Synthesis of nitrocyclopropanedicarboxylic acid derivatives by addition of α-bromonitroalkanes to methylidene malonic, methylidene cyanoacetic or maleic acid derivatives*

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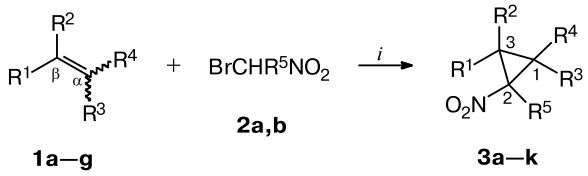
A potassium carbonate promoted addition of 2-bromonitroalkanes to methylidenemalonic and methylidenecyanoacetic acid derivatives and *N*-benzylmaleimide leads to the functionalized nitrocyclopropanes. In the case of less active olefins, it is reasonable to use the phase-transfer catalyst Bu_4NPF_6 (10 mol.%), whereas in the case of *N*-benzylmaleimide, to carry out the process in the ionic liquid [bmim]BF_4.

Key words: Michael reaction, tandem reactions, α-bromonitroalkanes, nitro compounds, cyclopropanes, phase-transfer catalysis, ionic liquids.

Cyclopropanes containing nitro- and carboxy(cyano) groups are intermediate products in the preparation of amino acids, whose structural fragments are included into composition of natural compounds (peptides,[1a—e] coronatin,[1a,b] carnosadin,[1a] *etc.*). 3-(4-Chlorophenyl)-2-nitrocyclopropanecarboxaldehyde was used for obtaining the drug baclofen[2] for treatment of the central nervous system (CNS) malfunctions; this compound is a derivative of very important neuromediator, γ-aminobutanoic acid. Functionally substituted nitrocyclopropanes are synthesized by addition of nitroalkanes to α-halo-substituted cycloalkenones,[3a—c] by cyclopropanation of nitro olefins,[3a,4] by reactions of nitro-iodonium ylides and nitro-diazo compounds with alkenes,[1a,3a,5] and by reactions of α-halonitroalkanes with α,β-unsaturated aldehydes and ketones.[2,6] The latter, the most practical and efficient reaction, is a tandem process including a sequence of the Michael reaction and intramolecular alkylation.

We found that available alkylidene(arylidene)malonic or cyanoacetic esters and maleimides can play the role of Michael acceptors in this reaction. Thus, activated alkenes **1a**—**g** add α-bromonitroalkanes **2a**,**b** upon the action of K_2CO_3 in toluene at room temperature giving rise to esters and nitriles of 3-alkyl(aryl)-2-nitrocyclopropane-1,1-dicarboxylic acid **3a**—**k** in one experimental step. The yields of products **3a**—**k** depend on the nature of substituents R^1 and R^2 in compounds **1**. In the absence of a phase-transfer catalyst (PTC), they are very high in the addition reactions to the trisubstituted alkenes **1c**—**e** bearing alkyl or aryl groups on the β-carbon atom, however, they are considerably lower in the case of compounds **1f**,**g**, in which this atom is bound to the alkenyl group and, especially, in the case of compounds **1a**,**b** containing a tetrasubstituted double bond (Scheme 1, Table 1).

Scheme 1



Reagents and conditions: K_2CO_3 (1.5 equiv.), $Bu^n_4NPF_6$ (10 mol.%), PhMe, 20 °C, 1—5 h.

We managed to considerably increase the yields of nitrocyclopropanes based on these "problematic" compounds by carrying out the reaction in the presence of tetrabutylammonium hexafluorophosphate Bu_4NPF_6 (10 mol.%), which plays apparently the role of PTC. The fluorine-containing PTC, being poorly soluble in organic and aqueous phases, can be easily separated from the reaction mixture and reused no less that three times without decrease in the reaction rate and the yield of the product (see Table 1, entry *2*).

Bromonitromethane **2a** does not react with maleimide **4** in toluene in the presence of K_2CO_3 and Bu_4NPF_6, apparently, because of insufficient polarization of the double bond in compound **4**. However, the adduct **5**, which is used for the preparation of antibacterial drug Trovafloxa-

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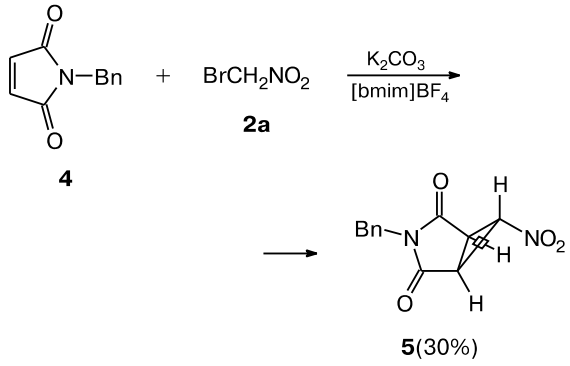
Table 1. Yields and isomeric composition of the functionally substituted nitrocyclopropanes **3a—k**

Entry	Alkene	Bromo-nitro-alkane	R^1	R^2	R^3	R^4	R^5	Cyclo-propane	τ/h	Yield of compound **3** (%)[a]	
										in the presence of Bu_4NPF_6	without PTC
1	**1a**	**2a**	Me	Me	CO_2Et	CN	H	**3a**	5.0	66	16
2	**1a**	**2b**	Me	Me	CO_2Et	CN	Me	**3b**	3.0	88[b]	
3	**1b**	**2a**	$-(CH_2)_5-$		CO_2Et	CN	H	**3c**	1.5	88	43
4	**1b**	**2b**	$-(CH_2)_5-$		CO_2Et	CN	Me	**3d**	3.0	73	15
5	**1c**	**2a**	Me	H	CO_2Et	CN	H	**3e**	4.0	75	85
6	**1c**	**2b**	Me	H	CO_2Et	CN	Me	**3f**	3.0	84	93
7	**1d**	**2a**	Ph	H	CO_2Et	CN	H	**3g**	2.0	77	61[44[c]]
8	**1d**	**2b**	Ph	H	CO_2Et	CN	Me	**3h**	3.0	98	98
9	**1e**	**2a**	[d]	H	CO_2Me	CO_2Me	H	**3i**	5.0	91	82
10	**1f**	**2b**	$Me_2C=CH$	H	CO_2Et	CN	Me	**3j**	5.0	89	60
11	**1g**	**2b**	[e]	H	CO_2Et	CN	Me	**3k**	6.0	92	45

[a] The ratios of isomers are given in Experimental.
[b] 90% each in the second and third cycles.
[c] Was synthesized earlier[7a] from β-bromo-β-nitrostyrene and ethyl cyanoacetate upon the action of MeONa.
[d] $R^1 = Me_2C=CH(CH_2)_2CH(Me)CH_2$.
[e] $R^1 = Me_2C=CH(CH_2)_2C(Me)=CH$.

cin,[8] was synthesized in 30% yield when the reaction was carried out in the ionic liquid, *viz.*, 1-butyl-3-methylimidazolium tetrafluoroborate ([bmim]BF_4) (Scheme 2).

Scheme 2



Most of the synthesized compounds are mixtures of stereoisomers, whose number and structures depend on substituents in the cyclopropane ring. The relative configuration of substituents in compounds **3** was established by NMR spectroscopy using the nuclear Overhauser effect (NOE) and the $^3J_{H,H}$ and $^3J_{H,C}$ spin-spin coupling constant values. In the one-dimensional differential NOE experiments, the values for the protons in the *cis*-oriented fragments were relatively small, but reliably detectable. The $^3J_{H,C}$ spin-spin coupling constant values in compounds containing protons in the cyclopropane ring, were measured in one-dimensional (^{13}C Gated Decoupling, GD) and two-dimensional (^1H, ^{13}C *J*-HMBC, Refs 9 and 10) experiments. To determine the relative orientation of the

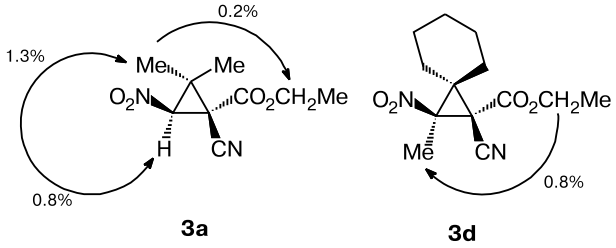
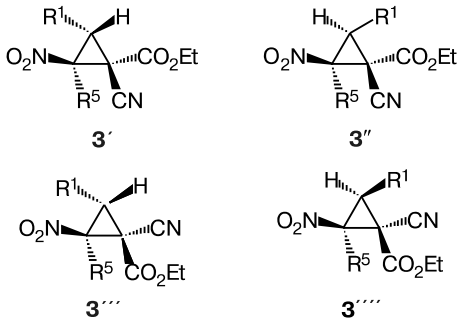


Fig. 1. Results of the 1D selective NOESY experiments for products **3a** and **3d**.

proton and the substituent, the same tendency in the change of the spin-spin coupling constant $^3J_{H,C}$ was used as for $^3J_{H,H}$ (see Refs 7b and 11): for other conditions being equal, the *cis*-constants are larger than the *trans*-constants.

Compounds **3a—d** are individual stereoisomers, which were assigned the structures with the *trans*-arrangement of the NO_2 and CO_2Et groups based on the NOE data for products **3a** and **3d** (Fig. 1).

The rest of the compounds can theoretically exist as four stereoisomers **3′—3′′′′**, nevertheless, nitrocyclo-



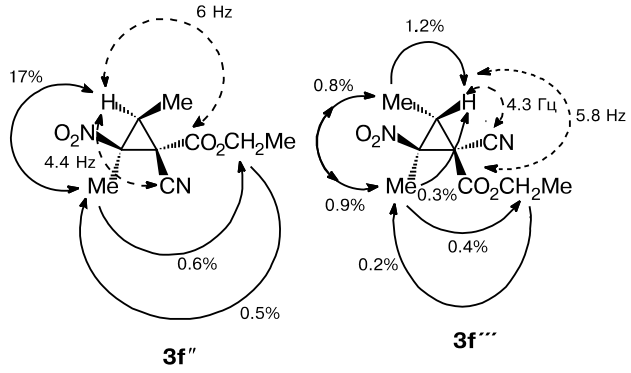


Fig. 2. Results of the NOE experiments (solid lines) and the spin-spin coupling constant values $^3J_{H,C}$ (dashed lines) for compound **3f**.

propanes **3f**—**k** according to the ^{1}H NMR spectroscopic data consist of two diastereomers.

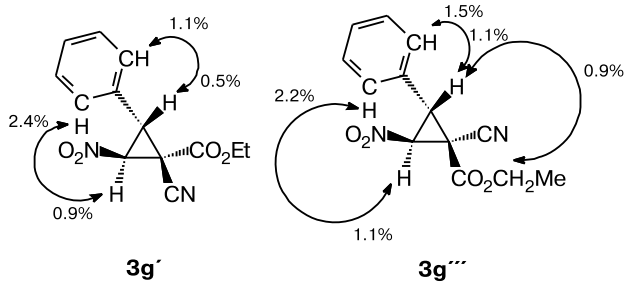
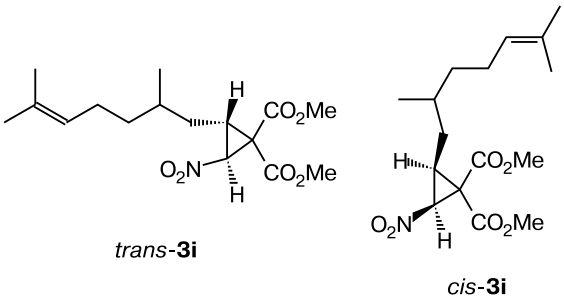


Fig. 3. Results of the NOE experiments for compound **3g**.

The NOE experiments and analysis of the $^3J_{H,C}$ spin-spin coupling constant values for the pentasubstituted cyclopropanes **3f**, **3h**, **3j**, and **3k** allows us to assign them the **3″** and **3‴** structural types, differing in the mutual orientation of substituents R^1—NO_2 (*cis/trans*) and NO_2—CO_2Et (*trans/cis*) (Fig. 2).

Diastereomers of the nitro ester **3g**, according to the literature data for the corresponding methyl ester,[7b] belong to the **3′** and **3‴** types (the spin-spin coupling constant values $^3J_{H,H}$ = 6.6 and 7.0 Hz are characteristic of the *trans*-arrangement of vicinal protons (see Refs 7b and 11: $^3J_{H,H}$ = 3—8 Hz)). This assignment was also confirmed by the NOE experiments (Fig. 3) and analysis of the $^3J_{H,C}$ spin-spin coupling constants (Figs 4 and 5).

The presence of isomers with *trans*- and *cis*-arrangement of substituents (1 : 1) was also observed in cyclopropanes **3i**, in this case the signal for the proton at C(2)NO_2 with δ 4.78 has $^3J_{trans}$ = 5.9 Hz, whereas at δ 4.80, J_{cis} = 9.2 Hz.



Unlike **3g**, the related to it compound **3e** according to the ^{1}H NMR spectral data (the signals for the protons

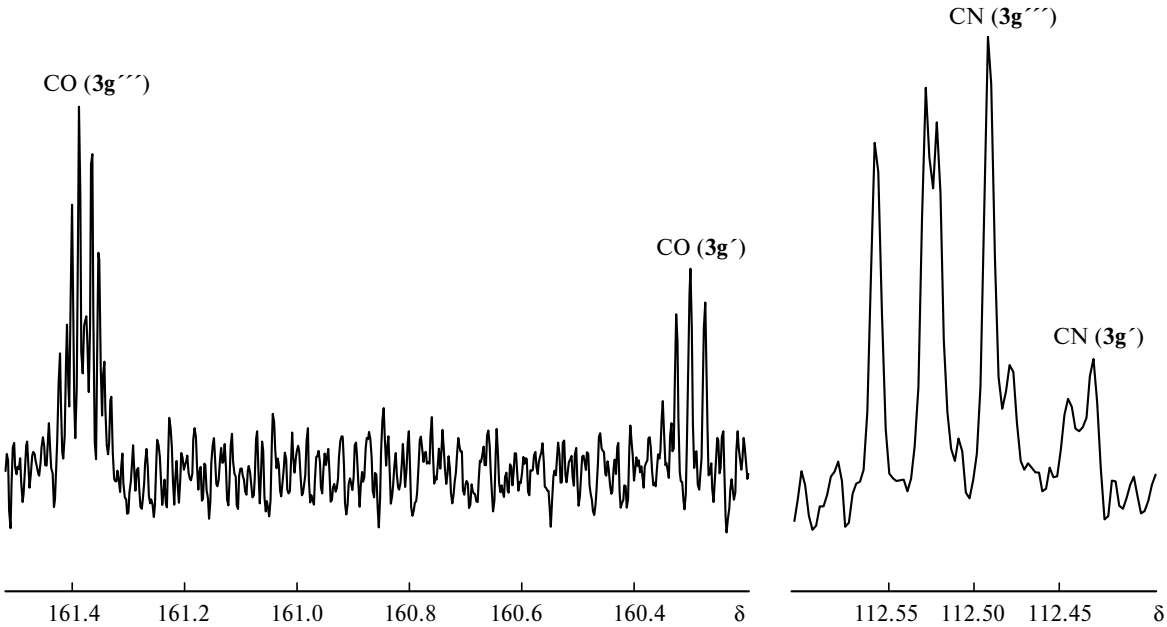


Fig. 4. The parts of the ^{13}C GD spectrum showing splitting of the signals for the CO and CN groups due to the interaction with the protons of the cyclopropane ring (CO and CN) and the protons of the OCH_2 groups (CO). The $^3J_{H,CO}$ and $^3J_{H,CN}$ spin-spin coupling constant values are given in Fig. 5.

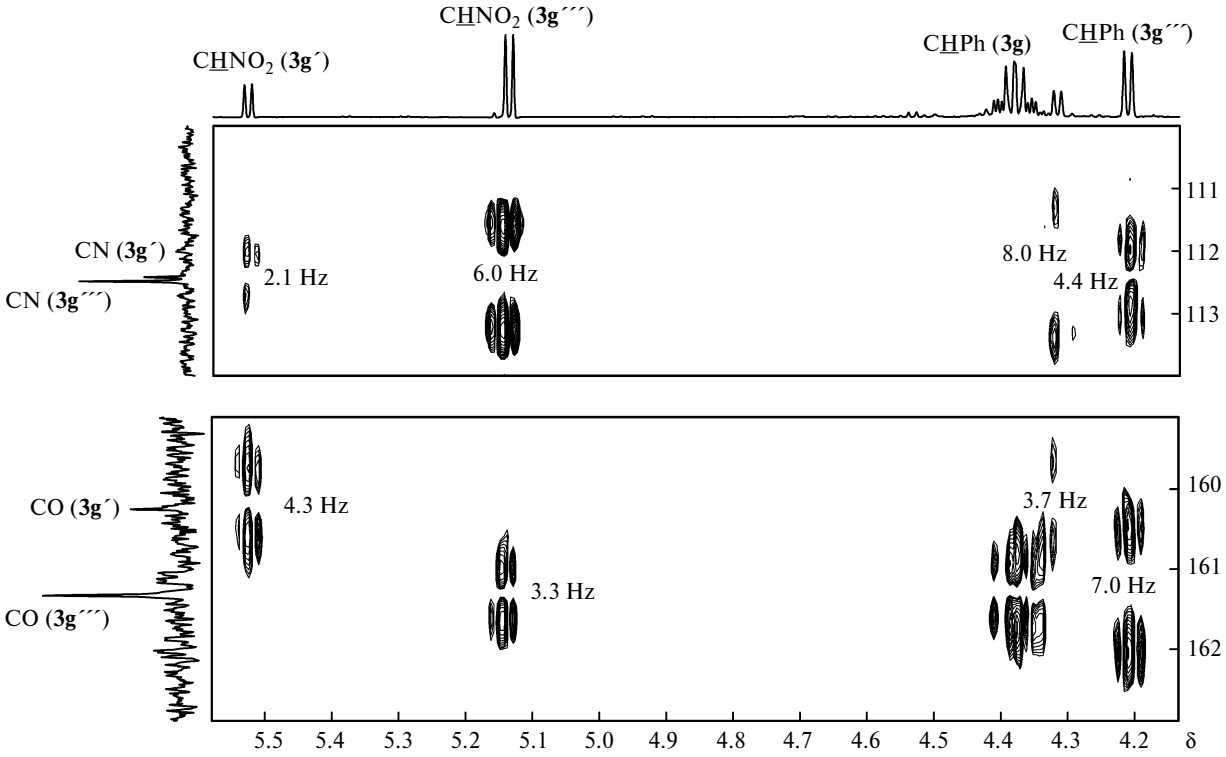


Fig. 5. The parts of the *J*-HMBC [9,10,12,13] two-dimensional spectrum of compound **3g**. The spin-spin coupling constant values were obtained by the division of the distance (in Hz) between the two components of the correlation peak along the vertical axis by the splitting factor $f = 33$.

$CHNO_2$) consists of three stereoisomers, which according to the NOE experimental data and the $^3J_{H,H}$ and $^3J_{H,C}$ spin-spin coupling constant values belong to the structural types **3e´**, **3e″**, and **3e´´´** (Fig. 6).* In the ^{1}H NMR spectrum of compound **3k**, two signals for the proton of the cyclopropane ring (δ 3.04 and 3.08) are observed, that is apparently due to the isomerism of the double bond in the isoprenoid group R^1 (the starting compound **1g** was obtained from the commercially available mixture of *E*- and *Z*-isomers of citral, 2 : 1).

In conclusion, we developed efficient methods for the synthesis of functionally substituted nitrocyclopropanecarboxylic acid derivatives **3a—k** (including the earlier unknown ones) and studied their spatial structures. These compounds can serve as precursors of β-aminodicarboxylic acids of cyclopropane series, the intermediate products

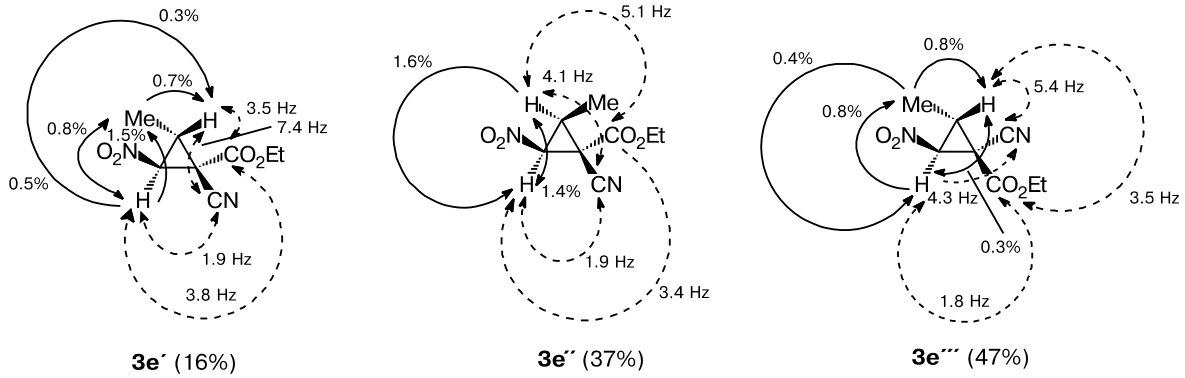


Fig. 6. Results of the NOE experiments (solid lines) and the $^3J_{H,H}$ and $^3J_{H,C}$ spin-spin coupling constant values (dashed lines) for compound **3e**.

* Appearance of the isomer **3e″** having the spin-spin coupling constant $^3J_{cis} = 8.8$ Hz is apparently due to the lower effects of the methyl substituent as compared to the phenyl one.

for the preparation of synthetic peptides and pyrethroid analogs.[1a,b] Examples of the reduction of nitrocyclopropanes to the corresponding aminocyclopropanes are described in the literature.[1e,4d,f,14]

Experimental

1D ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AM-300 spectrometer (300.13 MHz (^{1}H), 75.47 MHz (^{13}C)) for solutions in $CDCl_3$. 1D selective NOE spectra were recorded on a Bruker AVANCE 600 spectrometer using the *Selnogp* standard impulse program with the Gauss 1.1000 shaped pulse for excitation. The spectra were acquired with 2 s duration of relaxation time. 2D *J*-HMBC spectra (see Ref. 9) were recorded on an AVANCE 600 spectrometer; the experimental conditions and procedure for the measurement of the spin-spin coupling constant value have been in details described earlier (see Refs 12 and 13). IR spectra were recorded on a Specord M-82 spectrometer for neat samples. Elemental analysis was performed on a Perkin-Elmer 2400 microanalyzer. Reaction progress was monitored by TLC on Silufol plates (eluent: *n*-hexane—EtOAc (8 : 2), visualization by the UV light and I_2 vapors). Purification of synthesized compounds was accomplished by column chromatography on silica gel from Acros (0.060—0.200 mm). Bromonitromethane (**2a**), K_2CO_3, [bmim][BF_4], *N*-benzylmaleimide (**4**), and citral (as a mixture of *E*/*Z*-isomers 2 : 1) were purchased from Acros and used without additional purification. The catalyst Bu_4NPF_6,[15] activated alkenes **1a—d**,[16] **1e**,[17] **1f**[18], **1g**,[19] and α-bromonitroethane[20] were synthesized according to the known methods.

Reaction of olefins 1a—g with bromonitroalkanes 2a,b (general procedure). A mixture of **1** (1 mmol), **2** (1.1—1.5 mmol), K_2CO_3 (0.207 g, 1.5 mmol) and, if indicated, Bu_4NPF_6 (0.04 g, 10 mol.%) in toluene (0.5 mL) was vigorously stirred using a magnetic stirrer at 20 °C for several hours (see Table 1) until compound **1** disappeared, monitoring the reaction progress by TLC and adding, if necessary, compound **2** (to 1.5 mmol). The reaction mixture was diluted with water (in the case when Bu_4NPF_6 was used, the catalyst was filtered off) and extracted with Et_2O (2×5 mL). The combined organic extract was washed with water (20 mL), dried with $MgSO_4$, the solvent was evaporated at reduced pressure (40 °C, 40 Torr). Products were purified on a column with SiO_2, sequentially eluting with *n*-hexane and the *n*-hexane—EtOAc solvent mixture. Physicochemical properties, the IR, ^{1}H and ^{13}C NMR spectroscopic data, as well as results of elemental analysis of the newly synthesized compounds **3** are given below.

Ethyl 1-cyano-3,3-dimethyl-2-nitrocyclopropanecarboxylate (3a). Colorless oil, n_D^{20} 1.4725. Found (%): C, 50.82; H, 5.80; N, 13.25. $C_9H_{12}N_2O_4$. Calculated (%): C, 50.94; H, 5.70; N, 13.20. IR, ν/cm^{-1}: 1368, 1556 (NO_2); 1740 (C=O); 2248 (CN). ^{1}H NMR, δ: 1.35 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.42 (s, 3 H, C(3)Me); 1.65 (s, 3 H, C(3)Me); 4.32 (q, 2 H, OCH$_2$, *J* = 7.0 Hz); 4.90 (s, 1 H, CH—NO_2). ^{13}C NMR, δ: 13.9 (MeCH$_2$), 18.1 (MeC(3)), 19.2 (MeC(3)), 32.6 (C(1)), 38.3 (C(3)), 64.1 (OCH$_2$), 71.3 (C(2)), 112.2 (CN), 162.6 (C=O).

Ethyl 1-cyano-2,3,3-trimethyl-2-nitrocyclopropanecarboxylate (3b). Colorless oil, n_D^{20} 1.4670. Found (%): C, 53.23; H, 6.28; N, 12.45. $C_{10}H_{14}N_2O_4$. Calculated (%): C, 53.09; H, 6.24; N, 12.38. IR, ν/cm^{-1}: 1352, 1548 (NO_2); 1740 (C=O); 2244 (CN). ^{1}H NMR, δ: 1.35 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.42 (s, 3 H, C(3)Me); 1.55 (s, 3 H, C(3)Me); 2.05 (s, 3 H, C(NO_2)Me); 4.30 (q, 2 H, OCH$_2$, *J* = 7.0 Hz). ^{13}C NMR, δ: 14.0 (MeCH$_2$), 15.4 (MeC(3)), 16.0 (MeC(3)), 22.1 (MeC(2)), 32.3 (C(1)), 37.9 (C(3)), 63.4 (OCH$_2$), 80.5 (C(2)), 114.1 (CN), 162.6 (C=O).

Ethyl 1-cyano-2-nitrospiro[2.5]octane-1-carboxylate (3c). Colorless oil, n_D^{20} 1.4910. Found (%): C, 57.27; H, 6.47; N, 11.20. $C_{12}H_{16}N_2O_4$. Calculated (%): C, 57.13; H, 6.39; N, 11.10. IR, ν/cm^{-1}: 1368, 1560 (NO_2); 1740 (C=O); 2252 (CN). ^{1}H NMR, δ: 1.32 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.43—2.10 (m, 10 H, 5 CH$_2$); 4.28 (q, 2 H, OCH$_2$, *J* = 7.0 Hz); 4.86 (s, 1 H, CH—NO_2). ^{13}C NMR, δ: 14.1 (MeCH$_2$), 24.4 (CH$_2$), 25.7 (CH$_2$), 28.1 (CH$_2$), 29.1 (C(1)), 44.8 (C(3)), 64.1 (OCH$_2$Me), 71.2 (C(2)), 112.2 (CN), 162.7 (C=O).

Ethyl 1-cyano-2-methyl-2-nitrospiro[2.5]octane-1-carboxylate (3d). Colorless oil, n_D^{20} 1.4937. Found (%): C, 58.74; H, 6.85; N, 10.55. $C_{13}H_{18}N_2O_4$. Calculated (%): C, 58.63; H, 6.81 N, 10.52. IR, ν/cm^{-1}: 1356, 1560 (NO_2); 1748 (C=O); 2248 (CN). ^{1}H NMR, δ: 1.36 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.40—2.15 (m, 10 H, 5 CH$_2$); 2.02 (s, 3 H, C(NO_2)Me); 4.28 (q, 2 H, OCH$_2$, *J* = 7.0 Hz). ^{13}C NMR, δ: 13.9 (MeCH$_2$), 17.5 (MeC(2)), 24.3 (CH$_2$), 25.1 (CH$_2$), 26.5 (CH$_2$), 30.8 (C(1)), 44.2 (C(3)), 63.4 (OCH$_2$), 78.2 (C(2)), 114.2 (CN), 162.1 (C=O).

Ethyl 1-cyano-3-methyl-2-nitrocyclopropanecarboxylate, a mixture of isomers **3e′** : **3e″** : **3e‴** = 16 : 37 : 47. Colorless oil, n_D^{20} 1.4720. Found (%): C, 48.60; H, 5.17; N, 14.23. $C_8H_{10}N_2O_4$. Calculated (%): C, 48.48; H, 5.09; N, 14.14. IR, ν/cm^{-1}: 1372, 1560 (NO_2); 1740 (C=O); 2256 (CN).

Isomer **3e′**. ^{1}H NMR, δ: 1.39 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.55 (d, 3 H, Me, *J* = 6.6 Hz); 3.05 (dq, 1 H, MeCH, $J_1 = J_2$ = 6.6 Hz); 4.23—4.35 (m, 2 H, OCH$_2$); 4.88 (d, 1 H, CH—NO_2, *J* = 6.6 Hz). ^{13}C NMR, δ: 9.2 (Me), 13.9 (MeCH$_2$), 27.9 (C(3)), 33.7 (C(1)), 64.8 (OCH$_2$), 67.9 (C(2)), 112.6 (CN), 161.7 (C=O).

Isomer **3e″**. ^{1}H NMR, δ: 1.32 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.62 (d, 3 H, Me, *J* = 6.6 Hz); 2.47 (dq, 1 H, MeCH, J_1 = 8.8 Hz, J_2 = 6.6 Hz); 4.23—4.35 (m, 2 H, OCH$_2$); 4.86 (d, 1 H, CH—NO_2, *J* = 8.8 Hz). ^{13}C NMR, δ: 8.5 (Me), 13.8 (MeCH$_2$), 28.8 (C(3)), 32.7 (C(1)), 64.3 (OCH$_2$), 67.0 (C(2)), 111.0 (CN), 164.1 (C=O).

Isomer **3e‴**. ^{1}H NMR, δ: 1.37 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.49 (d, 3 H, Me, *J* = 6.6 Hz); 2.99 (dq, 1 H, MeCH, $J_1 = J_2$ = 6.6 Hz); 4.23—4.35 (m, 2 H, OCH$_2$); 4.53 (d, 1 H, CH—NO_2, *J* = 6.6 Hz). ^{13}C NMR, δ: 12.4 (Me), 13.7 (MeCH$_2$), 28.5 (C(3)), 30.2 (C(1)), 64.2 (OCH$_2$), 69.4 (C(2)), 113.1 (CN), 161.5 (C=O).

Ethyl 1-cyano-2,3-dimethyl-2-nitrocyclopropanecarboxylate, a mixture of isomers **3f″** : **3f‴** = 66 : 34. Colorless oil, n_D^{20} 1.4647. Found (%): C, 50.75; H, 5.76; N, 13.31. $C_9H_{12}N_2O_4$. Calculated (%): C, 50.94; H, 5.70; N, 13.20. IR, ν/cm^{-1}: 1352, 1548 (NO_2); 1740 (C=O); 2248 (CN).

Isomer **3f″**. ^{1}H NMR, δ: 1.37 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.51 (d, 3 H, Me—CH, *J* = 6.6 Hz); 1.92 (s, 3 H, C(NO_2)Me); 2.35 (q, 1 H, MeCH, *J* = 6.6 Hz); 4.20—4.35 (m, 2 H, OCH$_2$). ^{13}C NMR, δ: 10.6 (MeC(3)), 14.0 (MeCH$_2$), 17.5 (MeC(2)), 32.0 (C(3)), 32.7 (C(1)), 64.1 (OCH$_2$), 76.3 (C(2)), 112.7 (CN), 163.4 (C=O).

Isomer **3f‴**. ^{1}H NMR, δ: 1.32 (t, 3 H, MeCH$_2$, *J* = 7.0 Hz); 1.40 (d, 3 H, Me—CH, *J* = 6.6 Hz); 1.95 (s, 3 H, C(NO_2)Me); 3.04 (q, 1 H, MeCH, *J* = 6.6 Hz); 4.20—4.35 (m, 2 H, OCH$_2$). ^{13}C NMR, δ: 9.4 (MeC(3)), 13.7 (MeCH$_2$), 15.0 (MeC(2)), 31.2 (C(3)), 32.6 (C(1)), 63.7 (OCH$_2$), 76.3 (C(2)), 112.8 (CN), 162.8 (C=O).

Ethyl 1-cyano-2-nitro-3-phenylcyclopropanecarboxylate, a mixture of isomers **3g´** : **3g″** = 26 : 72. Colorless oil, n_D^{20} 1.5350. IR, ν/cm^{-1}: 1368, 1564 (NO_2); 1740 (C=O); 2252 (CN) (the literature data for similar mixture of the methyl ester isomers:[7b] 1366, 1567 (NO_2); 1747 (C=O); 2250 (CN)).

Isomer **3g´**. ^{1}H NMR, δ: 1.07 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 4.08 (q, 2 H, OCH$_2$, J = 7.0 Hz); 4.32 (d, 1 H, Ph—CH, J = 6.6 Hz); 5.53 (d, 1 H, CH—NO$_2$, J = 6.6 Hz); 7.25—7.55 (m, 5 H, Ph). ^{13}C NMR, δ: 13.6 (MeCH$_2$); 31.9 (C(1)); 40.5 (C(3)); 64.1 (OCH$_2$); 76.7 (C(2)); 112.4 (CN); 128.6, 129.0, 129.3, 129.7 (Ph); 160.3 (C=O).

Isomer **3g″**. ^{1}H NMR, δ: 1.35 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 4.38 (q, 2 H, OCH$_2$, J = 7.0 Hz); 4.21 (d, 1 H, Ph—CH, J = 7.0 Hz); 5.13 (d, 1 H, CH—NO$_2$, J = 7.0 Hz); 7.25—7.55 (m, 5 H, Ph). ^{13}C NMR, δ: 13.8 (MeCH$_2$); 39.6 (C(1)); 37.5 (C(3)); 64.6 (OCH$_2$); 76.7 (C(2)); 112.5 (CN); 128.2, 128.4, 128.9, 129.1 (Ph); 161.4 (C=O). Signals of low intensities were also observed in the ^{1}H NMR spectrum at δ = 3.68 (d, Ph—CH, J = 8.8 Hz) and δ = 5.16 (d, CH—NO$_2$, J = 8.8 Hz), which indicate the presence of a minor isomer (~2—3%) with the *cis*-arrangement of vicinal protons.

Ethyl 1-cyano-2-methyl-2-nitro-3-phenylcyclopropanecarboxylate, a mixture of isomers **3h″** : **3h´´´** = 42 : 58. Light yellow viscous oil, n_D^{20} 1.5180. Found (%): C, 61.44; H, 5.20; N, 10.29. $C_{14}H_{14}N_2O_4$. Calculated (%): C, 61.31; H, 5.14; N, 10.21. IR, ν/cm^{-1}: 1364, 1552 (NO_2); 1744 (C=O); 2248 (CN). Individual isomers were isolated by chromatography on SiO_2 (eluent: hexane—PhH (1 : 1) and PhH).

Isomer **3h″**. ^{1}H NMR, δ: 1.38 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 1.92 (s, 3 H, C(NO$_2$)Me); 4.28 (s, 1 H, Ph—CH); 4.37 (q, 2 H, OCH$_2$, J = 7.0 Hz); 7.30—7.50 (m, 5 H, Ph). ^{13}C NMR, δ: 13.9 (MeCH$_2$); 16.9 (MeC(2)); 32.8 (C(1)); 40.3 (C(3)); 64.5 (OCH$_2$); 75.7 (C(2)); 112.6 (CN); 128.2, 128.8, 129.1, 129.3 (Ph); 162.8 (C=O).

Isomer **3h´´´**. ^{1}H NMR, δ: 1.43 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 2.05 (s, 3 H, C(NO$_2$)Me); 3.67 (s, 1 H, Ph—CH); 4.43 (q, 2 H, OCH$_2$, J = 7.0 Hz); 7.30—7.45 (m, 5 H, Ph). ^{13}C NMR, δ: 14.1 (MeCH$_2$); 17.0 (MeC(2)); 32.3 (C(1)); 40.5 (C(3)); 64.7 (OCH$_2$); 74.3 (C(2)); 112.3 (CN); 128.2, 128.4, 128.9, 129.1 (Ph); 163.3 (C=O).

Dimethyl 3-(2,6-dimethylhept-5-enyl)-2-nitrocyclopropanedicarboxylate (3i), a mixture of *trans*- and *cis*-isomers 45 : 55. Colorless oil, n_D^{20} 1.4750. Found (%): C, 58.92; H, 7.75; N, 4.35. $C_{16}H_{25}NO_6$. Calculated (%): C, 58.70; H, 7.70; N, 4.28. IR, ν/cm^{-1}: 1368, 1556 (NO_2); 1744 (C=O).

trans-Isomer **3i**. ^{1}H NMR, δ: 0.92 (d, 3 H, MeCH, J = 6.0 Hz); 1.15—1.55 (m, 5 H, 2 CH$_2$, CH$_3$CH); 1.68 (s, 6 H, Me$_2$C=); 1.88—2.07 (m, 2 H, CH$_2$); 2.85—2.95 (m, 1 H, CH); 3.79 (s, 3 H, OMe); 4.78 (d, 1 H, CH-NO$_2$, J = 5.9 Hz); 5.0—5.12 (m, 1 H, Me$_2$C=CH). ^{13}C NMR, δ: 17.7 (Me), 19.1 (Me), 25.5 (CH$_2$), 25.7 (Me), 31.5 (CH$_2$), 32.2 (CH$_2$), 33.7 (CH), 36.7 (C(3)), 44.3 (C(1)), 53.5 (OMe), 67.3 (C(2)), 124.2 (CH=), 131.7 (Me$_2$C=), 165.0 (C=O).

cis-Isomer **3i**. ^{1}H NMR, δ: 0.98 (d, 3 H, MeCH, J = 6.0 Hz); 1.15—1.55 (m, 5 H, 2 CH$_2$, CH$_3$CH); 1.60 (s, 6 H, Me$_2$C=); 1.88—2.07 (m, 2 H, CH$_2$); 2.85—2.95 (m, 1 H, CH); 3.77 (s, 3 H, OMe); 4.80 (d, 1H, CH—NO$_2$, J = 9.2 Hz); 5.0—5.12 (m, 1 H, Me$_2$C=CH). ^{13}C NMR, δ: 17.7 (Me), 19.0 (Me), 25.3 (CH$_2$), 25.5 (Me), 31.7 (CH$_2$), 32.0 (CH$_2$), 33.4 (CH), 36.8 (C(3)), 44.5 (C(1)), 53.9 (OMe), 67.7 (C(2)), 123.5 (CH=), 129.8 (Me$_2$C=), 164.3 (C=O).

Ethyl 1-cyano-2-methyl-3-(2-methylpropenyl)-2-nitrocyclopropanecarboxylate, a mixture of isomers **3j″** : **3j´´´** = 50 : 50. Colorless oil, n_D^{20} 1.4865. Found (%): C, 57.02; H, 6.27; N, 11.16. $C_{12}H_{16}N_2O_4$. Calculated (%): C, 57.13; H 6.39; N, 11.10. IR, ν/cm^{-1}: 1348, 1556 (NO_2); 1744 (C=O); 2248 (CN). Individual isomers were isolated by chromatography on SiO_2 (eluent: hexane—PhH (1 : 1)).

Isomer **3j″**. ^{1}H NMR, δ: 1.35 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 1.78 and 1.83 (both s, 3 H, Me$_2$C=); 1.93 (s, 3 H, C(NO$_2$)Me); 3.03 (d, 1 H, H(3), J = 7.7 Hz); 4.32 (q, 2 H, OCH$_2$, J = 7.0 Hz); 5.11 (dt, 1 H, Me$_2$C=CH, J_1 = 7.7 Hz, J_2 = 1.5 Hz). ^{13}C NMR, δ: 14.1 (MeCH$_2$); 17.2 (MeC(2)); 19.3 and 26.0 (Me$_2$C=); 32.3 (C(1)); 37.6 (C(3)); 64.3 (OCH$_2$); 75.4 (C(2)); 111.9 (CN); 128.4 (CH=); 144.1 (Me$_2$C=); 163.4 (C=O).

Isomer **3j´´´**. ^{1}H NMR, δ: 1.30 (t, 3 H, MeCH$_2$, J = 7.0 Hz); 1.76 and 1.83 (both s, 3 H, Me$_2$C=); 1.91 (s, 3 H, C(NO$_2$)Me); 3.63 (d, 1 H, H(3), J = 7.0 Hz); 4.25 (q, 2 H, OCH$_2$, J = 7.0 Hz); 4.90 (dt, 1 H, Me$_2$C=CH, J_1 = 7.0 Hz, J_2 = 1.5 Hz). ^{13}C NMR, δ: 14.0 (MeCH$_2$); 17.1 (MeC(2)); 19.1 and 25.9 (Me$_2$C=); 32.3 (C(1)); 37.0 (C(3)); 63.1 (OCH$_2$); 76.6 (C(2)); 112.6 (CN); 128.6 (CH=); 144.2 (Me$_2$C=); 162.9 (C=O).

Ethyl 1-cyano-2-methyl-3-(2,6-dimethylhept-1,5-dienyl)-2-nitrocyclopropanecarboxylate (3k), a mixture of *Z*/*E*-isomers 35 : 65. Colorless oil, n_D^{20} 1.4933. Found (%): C, 63.90; H, 7.62; N, 8.81. $C_{17}H_{24}N_2O_4$. Calculated (%): C, 63.73; H, 7.55; N, 8.74. IR, ν/cm^{-1}: 1352, 1552 (NO_2); 1740 (C=O); 2248 (CN). ^{1}H NMR, δ: 1.37 and 1.38 (both t, 3 H, MeCH$_2$, J = 7.0 Hz); 1.01—1.53 (m, 5 H, 2 CH$_2$, MeCH); 1.59 and 1.68 (*Z*-isomer) (both s, Me$_2$C=); 1.77 and 1.84 (*E*-isomer) (both s, Me$_2$C=); 1.93 and 1.95 (both s, 3 H, C(NO$_2$)Me); 3.04 and 3.08 (both d, 1 H, H(3), J = 6.6 Hz, J = 8.0 Hz); 4.33 and 4.36 (both q, 2 H, OCH$_2$, J = 7.0 Hz); 5.07 (br.s, 1 H, Me$_2$C=CH); 5.15 (d, 1 H, MeC=CH, J = 8.0 Hz). ^{13}C NMR, δ: 14.0 (MeCH$_2$); 17.1 and 24.7 (Me$_2$C=); 17.2 and 23.6 (MeCH=); 17.7 (MeC(2)); 26.2 (CH$_2$); 32.4 (*Z*-isomer) and 39.5 (*E*-isomer) (CH$_2$); 33.3 (C(1)); 36.9 (C(3)); 63.1 (OCH$_2$); 75.4 (C(2)); 112.5 (CN); 122.9, 123.0, 123.2, 123.3 (2 CH=); 132.3, 132.9 (Me$_2$C=); 147.5, 147.6 (—(Me)C=); 163.4 (C=O).

(1α,5α,6α)-3-Benzyl-6-nitro-2,4-dioxo-3-azabicyclo[3.1.0]-hexane (5). Potassium carbonate (0.207 g, 1.5 mmol) and **2a** (0.21 g, 1.5 mmol) were added to a solution of *N*-benzylmaleimide (**4**) (0.187 g, 1 mmol), [bmim][BF_4] (2.26 g, 10 mmol) and H_2O (5 drops) with stirring and cooling (ice—water bath). The reaction mixture was stirred for 4 h at 20 °C and then sequentially extracted with Et_2O (2×10 mL) and EtOAc (2×10 mL). The combined organic extract was washed with H_2O (2×15 mL) and dried with $MgSO_4$. The solvent was evaporated at reduced pressure (40 °C, 40 Torr) to obtain **5** as a white crystalline compound, m.p. 118—119 °C (see Refs : m.p. 116—118 °C,[8a] 119—120 °C[8b]). ^{1}H NMR, δ: 3.35 (s, 2 H); 4.47 (s, 1 H); 4.55 (s, 2 H); 7.33 (m, 5 H) agrees with that given in the literature.[8a]

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