Stereoselective electrocatalytic cyclization of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acid esters to form 6-substituted (1*R*,5*R*,6*R*)*-4,4-dialkoxy-5-cyano-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylic acid esters

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Electrolysis of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acid esters in alcohols in an undivided cell in the presence of NaBr or NaOAc afforded 6-substituted (1*R*,5*R*,6*R*)*-4,4-dialkoxy-5-cyano-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylic acid esters in 80—95% yields.

Key words: electrolysis, stereoselectivity, electrocatalytic cyclization, chain reaction, bicyclic pyrrolidones.

Functionalized cyclopropanes have a broad spectrum of physiological activities.[1] In addition, these compounds are used in the synthesis of natural biologically active compounds.[1—3] Cyclopropanecarboxylic acid derivatives are successfully used in medicine and agriculture. These compounds are well known as components of natural and synthetic pyrethroids.[1,4]

Functionalized bicyclic, including heterocyclic, compounds containing the cyclopropane fragment belong to a new important class of biologically active compounds[5] and are widely used in the synthesis of natural biologically active compounds and modern drugs.[6,7]

Due to considerable advances made in electrochemistry of organic compounds in the last three decades, the electrosynthesis became a competitive method of modern organic chemistry.[8]

Nowadays, the electrochemical synthesis is becoming increasingly important because it offers broad, and sometimes unique possibilities for various transformations of organic compounds.[9]

The present study is a continuation of reasearch on electrochemical transformations of CH acids, such as malononitrile, cyanoacetic ester, and malonic ester, into functionalized cyclopropanes using alkali metal halides as mediators. Earlier, when studying mediator-assisted catalytic oxidation of organic compounds, we have performed electrochemical cyclotrimerization of malonic[10] and cyanoacetic esters,[11] transformed aldehydes and cyanoacetic ester[12] into functionalized cyclopropanes, and transformed ketones and malononitrile into 3,3-disubstituted tetracyanocyclopropanes.[13]

The latter process is an electrochemical analog of Wideqvist's reaction, *viz.*, the reaction of bromomalononitrile with ketones in the presence of stoichiometric amounts of sodium iodide.[14] The electrochemical modification of this reaction is performed with the use of malononitrile (instead of bromomalononitrile) and catalytic amounts of sodium bromide, which is completely regenerated during the reaction.[15]

Studies of the electrochemical modification of Wideqvist's reaction demonstrated that simultaneous electrolysis of malonodinitrile and cyclohexanone in the presence of sodium bromide in ethanol in an undivided cell afforded tricyclic pyrroline **1** rather than the expected 1,1,2,2-tetracyano-3,3-pentamethylenocyclopropane[13] (Scheme 1).

The closest analogs of bicyclic and tricyclic pyrrolines of type **1** were found to exhibit antitumor activity.[16]

Further investigations[17] have revealed the electrocatalytic chain transformation of tetracyanocyclopropanes into the corresponding bicyclic pyrrolines that occurs during electrolysis in alcohols in an undivided cell when a catalytic amount of electricity is passed (Scheme 2).

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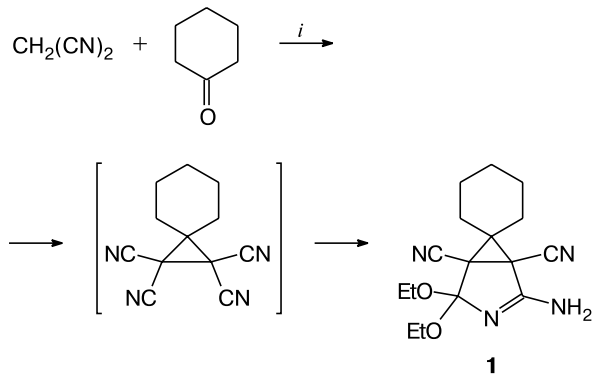
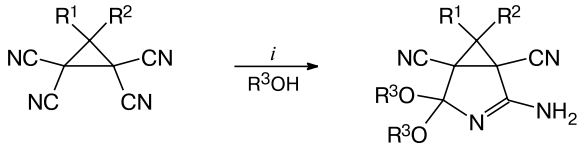
Scheme 1



i. Electrolysis, NaBr, EtOH

Scheme 2



i. 0.05—0.20 F mol^{-1}

The pyrroline ring is formed as a result of a chain process initiated by the electrogenerated alkoxy anion in an undivided cell and is accompanied by regeneration of the alkoxy anion in the course of subsequent chemical transformations (Scheme 3).

More recently, analogous cyclization was carried out with the use of catalytic[18,19] or stoichiometric[20] amounts of alkoxides in alcohols.

In the present study, we performed stereoselective electrocatalytic cyclization of dimethyl esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids (**2a—k**) into the corresponding esters of 6-substituted

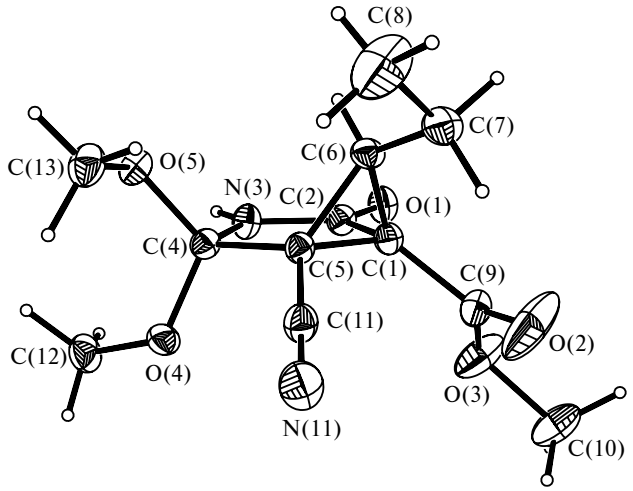


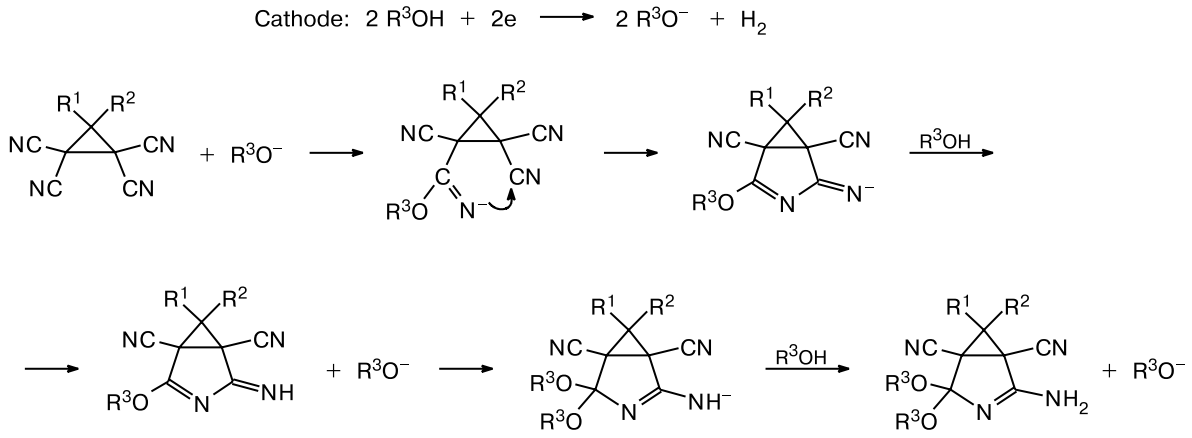
Fig. 1. Molecular structure of **3b**.

(1*R*,5*R*,6*R*)*-4,4-dialkoxy-5-cyano-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylic acids (**3a—k**). The reactions were performed in an undivided cell in alcohol (methanol or ethanol) by passing a catalytic amount of electricity with the use of NaBr or NaOAc as the electrolyte (Scheme 4, Table 1, for a preliminary communication, see Ref. 21).

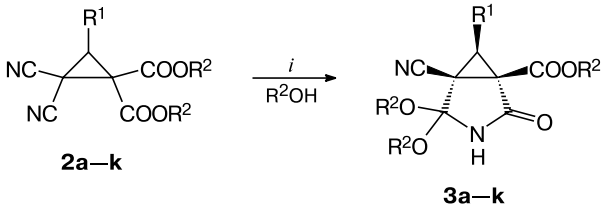
Electrolysis of esters **2** in methanol or ethanol was carried out in the presence of NaBr or NaOAc at 20 °C in a direct-current mode in an undivided cell equipped with a graphite anode and an iron cathode. Under these conditions, bicyclic pyrrolidones **3a—k** were obtained in 80—95% yields by passing a catalytic amount of electricity (0.2 F mol^{-1}), the complete conversion of cyclopropanes **2a—k** being observed.

The stereoselectivity of the reaction is provided by the steric factors due to which the pyrrolidine ring is formed from the CN and COOMe groups in *trans* positions with respect to the aryl or alkyl substituent. The fact that only one of two possible isomers was produced is evident from

Scheme 3



Scheme 4



i. 0.2 F mol^{-1}

Table 1. Stereoselective electrocatalytic transformation of esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids **2a—k** into bicyclic pyrrolidones **3a—k**[a]

Cyclo-propane	R^1	R^2	Elec-trolyte	Pyrrol-idone	Yield[b] (%)
2a	Me	Me	NaBr	**3a**	84
2a	Me	Me	NaOAc	**3a**	87
2b	Et	Me	NaBr	**3b**	81
2c	Pr	Me	NaOAc	**3c**	79
2d	Ph	Me	NaBr	**3d**	92
2d	Ph	Me	NaOAc	**3d**	91
2e	Ph	Et	NaOAc	**3e**	82
2f	4-MeC_6H_4	Me	NaBr	**3f**	83
2g	4-$MeOC_6H_4$	Me	NaBr	**3g**	79
2h	4-ClC_6H_4	Me	NaBr	**3h**	95
2i	2-ClC_6H_4	Me	NaBr	**3i**	81
2j	4-$NO_2C_6H_4$	Me	NaBr	**3j**	78
2k	2-FC_6H_4	Me	NaBr	**3k**	84

[a] Reagents and conditions: 5 mmol of **2a—k**, 5 mmol of the electrolyte, 20 mL of alcohol, a Fe cathode, a C anode, the current density was 20 mA cm^{-2}, the quantity of electricity was 0.2 F mol^{-1} at 20 °C.
[b] Based on isolated bicyclic pyrrolidone.

the ^{1}H and ^{13}C NMR spectroscopic data. The structures of **3b** (Fig. 1) and **3d** were established by X-ray diffraction.

Table 2. Stereoselective catalytic transformation of esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids **2a—h** into bicyclic pyrrolidones **3a—h**[a]

Starting cyclopropane	Bicyclic pyrrolidone	Yield[b] (%)
2a	**3a**	93
2b	**3b**	87
2c	**3c**	85
2d	**3d**	91
2e	**3e**	89
2f	**3f**	86
2g	**3g**	85
2h	**3h**	92

[a] Reagents and conditions: 5 mmol of **2a—h**, 0.5 mmol of sodium alkoxide, 20 mL of alcohol, 30 min at 20 °C.
[b] Based on isolated bicyclic pyrrolidone.

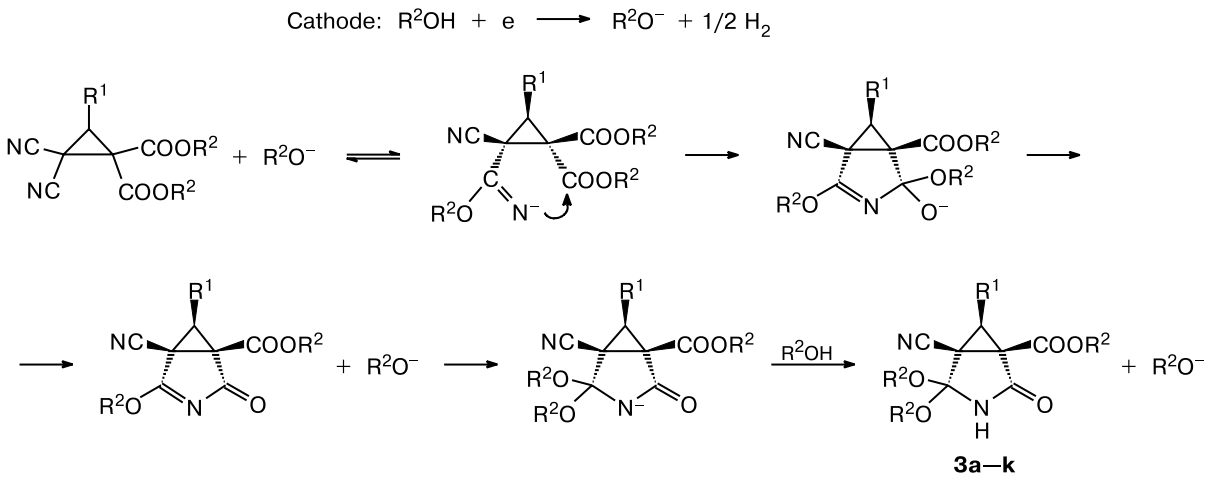
Taking into account that the formation of the pyrrolidine ring should be accompanied by the minimum steric hindrance, the pyrrolidine ring and the substituent R^1 in all bicyclic pyrrolidones **3** are, presumably, in *trans* positions with respect to the cyclopropane ring.

As is evident from the mechanism of electrocatalytic cyclization, the generation of one alkoxide anion is theoretically sufficient (Scheme 5).

To summarize, we performed the chain electrocatalytic stereoselective transformation of esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids into esters of 6-substituted (1*R*,5*R*,6*R*)*-4,4-dialkoxy-5-cyano-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylic acids in 80—95% yields in an undivided cell by passing a catalytic amount of electricity.

This cyclization can be carried out without the use of electric current under the action of a catalytic amount of sodium alkoxide on esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids in alcohols (Table 2).

Scheme 5



The processes developed in the present study are convenient and economical for the stereoselective transformation of esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acid esters into 6-substituted (1*R*,5*R*,6*R*)*-4,4-dialkoxy-5-cyano-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylic acids. The reactions can be performed with the use of standard and commercially available reagents, inexpensive apparatus, and an undivided cell. The procedures for the reactions and isolation of the reaction products (crystallization directly from the reaction mixture after completion of electrolysis) are simple and convenient for performing both in laboratory conditions and on large-scale apparatus.

Experimental

The ^{1}H and ^{13}C NMR spectra were measured on Bruker WM-250 and Bruker AM-300 instruments operating at 250 and 300 MHz, respectively, in deuterodimethyl sulfoxide or deuterochloroform. The chemical shifts in the NMR spectra are given on the δ scale relative to Me_4Si. X-ray diffraction data for compounds **3b** and **3d** were collected on Bruker SMART (compound **3b**) and Syntex $P2_1$ (compound **3d**) diffractometers (graphite monochromator, Mo-Kα, λ = 0.71073 Å). Main crystallographic characteristics, parameters of X-ray diffraction study, and details of the structure refinement are given in Table 3. All structures were solved by direct methods and refined by the least-squares method against F^2_{hkl} with anisotropic displacement parameters for all nonhydrogen atoms. The hydrogen atoms were located from difference electron density maps and refined isotropically. All calculations were carried out using the SHELXTL PLUS 5 program package.[22]

Esters of 3-substituted 2,2-dicyanocyclopropane-1,1-dicarboxylic acids were prepared by simultaneous electrolysis of malonic ester and alkylidenemalononitrile according to a known procedure.[23] The physicochemical properties of cyclopropanes **2a—j** are analogous to those described earlier.

Dimethyl 2,2-dicyano-3-(2-fluorophenyl)cyclopropane-1,1-dicarboxylate (2k), the yield was 78%, m.p. >350 °C. Found (%): C, 59.45; H, 3.51, F, 6.13; N, 9.08. $C_{15}H_{11}FN_2O_4$. Calculated (%): C, 59.61; H, 3.67; F, 6.29; N, 9.27. ^{1}H NMR ($CDCl_3$), δ: 3.83 (s, 3 H, MeO); 3.96 (s, 1 H, CH); 4.00 (s, 3 H, MeO); 7.12—7.22 (m, 2 H, Ar); 7.32—7.50 (m, 2 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 16.25 (d, $^4J_{C,F}$ = 1 Hz); 35.14 (d, $^3J_{C,F}$ = 3 Hz); 45.51, 53.98, 54.75, 109.21, 111.45, 114.96 (d, $^2J_{C,F}$ = 14 Hz); 115.99 (d, $^2J_{C,F}$ = 21 Hz); 124.59 (d, $^4J_{C,F}$ = 4 Hz); 129.02 (d, $^3J_{C,F}$ = 2 Hz); 131.65 (d, $^3J_{C,F}$ = 9 Hz); 160.11 (d, $^1J_{C,F}$ = 129 Hz); 163.09, 163.79.

Stereoselective electrocatalytic transformation of cyclopropanes 2 into bicyclic pyrrolidones 3 (general procedure). A solution of cyclopropane **2** (5 mmol) and an electrolyte (NaBr or NaOAc) (5 mmol) in alcohol (20 mL) was subjected to electrolysis in an undivided cell equipped with a C anode and a Fe cathode (the surface area of electrodes was 5 cm^2) at a constant current density of 20 mA cm^{-2}; 0.2 F mol^{-1} of electricity was passed at 20 °C. After the electrolysis, the solution was cooled to −10 °C. Pyrrolidone **3** that precipitated was filtered off and washed with cold alcohol. An additional amount of pyrrolidone **3** was obtained according to the following procedure. The reaction mixture was concentrated, extracted with chloroform, washed with water, and dried with Na_2SO_4. The chloroform was distilled off, the residue was recrystallized from an acetone—hexane mixture, and pyrrolidone **3** was isolated.

Stereoselective catalytic transformation of cyclopropanes 2 into bicyclic pyrrolidones 3 (general procedure). A solution of cyclopropane **2** (5 mmol) and sodium alkoxide (0.5 mmol) in alcohol (20 mL) was stirred at 20 °C for 30 min. Then the solution was cooled to −10 °C. Pyrrolidone **3** that precipitated was filtered off and washed with cold alcohol. An additional amount of pyrrolidone **3** was isolated according to the following procedure. The reaction mixture was concentrated, extracted with chloroform, washed with water, and dried with Na_2SO_4. The chloroform was distilled off, the residue was recrystallized from an acetone—hexane mixture, and pyrrolidone **3** was isolated.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-6-methyl-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3a), m.p. 150—151 °C. Found (%): C, 51.73; H, 5.61, N, 10.87. $C_{11}H_{14}N_2O_5$. Calculated (%): C, 51.97; H, 5.55; N, 11.02. ^{1}H NMR ($CDCl_3$), δ: 1.58 (d, 3 H, Me, J = 7 Hz); 2.15 (q, 1 H, CH, J = 7 Hz); 3.42, 3.48, and 3.90 (all s, 3 H each, MeO); 6.35 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 10.54, 31.95, 32.37, 42.90, 49.91, 51.68, 53.28, 106.41, 112.87, 162.51, 167.27. IR (KBr), ν_{max}/cm^{-1}: 2248, 1744, 1724.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-6-ethyl-4,4-dimethoxy-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3b), m.p. 144—146 °C. Found (%):C, 53.54; H, 5.95; N, 10.27. $C_{12}H_{16}N_2O_5$. Calculated (%): C, 53.73; H, 6.01; N, 10.44. ^{1}H NMR ($CDCl_3$), δ: 1.16 (t, 3 H, Me, J = 7 Hz); 1.79 and 1.89 (both m, 1 H each, CH_2); 1.95 (m, 1 H, CH); 3.40, 3.47, and 3.85 (all s, 3 H each, MeO); 7.63 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 12.35, 19.17, 31.56, 38.56, 42.95, 49.92, 51.45, 53.25, 106.40, 112.94, 162.58, 167.47. IR (KBr), ν_{max}/cm^{-1}: 2248, 1748, 1720. X-ray diffraction data are given in Table 3. The crystallographic data for compounds **3b** (CCDC 262939) and **3d** (CCDC 262938) were deposited with the Cambridge Structural Database.*

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-2-oxo-6-propyl-3-azabicyclo[3.1.0]hexane-1-carboxylate (3c), m.p. 138—140 °C. Found (%): C, 55.39; H, 6.25; N, 9.85. $C_{13}H_{18}N_2O_5$. Calculated (%): C, 55.31; H, 6.43; N, 9.92. ^{1}H NMR ($CDCl_3$), δ: 0.97 (t, 3 H, Me, J = 7 Hz); 1.49—1.90 (m, 4 H, CH_2); 2.05 (m, 1 H, CH); 3.36, 3.44, and 3.83 (all s, 3 H each, MeO); 7.85 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 13.55, 21.46, 27.42, 31.66, 36.98, 42.80, 49.92, 51.47, 53.21, 106.44, 112.99, 162.61, 167.50. IR (KBr), ν_{max}/cm^{-1}: 2248, 1756, 1736.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-2-oxo-6-phenyl-3-azabicyclo[3.1.0]hexane-1-carboxylate (3d), m.p. 110—112 °C. Found (%): C, 60.58; H, 5.15; N, 8.65. $C_{16}H_{16}N_2O_5$. Calculated (%): C, 60.75; H, 5.10; N, 8.86. ^{1}H NMR ($CDCl_3$), δ: 3.29 (s, 1 H, CH); 3.46, 3.58, and 3.65 (all s, 3 H each, OMe); 7.35 (s, 1 H, NH); 7.40 (m, 5 H, C_6H_5). ^{13}C NMR ($CDCl_3$), δ: 31.66, 39.87, 43.51, 50.17, 51.66, 53.00, 106.64, 112.82, 128.36, 128.45, 128.79, 129.21, 162.06, 167.21.

* These data can be obtained, free of charge, on application to the Cambridge Crystallographic Data Centre (CCDC): 12 Union Road, Cambridge CD2 1EZ, UK; fax: +44-(0)1223-336033, e-mail: deposit@ccdc.cam.ac.uk.

Table 3. Main crystallographic characteristics, parameters of X-ray diffraction collection, and details of structure refinement for **3b** and **3d**

Parameter	**3b**	**3d**
Formula	$C_{12}H_{16}N_2O_5$	$C_{16}H_{16}N_2O_5$
Molecular weight	268.27	316.31
Temperature/K	115(2)	115(2)
Space group	$P2_1/c$	$C2/c$
a/Å	7.7817(7)	18.691(9)
b/Å	10.5320(9)	15.080(6)
c/Å	16.6245(14)	13.292(7)
β/deg	101.490(2)	121.39(3)
V/Å^3	1335.2(2)	3198.2(26)
Z	4	8
d_{calc}/g cm^{-3}	1.335	1.314
$2\theta_{max}$/deg	60.02	52.10
Number of measured reflections	12505	3257
Number of reflections with $I > 2\sigma(I)$	3880	3119
Number of parameters in refinement	236	307
Final R factors		
R_1 (based on F_{hkl} for reflections with $I > 2\sigma(I)$)	0.0588	0.0559
wR_2 (based on F^2_{hkl} for all reflections)	0.2205	0.1277

IR (KBr), ν_{max}/cm^{-1}: 2256, 1760, 1708. X-ray diffraction data are given in Table 3.

Ethyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-diethoxy-2-oxo-6-phenyl-3-azabicyclo[3.1.0]hexane-1-carboxylate (3e), m.p. 77—79 °C. Found (%): C, 63.45; H, 6.07; N, 7.63. $C_{19}H_{22}N_2O_5$. Calculated (%): C, 63.68; H, 6.19; N, 7.82. ^{1}H NMR ($CDCl_3$), δ: 1.22, 1.25, and 1.28 (all t, 3 H each, Me, J = 7 Hz); 3.31 (s, 1 H, CH); 3.75, 3.88, and 4.25 (all q, 2 H each, CH_2O, J = 7 Hz); 3.65 (s, 3 H, OMe); 7.32 (s, 1 H, NH); 7.40 (m, 5 H, C_6H_5). ^{13}C NMR ($CDCl_3$), δ: 14.74, 14.99, 15.11, 32.47, 40.04, 43.51, 58.98, 60.10, 62.53, 105.95, 113.01, 128.34, 128.56, 128.82, 129.29, 162.28, 167.36. IR (KBr), ν_{max}/cm^{-1}: 2250, 1758, 1734.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-6-(4-methylphenyl)-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3f), m.p. 127—129 °C. Found (%): C, 61.57; H, 5.45; N, 8.35. $C_{17}H_{18}N_2O_5$. Calculated (%): C, 61.81; H, 5.49; N, 8.48. ^{1}H NMR ($CDCl_3$), δ: 2.34 (s, 3 H, Me); 3.25 (s, 1 H, CH); 3.47, 3.58, and 3.71 (all s, 3 H each, OMe); 7.20 and 7.38 (both d, 2 H each, Ar, J = 8 Hz); 7.64 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 21.18, 31.75, 39.82, 43.98, 50.26, 51.81, 53.15, 106.79, 112.98, 126.26, 128.49, 129.59, 138.95, 161.82, 167.14. IR (KBr), ν_{max}/cm^{-1}: 2252, 1760, 1728.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-6-(4-methoxyphenyl)-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3g), m.p. 146—147 °C. Found (%): C, 59.05; H, 5.31; N, 7.86. $C_{17}H_{18}N_2O_6$. Calculated (%): C, 58.96; H, 5.24; N, 8.09. ^{1}H NMR ($CDCl_3$), δ: 3.20 (s, 1 H, CH); 3.43, 3.55, 3.71, and 3.80 (all s, 3 H each, OMe); 6.88 and 7.31 (both d, 2 H each, Ar, J = 8 Hz); 7.77 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 31.44, 39.22, 43.80, 49.91, 51.47, 52.87, 55.02, 106.53, 112.87, 114.03, 120.96, 129.61, 159.64, 161.72, 166.63. IR (KBr), ν_{max}/cm^{-1}: 2252, 1760, 1744.

Methyl (1*R*,5*R*,6*R*)*-6-(4-chlorophenyl)-5-cyano-4,4-dimethoxy-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3h), m.p. 130—132 °C. Found (%): C, 54.65; H, 4.35; Cl, 9.92; N, 7.78. $C_{16}H_{15}ClN_2O_5$. Calculated (%): C, 54.79; H, 4.31; Cl, 10.11; N, 7.99. ^{1}H NMR ($CDCl_3$), δ: 3.23 (s, 1 H, CH); 3.46, 3.58, and 3.72 (all s, 3 H each, OMe); 7.18 (s, 1 H, NH); 7.38 (m, 4 H, Ar). ^{13}C NMR ($CDCl_3$), δ: 31.65, 38.88, 43.53, 50.15, 51.84, 53.32, 106.42, 112.51, 127.65, 129.16, 129.98, 135.18, 161.31, 166.16. IR (KBr), ν_{max}/cm^{-1}: 2252, 1744, 1728.

Methyl (1*R*,5*R*,6*R*)*-6-(2-chlorophenyl)-5-cyano-4,4-dimethoxy-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3i), m.p. 138—140 °C. Found (%): C, 54.57; H, 4.26; Cl, 9.87; N, 7.83. $C_{16}H_{15}ClN_2O_5$. Calculated (%): C, 54.79; H, 4.31; Cl, 10.11; N, 7.99. ^{1}H NMR ($CDCl_3$), δ: 3.26 (s, 1 H, CH); 3.48, 3.61, and 3.71 (all s, 3 H each, OMe); 6.92 (s, 1 H, NH); 7.35 (m, 2 H, Ar); 7.44 and 7.69 (both m, 1 H each, Ar). ^{13}C NMR ($CDCl_3$), δ: 32.62, 38.41, 42.67, 50.04, 51.78, 53.11, 106.46, 112.62, 127.05, 127.83, 128.98, 129.83, 130.00, 135.39, 162.05, 166.56. IR (KBr), ν_{max}/cm^{-1}: 2252, 1740, 1728.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-4,4-dimethoxy-6-(4-nitrophenyl)-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3j), m.p. 178—179 °C. Found (%): C, 53.03; H, 4.21; N, 11.54. $C_{16}H_{15}N_3O_7$. Calculated (%): C, 53.19; H, 4.18; N, 11.63. ^{1}H NMR ($CDCl_3$), δ: 3.31 (s, 1 H, CH); 3.50, 3.60, and 3.78 (all s, 3 H each, OMe); 6.39 (s, 1 H, NH); 7.65 and 8.28 (both d, 2 H each, Ar, J = 8 Hz). ^{13}C NMR ($CDCl_3$), δ: 31.28, 37.38, 44.23, 50.07, 51.37, 53.39, 106.84, 113.00, 123.63, 130.06, 137.70, 147.35, 162.11, 164.75. IR (KBr), ν_{max}/cm^{-1}: 2248, 1756, 1728.

Methyl (1*R*,5*R*,6*R*)*-5-cyano-6-(2-fluorophenyl)-4,4-dimethoxy-2-oxo-3-azabicyclo[3.1.0]hexane-1-carboxylate (3k), m.p. 160—162 °C. Found (%): C, 57.28; H, 4.31; F, 5.49; N, 11.54. $C_{16}H_{15}FN_2O_5$. Calculated (%): C, 57.49; H, 4.42; F, 5.68; N, 8.38. ^{1}H NMR (DMSO-d_6), δ: 3.32 (s, 1 H, CH); 3.33, 3.48, and 3.68 (all s, 3 H each, OMe); 7.25—7.45 (m, 4 H, Ar); 9.80 (s, 1 H, NH). ^{13}C NMR ($CDCl_3$), δ: 31.48, 33.90, 42.15, 49.89, 51.27, 53.03, 106.66, 113.17, 115.63 (d, $^2J_{C,F}$ = 21 Hz); 117.54 (d, $^2J_{C,F}$ = 14 Hz); 124.61 (d, $^3J_{C,F}$ = 3 Hz); 129.76 (d, $^4J_{C,F}$ = 2 Hz); 131.74 (d, $^3J_{C,F}$ = 9 Hz); 160.75 (d, $^1J_{C,F}$ = 157 Hz); 162.11, 164.75. IR (KBr), ν_{max}/cm^{-1}: 2252, 1744, 1724.

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