were completely identical in terms of melting point and TLC data to 1,3-oxazinoquinolines **10a-f**, and their yields did not significantly differ.

We have also studied the oxidation of 8-R-4,4,6-trimethyl-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **9a-e** containing a multiple bond in the heterocycle under similar conditions, that being the treatment of these substrates with a solution *m*-chloroperbenzoic acid at room temperature. It should be noted that polymerization is possible for 1,2-dihydroquinolines.[44] In addition, it is known that *N*-acyl-1,2-dihydroquinolines are oxidized by peroxides to form *N*-acyl-1,2-dihydroquinoline-3,4-epoxides.[45] The interaction proceeded smoothly, and as the reaction proceeded, the color of the reaction mixture also changed from dark red to yellow. Using a combination of ^{1}H NMR and ^{13}C NMR spectroscopy and mass spectrometry data, it was found that the oxidation reaction of pyrroloquinolinediones **9a-e** proceeded selectively, without affecting the multiple bond, and led to 9-R-5,5,7-trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones **12a-c** (yields 67-82% - Scheme 3). Recyclization/rearrangement of intermediate **9'a-e** to 9-ethyl-5,5,7-trimethyl-5*H*-[1,4]oxazino[2,3,4-*ij*]quinoline-2,3-diones **13a-e** did not occur, even when the reaction mixture was heated to 60 ° C for 1 hour after addition of the oxidizing agent. The formation of polymerization products and epoxides was also not detected in this case.



						R	R’
8a	**9a**	**10a**	**11a**	**12a**	**13a**	H	H
8b	**9b**	**10b**	**11b**	**12b**	**13b**	Me	H
8c	**9c**	**10c**	**11c**	**12c**	**13c**	OMe	H
8d	**9d**	**10d**	**11d**	**12d**	**13d**	Et	H
8e	**9e**	**10e**	**11e**	**12e**	**13e**	F	H

8f	-	**10f**	**11f**	-	-	Me	Ph

Scheme 3. Oxidation of pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **8** and **9** with *m*-chloroperbenzoic acid.

In terms of understanding the outcome of the reactions performed, it was decided to investigate the substrates by computational methods. For all the molecules, a complete geometry optimization was also performed using the B3LYP exchange-correlation density functional in the cc-pVDZ basis set. Calculation and analysis of normal vibrations of molecules showed that the optimized structures correspond to the energy minimum on the potential energy surface. The calculation of charges on atoms was carried out using the method based on the reproduction of the molecular electrostatic potential CHELPG.[46] This method of calculating charges on atoms shows more accurate results, which are less dependent on the choice of the basis set. All quantum chemical calculations were performed using the Gaussian 09 program.[47]

In terms of outcomes, the quantum-chemical calculations of atomic charges in compounds **8** and **9** (Figure 1) showed that quite large positive charges are localized on the C^1 and C^2 atoms, while the C^{9a} atom bears a weak negative charge. This explains why the recyclization/rearrangement of the pyrroledione fragment into the oxazine fragment preferentially proceeds with the breaking of the bond between the C^1 and C^2 atoms. An alternative variant of recyclization/rearrangement, due to the breaking of the bond between the C^1 and C^{9a} atoms, does not occur, even in the presence of substituents in the 6th and 8th positions of pyrroloquinolines **8** and **9**, since the influence of the substituent is reflected only on the charges of the C^6 and C^8 atoms and practically does not affect the charges of the C^1, C^2 atoms and C^{9a} (Table 1).

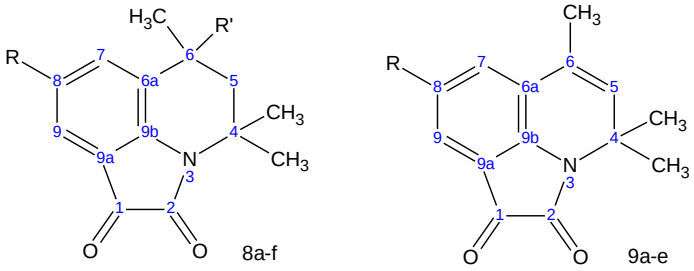


Figure 1. Numbered skeleton structure of compounds **8** and **9**

Table 1

Calculated atomic charges according to CHELPG on the atoms of compounds 8 and 9

Atom*	Compound										
	8a	8b	8c	8d	8e	8f	9a	9b	9c	9d	9e
C^1	0.358	0.367	0.394	0.362	0.371	0.409	0.398	0.407	0.434	0.391	0.425
C^2	0.508	0.489	0.455	0.501	0.478	0.468	0.445	0.446	0.385	0.439	0.412
N	-0.478	-0.429	-0.383	-0.429	-0.410	-0.467	-0.358	-0.374	-0.245	-0.345	-0.317
C^4	0.633	0.595	0.602	0.586	0.584	0.833	0.670	0.673	0.596	0.664	0.643
C^5	-0.132	-0.155	-0.222	-0.119	-0.163	-0.250	-0.360	-0.363	-0.351	-0.366	-0.356
C^6	0.304	0.320	0.363	0.248	0.330	0.310	0.073	0.065	0.074	0.067	0.076
C^{6a}	-0.111	-0.088	-0.047	-0.057	-0.070	-0.036	0.008	0.013	0.065	0.033	0.029
C^7	-0.088	-0.200	-0.260	-0.168	-0.223	-0.140	-0.097	-0.186	-0.238	-0.184	-0.206
C^8	-0.128	0.120	0.336	-0.002	0.276	0.089	-0.149	0.100	0.299	-0.002	0.240

C^9	-0.058	-0.160	-0.232	-0.126	-0.187	-0.164	-0.026	-0.140	-0.188	-0.113	-0.156
C^{9a}	-0.102	-0.087	-0.075	-0.080	-0.066	-0.100	-0.144	-0.121	-0.124	-0.108	-0.115

* The numbering of the atoms is given according to the **Scheme 3.**

Conclusions

We have found that during the oxidative recyclization/rearrangement of 8-R-6-R'-4,4,6-trimethyl-6-R'-5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **8a-f** and 8-R-4,4,6-trimethyl-4*H*-pyrrolo[3,2,1-*ij*]quinoline-1,2-diones **9a-e** with *m*-chloroperbenzoic acid, the 9-R-7-R'-5,5,7-trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones **10a-f** and 9-R-5,5,7-trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones **12a-e** were formed, respectively, but not the 7-R-9-R'-5,5,7-trimethyl-6,7-dihydro-5*H*-[1,4]oxazino[2,3,4-*ij*]quinoline-2,3-diones **12a-f** and 9-ethyl-5,5,7-trimethyl-5*H*-[1,4]oxazino[2,3,4-*ij*]quinoline-2,3-diones **13a-e**. In terms of the reaction mechanism, presumably, at the first stage of the process, the peracid is added to the carbon atom of the carbonyl group of the starting compounds and the subsequent recyclization/rearrangement of the resulting intermediates leads to the formation of products with the 1,3-oxazine fragment. The quantum-chemical calculations of atomic charges in the starting compounds showed that the electronic properties of the substituent in the hydroquinoline fragment of these compounds did not affect the reaction mechanism .

Experimental Section

General. Melting points were determined on a PTP-M apparatus. The ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AM-400 spectrometer in $CDCl_3$ and in DMSO-*d*6 at 500 and 125 MHz, respectively. TMS was used as the internal standard. Mass spectra were recorded on a Finnigan MAT Incos 50 instrument with direct introduction of sample into the ion source at 100-150 °C, with EI ionization and accelerating voltage of 70 eV. HPLC–MS analyses were performed on an Agilent Infinity 1260 liquid chromatograph equipped with an Agilent 6230 TOF mass selective detector. The conditions of chromatographic separation were the following: mobile phase 0.1% formic acid in MeCN (eluent A) / 0.1% formic acid in water (eluent B), gradient 0–100%: A, 3.5 min, 50%; A, 1.5 min, 50–100%; B, 3.5 min, 50%; B, 1.5 min, 50–0%; flow rate 0.4mL/min, column – Poroshell 120 EC-C18 (4.6 × 50 mm, 2.7 μm), thermostat at 28°C, electrospray ionization (capillary voltage –3.5 kV; fragmentor voltage +191 V; OctRF +66 V – positive polarity).The reactions were monitored and the purity of the products were checked by TLC with Silufol UV-254 (silica gel STC-1A as the sorbent) using chloroform as the mobile phase. Commercially available reagents from Lancaster were used in the syntheses. The starting compounds **8a–f** and **9a-e** were synthesized according to literature procedures.[42] The solvents were purified according to standard methods.

General procedure for the synthesis of dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones 10a-f. To a solution of substituted pyrrolo[3,2,1-*ij*]quinoline-1,2-dione **8a-f** (10 mmol) in *abs.* THF (20mL), was added dropwise a solution of *m*-chloroperbenzoic acid (2.59 g, 15.0 mmol) in *abs.* THF (15 mL) over 30 min at a temperature of -2-3 °C. The reaction mixture was then kept at room temperature for 4-5 hours. Excess solvent was removed under reduced pressure and the resulting colorless precipitate was filtered off, dried in air, and recrystallized from CCl_4, to give products **10a-f**.

5,5,7-Trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10a). Colorless powder (1.91 g, 78%); mp 166-167 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.43 (d, *J* 6.9 Hz, 3 H, CH_3), 1.65 (s, 3 H, $2CH_3$), 1.75 (d,

J 3.9 Hz, 1 H, CH_2), 1.79 (s, 3 H, $2CH_3$), 1.96 (d, *J* 3.9 Hz, 1 H, CH_2), 2.97-3.03 (m, 1 H, CH), 7.21 (t, *J* 7.7 Hz, 1 H, Ar-H(6)), 7.62 (d, *J* 7.7 Hz, 1 H, Ar-H(8)), 8.00 (d, *J* 7.7 Hz, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 19.7, 24.8, 30.0, 47.2, 59.5, 112.1, 123.7, 128.9, 131.3, 133.9, 139.4, 146.3, 159.9; MS (EI) *m/z* (%): 245 (M^+, 19), 201 (50), 186 (100), 158 (13). HRMS (ESI): Calc'd for $C_{14}H_{15}NO_3$ $[M+H]^+$ 246.1126; found 246.1127.

5,5,7,9-Tetramethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10b). Colorless powder (1.94 g, 75%); mp 170-171 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.42 (d, *J* 6.6 Hz, 3 H, CH_3), 1.63 (s, 3 H, $2CH_3$), 1.74 (d, *J* 4.0 Hz, 1 H, CH_2), 1.78 (s, 3 H, $2CH_3$), 1.95 (d, *J* 4.0 Hz, 1 H, CH_2), 2.38 (s, 3 H, Ar-CH_3), 2.93-2.99 (m, 1 H, CH), 7.43 (s, 1 H, Ar-H(8)), 7.78 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 19.7, 20.9, 24.6,29.0, 47.3, 59.3, 111.9, 128.5, 131.2, 133.5, 135.0, 137.2, 146.4, 160.0; MS (EI) *m/z* (%): 259 (M^+, 19), 215 (50), 200 (100), 172 (10). HRMS (ESI): Calc'd for $C_{15}H_{17}NO_3$ $[M+H]^+$ 260.1282; found 260.1284.

9-Methoxy-5,5,7-trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10c). Colorless powder (1.76 g, 64%); mp 168-169 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.41 (d, *J* 6.6 Hz, 3 H, CH_3), 1.64 (s, 3 H, $2CH_3$), 1.74 (d, *J* 4.0 Hz, 1 H, CH_2), 1.78 (s, 3 H, $2CH_3$), 1.94 (d, *J* 4.0 Hz, 1 H, CH_2), 2.94-2.99 (m, 1 H, CH), 3.85 (s, 3 H, Ar-OCH_3), 7.20 (s, 1 H, Ar-H(8)), 7.40 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 15.7, 19.7, 24.6, 26.6, 29.0, 47.3, 59.3, 112.0, 127.3, 131.2, 134.0, 137.4, 139.8, 146.4, 160.1; MS (EI) *m/z* (%): 275 (M^+, 21), 231 (17), 216 (100), 188 (8). HRMS (ESI): Calc'd for $C_{15}H_{17}NO_4$ $[M+H]^+$ 276.1231; found 276.1236.

9-Ethyl-5,5,7-trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10d). Colorless powder (1.88 g, 69%); mp 179-180 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.26 (t, *J* 7.6 Hz, 3H, C*H*$_3$CH$_2$); 1.43 (d, *J* 6.6 Hz, 3 H,CH_3), 1.63 (s, 3 H, $2CH_3$), 1.74 (d, *J* 4.0 Hz, 1 H, CH_2), 1.78 (s, 3 H, $2CH_3$), 1.95 (d, *J* 4.0 Hz, 1 H, CH_2), 2.68 (q, *J* 7.6 Hz, 2H, CH_3C*H*$_2$), 2.95-3.00 (m, 1 H, CH), 7.43 (s, 1 H, Ar-H(8)), 7.82 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 19.6, 24.6, 26.8, 28.4, 28.9, 47.1, 56.2, 59.3, 109.1, 112.7, 123.1, 133.4, 133.8, 146.2, 155.7, 160.0; MS (EI) *m/z* (%): 273 (M^+, 15), 214 (50), 200 (100), 186 (8). HRMS (ESI): Calc'd for $C_{16}H_{19}NO_3$ $[M+H]^+$ 274,1439; found 274.1430.

9-Fluoro-5,5,7-trimethyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10e). Colorless powder (2.26 g, 86%); mp 149-150 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.42 (d, *J* 6.6 Hz, 3 H, CH_3), 1.65 (s, 3 H, $2CH_3$), 1.75 (d, *J* 4.0 Hz, 1 H, CH_2), 1.78 (s, 3 H, $2CH_3$), 1.97 (d, *J* 4.0 Hz, 1 H, CH_2), 2.97-3.02 (m, 1 H, CH), 7.34 (d, *J* 7.4 Hz, 1 H, Ar-H(8)), 7.65 (d, *J* 7.4 Hz, 1 H, Ar-H(10)); ^{13}C NMR (500 MHz, $CDCl_3$): δ 19.1, 24.3, 26.5, 28.4, 46.5, 59.2, 113.0, 113.6, 121.3, 133.9, 135.5, 145.5, 157.0, 158.6; MS (EI) *m/z* (%): 263 (M^+, 15), 219 (16), 204 (100), 176 (11). HRMS (ESI): Calc'd for $C_{14}H_{14}FNO_3$ $[M+H]^+$ 264.1031; found 264.1034.

5,5,7,9-Tetramethyl-7-phenyl-6,7-dihydro-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (10f). Colorless powder (2.44 g, 73%); mp 186-187 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 0.98 (s, 3 H, CH_3), 1.70 (s, 3 H, $2CH_3$), 1.78 (s, 3 H, $2CH_3$), 2.28 (d, *J* 14.4 Hz, 1 H, CH_2), 2.41 (s, 3 H, Ar-CH_3), 2.50 (d, *J* 14.4 Hz, 1 H, CH_2), 6.96 (d, *J* 7.6 Hz, 2 H, Ph-H(2,6)), 7.21 (t, *J* 7.6 Hz, 1 H, Ph-H(4)), 7.26 (d, *J* 7.6 Hz, 2 H, Ph-H(3,5)), 7.51 (s, 1 H, Ar-H(8)), 7.95 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 20.5, 25.3, 29.7, 32.4, 39.6, 52.3, 58.9, 111.9, 126.5, 126.6, 126.7, 128.5, 128.6, 129.3, 131.7, 133.2, 136.8, 137.2, 145.7, 147.2, 159.5; MS (EI) *m/z* (%): 335 (M^+, 18), 291 (8), 276 (100). HRMS (ESI): Calc'd for $C_{21}H_{21}NO_3$ $[M+H]^+$ 336.1595; found 336.1592.

General procedure for the synthesis of 4*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-diones 12a-e.

To a solution of substituted pyrrolo[3,2,1-*ij*]quinoline-1,2-dione **9a-e** (10 mmol) in *abs.* THF (20 mL), was added with stirring at room temperature a solution of *m*-chloroperbenzoic acid(2.59 g, 15.0 mmol) in *abs.* THF (15mL) The reaction mixture was kept at room temperature for 4-5 hours. Excess solvent was removed under reduced pressure. The resulting colorless precipitate was filtered off, dried in air, and recrystallized from CCl_4, to give products **12a-e**.

5,5,7-Trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (12a). Colorless powder (1.82 g, 75%); mp 165-166 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.83 (s, 6 H, $2CH_3$), 2.04 (s, 3 H, CH_3), 5.46 (br. s, 1 H, CH), 7.17 (t, *J* 7.7 Hz, 1 H, Ar-H(9)), 7.45 (d, *J* 7.7 Hz, 1 H, Ar-H(8)), 8.93 (d, *J* 7.7 Hz, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 19.1, 28.4, 61.4, 110.8, 123.6, 124.1, 124.2, 129.4, 131.0, 132.7, 138.6, 145.3, 146.7, 159.2; MS (EI) *m/z* (%): 243 (M^+, 10), 228 (5), 184 (100), 156 (9). HRMS (ESI): Calc'd for $C_{14}H_{13}NO_3$ $[M+H]^+$ 244.0969; found 244.0992.

5,5,7,9-Tetramethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (12b). Colorless powder (1.72 g, 67%); mp 161-163 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.83 (s, 6 H, $2CH_3$), 2.04 (s, 3 H, CH_3), 2.36 (s, 3 H, Ar-CH_3), 5.45 (br. s, 1 H, CH), 7.24 (s, 1 H, Ar-H(8)), 7.27 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 18.6, 20.5, 27.8, 60.8, 110.3, 123.2, 123.6, 128.3, 129.8, 131.8, 132.3, 133.6, 136.0, 146.4, 159.0; MS (EI) *m/z* (%): 257 (M^+, 5), 242 (4), 198 (100), 154 (5). HRMS (ESI): Calc'd for $C_{15}H_{15}NO_3$ $[M+H]^+$ 258.1126; found 258.1125.

9-Methoxy-5,5,7-trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (12c). Colorless powder (2.23 g, 82%); mp 167-168 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.83 (s, 6 H, $2CH_3$), 2.02 (s, 3 H, CH_3), 3.85 (s, 3 H, Ar-OCH_3), 5.51 (br. s, 1 H, CH), 7.04 (s, 1 H, Ar-H(8)), 7.30 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 18.6, 27.7, 55,8, 60.7, 108.1, 111.0, 120.4, 123.0, 125.6, 132.5, 133.3, 146.1, 155.7, 159.0; MS (EI) *m/z* (%): 273 (M^+, 11), 229 (14), 214 (100), 186 (10). HRMS (ESI): Calc'd for $C_{15}H_{15}NO_4$ $[M+H]^+$ 274.1075; found 274.1079.

9-Ethyl-5,5,7-trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (12d). Colorless powder (2.17 g, 80%); mp 172-173 °C (CCl_4); ^{1}H NMR (500 MHz, DMSO-d_6): *δ* 1.19 (t, *J* 8.3 Hz, 3H, CH_3CH_2), 1.73 (s, 6 H, $2CH_3$), 2.01 (s, 3 H, CH_3), 2.64 (q, J = 8.3 Hz, 2H, CH_3CH_2), 5.66 (br. s, 1 H, CH), 7.41 (s, 1 H, Ar-H(8)), 7.60 (s, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, DMSO-d_6): δ 18.7, 28.8, 29.5, 56.2, 60.8, 109.3, 113.1, 123.6, 128.3, 114.4, 131.7, 132.2, 131.2, 146.4, 155.7, 159.0; MS (EI) *m/z* (%): 271 (M^+, 10), 227 (34), 212 (100), 184 (6). HRMS (ESI): Calc'd for $C_{16}H_{17}NO_3$ $[M+H]^+$ 272.1282; found 272.1288.

9-Fluoro-5,5,7-trimethyl-1*H*,5*H*-[1,3]oxazino[5,4,3-*ij*]quinoline-1,3-dione (12e). Colorless powder (2.19 g, 84%); mp 167-168 °C (CCl_4); ^{1}H NMR (500 MHz, $CDCl_3$): *δ* 1.86 (s, 6 H, $2CH_3$), 2.02 (s, 3 H,CH_3), 5.56 (br. s, 1 H, CH), 7.16 (dd, J_1 8.7, J_2 3.0 Hz, 1 H, Ar-H(8)), 7.56 (dd, J_1 8.7, J_2 3.0 Hz, 1 H, Ar-H(10)); ^{13}C NMR (125 MHz, $CDCl_3$): δ 18.9, 28.2, 61.6, 112.1, 113.7, 119.0, 123.0, 126.9, 134.3, 135.1, 146.3, 157.9, 158.3, 159.8; MS (EI) *m/z* (%): 261 (M^+, 5), 246 (5), 202 (100), 174 (7). HRMS (ESI): Calc'd for $C_{14}H_{12}FNO_3$ $[M+H]^+$ 262.0875; found 262.0877.

Acknowledgements

The study was supported by Russian Science Foundation grant (project No. 18-74-10097P). Analytical research was done using equipment of NRC "Kurchatov Institute" — IREA Shared Knowledge Center.

References

1. Parrino, B.; Ciancimino, C.; Carbone, A.; Spano, V.; Montalbano, A.; Barraja, P.; Cirrincione, C.; Diana, P. *Tetrahedron* **2015**, *71*, 7332-7338.
http://dx.doi.org/10.1016/j.tet.2015.04.083
2. Barraja, P.; Diana, P.; Montalbano, A.; Martorana. A.; Carbone, A.; Cirrincione, G. *Tetrahedron Lett.* **2009**, *50*, 4182-4184.
http://doi.org/10.1016/j.tetlet.2009.05.007
3. Sindhu, T. J.; Arikkatt, S. D.; Girly, V.; Meena, C.; Bhat, A. R.; Krishnakumar, K. *Int. J. Pharma Sci. Res.* **2013**, *4*, 134-143.
http://www.ijpsr.info/docs/IJPSR13-04-12-001.pdf

4. Coppola, G. M. *J. Heterocycl. Chem.* **1999**, *36*, 563-588.
http://doi.org/10.1002/jhet.5570360301
5. Zhong, Y.; Lu, Y.; Sun, Y.; Li, N.; Gu, T.; Wu, W.; Yu, Sh.; Shi, Zh. *Med. Chem.* **2018**, *14,* 478-484.
http://doi.org/10.2174/1573406413666170906130251
6. Kappe, T.; Stadlbauer, W. *Adv. Heterocycl. Chem.* **1981**, *28,* 127-182.
http://doi.org/10.1016/S0065-2725(08)60042-2
7. Shvekhgeimer, M.-G. A.; *Chem. Heterocycl. Compd.* **2001**, *37,* 385-443.
http://doi.org/10.1023/A:1017631318971
8. Dudley, D. A.; Bunker, A. M.; Chi, Liguo.; Cody, W. L.; Holland, D. R.; Ignasiak, D.P.; Janiczek-Dolphin, N.; McClanahan, Th. B.; Mertz, Th. E.; Narasimhan, L. S.; Rapundalo, St. T.; Trautschold, J. A.; Van Huis, Ch. A.; Edmunds, J. J. *J. Med. Chem.* **2000**, *43,* 4063-4070.
http://doi.org/10.1021/jm000074l
9. Sugimoto, Y.; Otani, T.; Oie, S.; Wiersba, K.; Yamada, Y. *J. Antibiot.* **1990**, *43,* 417-421.
http://doi.org/10.7164/antibiotics.43.417
10. Reusser, F. *J. Antibiot.* **1979**, *32,* 1186-1192.
https://doi.org/10.7164/antibiotics.32.1186
11. Asif, M.; Imran, M. *Int. J. New Chem.* **2020**, *7*, 60-73.
http://dx.doi.org/10.22034/ijnc.2020.116058.1061
12. Reuter, K.C.; Grunwitz, C. R.; Kaminski, B. M.; Steinhilber, D.; Radeke, H. H.; Stein J. *J. Pharmacol. Exp. Ther.* **2012**, *341*, 68-80.
http://dx.doi.org/10.1124/jpet.111.183947
13. Thuillier, G.; Laforest, J.; Bessin, P.; Bonnet, J.; Thuillier, J. *Eur. J. Med. Chem.* **1975**, *10*, 37-42.
https://doi.org/10.3406/rhef.1975.1540
14. Ramnauth, J.; Annedi, S. C.; Silverman, S.; Dove, P.; Maddaford, S.; Rakhit, S. PCT Int. Appl. WO2010000073, 2010; *Chem. Abstr.* **2010**, *152*, 119669.
15. Turk, C. F.; Krapcho, J.; Michel, I. M.; Weinryb, I. *J. Med. Chem.* **1977**, *20*, 729-732.
http://doi.org/10.1021/jm00215a024
16. Masuoka, Y.; Asako, T.; Goto, G.; Noguchi, S. *Chem. Pharm. Bull.* **1986**, *34*, 130-139.
http://doi.org/10.1248/cpb.34.130
17. Kimura, K.; Usui, Y.; Hattori, T.; Yamakawa, N.; Goto, H.; Usui, M.; Okada, S.; Shirato, K.; Tomoda, A. *Oncol. Rep.* **2008**, *19*, 3-10.
http://doi.org/10.3892/or.19.1.3
18. Ishihara, M.; Kawase, M.; Westman, G.; Samuelsson, K.; Motohashi, N.; Sakagami, H. *Anticancer Res.* **2007**, *27*, 4053-4058.
http://ar.iiarjournals.org/content/anticanres/27/6B/4053.full.pdf
19. Sulimov, V. B.; Gribkova, I. V.; Kochugaeva, M. P.; Katkova, E. V.; Sulimov, A. V.; Kutov, D. C.; Shikhaliev, Kh. S.; Medvedeva, S. M.; Krysin, M. Y.; Sinauridze, E. I.; Ataullakhanov, F. I. *BioMed Res. Int.* **2015**, *2015*, 1-15.
http://dx.doi.org/10.1155/2015/120802
20. Heier, R. F.; Dolak, L. A.; Duncan, J. N.; Hyslop, D. K.; Lipton, M. F.; Martin, I. J.; Mauragis, M. A.; Piercey, M. F.; Nichols, N. F.; Schreur, P. J. K. D.; Smith, M. W.; Moon, M. W. *J. Med. Chem.* **1997**, *40*, 639-646.
https://doi.org/10.1021/jm960360q
21. Tsotinis, A.; Panoussopoulou, M.; Eleutheriades, A.; Davidson, K.; Sugden, D. *Eur. J. Med. Chem.* **2007**, *42*, 1004-1013.

http://doi.org/10.1016/j.ejmech.2007.01.005
22. Appelbaum, P. C.; Hunter, P. A. *Int. J. Antimicrobal Agents* **2000**, *16*, 5-15.
http://doi.org/10.1016/s0924-8579(00)00192-8
23. Guruswamy, B.; Arul, R.; Chaitanya, M. V. S. R. K.; Praveen Kumar Darsi, S. S. *J. Heterocycl. Chem.* **2014**, *52*, 532-538.
http://doi:10.1002/jhet.2093
24. Jeyanthi, M.; Venkatraman, B. R. *Der Pharma. Chem.* **201**4, *6*, 440-442.
http://derpharmachemica.com/archive.html
25. Baraldi, P. G.; Saponaro, G.; Moorman, A. R.; Romagnoli, R.; Preti, D.; Baraldi, S.; Ruggiero, E.; Varani, K.; Targa, M.; Vincenzi, F.; Borea, P. A.; Aghazadeh Tabrizi, M. *J. Med. Chem.* **2012***, 55*, 6608-6623.
https://doi.org/10.1021/jm300763w
26. Bremm, K. D.; Endermann, R.; Hallenbach, W.; Himmler, T.; Jaetsch, T.; Mielke, B.; Pirro, F.; Stegemann, M.; Wetzstein, H.-G. PCT Int. Anm. WO 96/01829, 1996,
27. Amano, H.; Wakunaga, S.; Inoue, S.; Yakazaki, A.; Eur. Pat. Appl. EP0373531, 1990
28. Ziegler, E.; Kappe Th. *Monatsh. Chemie.* **1964**, *95*, 59-63.
http://doi:10.1007/bf00909252
29. Coppola, G. M. *J. Heterocycl. Chem.* **1978***, 15,* 645-647.
http://doi.org/10.1002/jhet.5570150424
30. Guan, Z.-H.; Chen, M.; Ren Z.-H. *J. Am. Chem. Soc.* **2012**, *134*, 17490-17493.
http://doi.org/10.1021/ja308976x
31. Nagarajan, K.; Nagana Goud, A.; Ranga Rao, V.; Shah, R. K.; Shenoy, S. J. *Proc. Indian Acad. Sci. (Chem. Sci.)* **1992**, *104*, 549-568.
https://www.ias.ac.in/article/fulltext/jcsc/104/05/0549-0568
32. Reissenweber, G.; Mangold D. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 222-223.
http://doi:10.1002/anie.198002221
33. Bogdanov, A. V.; Sadykov, T. I.; Musin, L. I.; Khamatgalimov, A. R.; Krivolapov, D. B.; Dobrynin, A. B.; Mironov, V. F. *Russ. J. Gen. Chem.* **2015**, *85*, 2030-2036.
http://doi:10.1134/s1070363215090030
34. Kurkin, A. V.; Bernovskaya, A. A.; Yurovskaya, M. A. *Tetrahedron: Asymmetry* **2010**, *21*, 2100-2107.
http://doi:10.1016/j.tetasy.2010.07.001
35. Dierynck, I.; Goeman, J. L.; Van Acker, K. L. A.; Van Der Eycken, J. T. A. PCT Int. Appl. WO2004/58787, 2004
36. Coppola, G. M.; Schuster, H. F. *J. Heterocycl. Chem.* **1989**, *26*, 957-964.
http://doi:10.1002/jhet.5570260414
37. Sahu, A.; Chatterjee, A. *Indian J. Chem., Sect. B: Org. Chem. 1990*, *29*, 603-605.
http://doi:10.1002/chin.199042325
38. Medvedeva, S. M.; Shikhaliev, Kh. S. *Butlerov Communications* **2015**, *42*, 86-90.
39. Medvedeva, S. M.; Plaksina, M. E.; Shikhaliev, Kh. S. *J. Org. Pharm. Chem.* **2015**, *13*, 21-25.
https://doi.org/10.24959/ophcj.15.847
40. Stollé, R. *Ber. Dtsch. Chem. Ges.* **1913**, *46*, 3915–3916.
https://doi.org/10.1002/cber.191304603186
41. Medvedeva, S. M.; Krysin, M. Yu.; Zubkov, F. I.; Nikitina, E. V.; Shikhaliev, Kh. S. *Chem. Heterocycl. Compd.* **2014**, *50*, 1280-1290.
https://doi.org/10.1007/s10593-014-1590-4

42. Lescheva, E.V., Medvedeva, S.M., Shihaliev, H.S. *J. Org. Pharm. Chem.* **2014**, *12*, 15-20.
43. Shikhaliev, Kh. S.; Selemenev, V. F.; Medvedeva, S. M.; Ponomareva, L. F.; Kopteva, N. I. *Sorption Chromatogr. Processes* **2014**, *14*, 332–337.
44. Brown, J. P.; Tidd, B. K. *J. Chem. Soc. C*, **1968**, *9*, 1075-1077.
https://doi.org/10.1039/J39680001075
45. Kratzel, M.; Hiessböck, R.; Völlenkle H. *Monatsh. Chem.* **1994**, *125*, 963-969.
http://doi:10.1007/bf00812711
46. C. M. Breneman,K. B. Wiberg *J. Comp. Chem.,* **1990**, *11*, 361-373.
https://doi.org/10.1002/jcc.540110311
47. Gaussian 09, Revision D.01, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, T. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J. M. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, O. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski, and D. J. Fox, Gaussian, Inc., Wallingford CT, **2013**.