Reactions of 3-carene, limonene, and α-pinene nitrosochlorides with imidazole, benzotriazole, and indole

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The reactions of terpene nitrosochlorides derived from 3-carene, α-pinene, and limonene, with simplest azaheterocycles (imidazole, benzotriazole, and indole) were studied. On the base of these transformations, preparative procedures to access chiral oximes bearing azaheterocyclic moieties in the α-position to the oxime fragment, namely, α-(1*H*-imidazol-1-yl)-, α-(1*H*-benzo[*d*][1,2,3]triazol-1-yl)-, and α-(1*H*-indol-3-yl)-substituted terpenic oximes, were developed. Transformations of the studied monoterpene nitrosochlorides into α-substituted oximes proceeded stereoselectively to give in the moderate yields (30—60%) the only stereoisomer arising from the attack of the heterocyclic anion from the less hindered side of the intermediate nitroso olefin generated *in situ* from nitrosochloride.

Key words: monoterpenoids, 3-carene, α-pinene, limonene, α-amino-oxime, imidazole, benzotriazole, indole, nitroso olefin.

The reactions between amines and olefin nitrosochlorides (products of addition of NOCl to olefins) including a number of terpene nitrosochlorides[1] are well known giving rise to α-amino-oximes, the novel chiral chelating ligands.[2] The promise of α-substituted oximes as synthons for the design of complex chiral polycyclic frameworks encourages further study of chemistry of nitrosochlorides and development of synthetic procedures to introduce various substituents into the α-position to the oxime fragment using nitrosochlorides as convenient highly reactive intermediates. We have previously shown that nitrosochlorides react with the C-nucleophiles giving chiral malonates[3] and some S-nucleophiles.[4] With the aim at expanding the synthetic utility of nitrosochlorides, in the present work we studied reactions (Scheme 1) of nitrosochlorides of natural monoterpenes, 3-carene (**1**), limonene (**6**), and α-pinene (**11**), with simplest azaheterocycles (imidazole, benzotriazole, and indole).

When the reaction of monoterpene nitrosochlorides with amines was carried out under "standard" conditions (EtOH, excess of amine, heating),[1] the satisfactory results for primary and secondary amines (aliphatic and aromatic) were achieved, however for the studied heterocyclic amines only trace amounts of the target substitution products were found. In all cases, the major products were α,β-unsaturated ketoximes, namely, 2-caren-4-one (*E*)-oxime,[5—7] carvone (*E*)-oxime,[8] and a mixture of pinocarvone (*E*)- and (*Z*)-oximes[9] formed in the reactions of nitrosochlorides of 3-carene (**1**), limonene (**6**), and α-pinene (**11**), respectively. These ketoximes are the result of the extremely easy dehydrochlorination typical of terpene nitrosochlorides. A detailed study of reaction of monoterpene nitrosochlorides with imidazole, benzotriazole, and indole under different conditions (different solvents and temperature, in the presence of additional bases and auxiliary agents) revealed the particular conditions required for the smooth transformations of monoterpene nitrosochlorides into α-substituted chiral ketoximes bearing azaheterocyclic fragment in the α-position to the oxime moiety (see Scheme 1).

Reproducible results and moderate yields of the target products were achieved *via* optimization of the reaction conditions. Thus, for the synthesis of α-(1*H*-imidazol-1-yl)-substituted derivatives, the reaction can be carried out in MeOH in the presence of NaOH at 30 °C. Syntheses of α-(1*H*-benzo[*d*][1,2,3]triazol-1-yl)-substituted derivatives were performed in MeOH at a slightly higher temperature (35 °C) in the presence of anhydrous $Mg(ClO_4)_2$ and K_2CO_3 as a base. Addition of preliminary prepared *N*-indolyl manganese bromide (prepared from indole and EtMgBr in diethyl ether at 15 °C under inert atmosphere) was necessary for the synthesis of α-(1*H*-indol-3-yl)-substituted oximes. In all cases, the corresponding α,β-unsaturated ketoximes mentioned above were the main side

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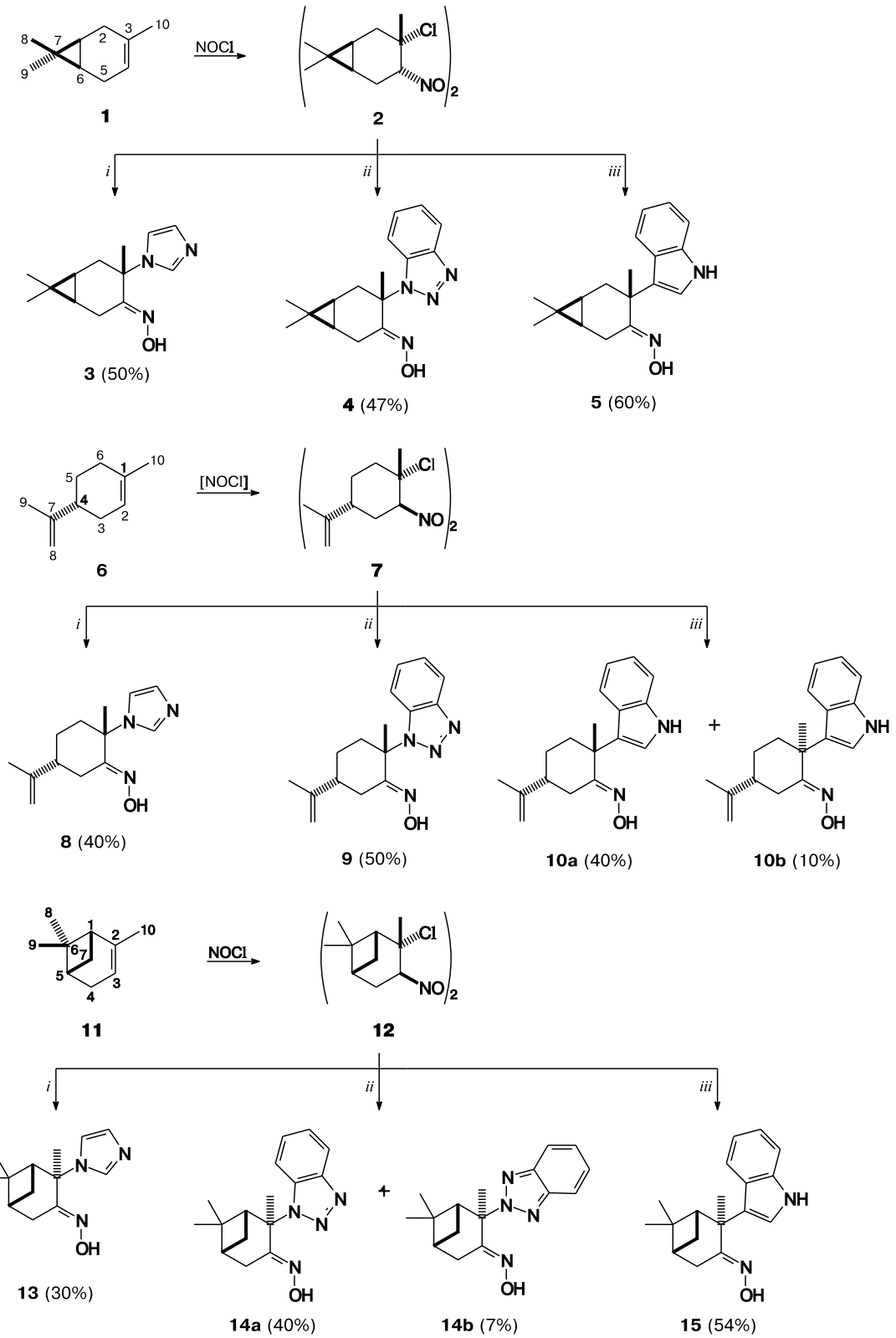
Scheme 1



i. Imidazole, NaOH, MeOH, 15 h, 30 °C; *ii*. Benzotriazole, $Mg(ClO_4)_2$, K_2CO_3, MeOH, 10 h, 35 °C; *iii*. Indole, EtMgBr, Et_2O, 10 h, 15 °C, under nitrogen.

Table 1. ^{1}H NMR spectra of (+)-3-carene derivatives **3**, **4**, and **5**

H Atom	δ_H (J/Hz)		
	3 ($CDCl_3$)	**4** (CCl_4—$CDCl_3$)	**5** ($CDCl_3$)
1	0.71 (ddd, J = 9.1, J = 9.1, J = 5.7)	1.09 (ddd, J = 9.3, J = 9.3, J = 5.3)	0.83 (ddd, J = 9.5, J = 8.6, J = 5.5)
2 (*pro-S*)	2.76 (dd, J = 16.1, J = 9.1)	3.72 (dd, J = 9.3, J = 15.3)	2.80 (dd, J = 15.0, J = 9.5)
2 (*pro-R*)	1.67 (dd, J = 16.1, J = 5.7)	1.81 (dd, J = 5.0, J = 15.2)	1.61 (dd, J = 15.0, J = 5.5)
5 (*pro-R*)	2.25 (dd, J = 19.0, J = 8.8)	1.86 (dd, J = 18.7, J = 8.9)	2.14 (dd, J = 18.5, J = 9.0)
5 (*pro-S*)	2.90 (dd, J = 19.0, J = 2.1)	3.15 (d, J = 18.7)	3.02 (dd, J = 18.5, J = 0.5)
6	0.63 (ddd, J = 9.1, J = 8.8, J = 2.1)	0.47 (ddd, J = 0.8, J = 9.0, J = 9.0)	0.57 (ddd, J = 9.0, J = 8.6, J = 0.5)
8	0.85 (s)	0.91 (s)	0.92 (s)
9	0.97 (s)	0.95 (s)	0.97 (s)
10	1.50 (s)	1.66 (s)	1.52 (s)
=NOH	10.9 (br, $W_{1/2}$ = 500)	9.90 (br.s)	9.80 (br.s)
NH			8.06 (br.s)
Ar<u>H</u>	6.95 (dd, J = 1.4, J = 1.4); 7.06 (dd, J = 1.4, J = 1.0); 7.66 (dd, J = 1.4, J = 1.0)	7.28 (dd, J = 8.2, J = 7.0); 7.33 (dd, J = 8.3, J = 7.0); 7.48 (ddd, J = 8.2, J = 1.0, J = 1.0); 8.05 (ddd, J = 8.2, J = 1.0, J = 1.0)	7.10 (dd, J = 8.0, J = 7.5); 7.11 (d, J = 2.5); 7.18 (dd, J = 8.0, J = 7.5); 7.34 (d, J = 8.0); 7.80 (d, J = 8.0)

products. The target products were purified by column chromatography on silica gel (for imidazole and benzotriazole derivatives) or aluminum oxide (for indole derivatives).

All heterocyclic monoterpene derivatives are colorless crystalline compounds isolated in the pure state and fully characterized by physicochemical and spectroscopic methods. The spatial structure of compounds synthesized were unambiguously established by comparison of their ^{1}H and ^{13}C NMR spectral data (Tables 1—6) with those of the corresponding α-hetaryl-substituted monooximes, derivatives of 3-carene, limonene, and α-pinene prepared by the reaction of nitrosochlorides with amines.[10,11] The following conclusions were drawn: (i) the new asymmetric atom C(3) of 3-carene derivatives **3**, **4**, and **5** has *S*-configuration; (ii) the new asymmetric atom C(1) of derivatives of a *para*-menthane series **8**, **9**, and **10** has *S*-configuration; (iii) the new asymmetric atom C(2) of pinane derivatives **13**, **14**, and **15** has *R*-configuration; (iv) the oxime group of all synthesized α-substituted oximes **3**—**15** has *E*-configuration.

This configuration of the molecules is in agreement with the generally accepted mechanistic description of the reaction between nitrosochlorides and nucleophiles as a two-step elimination—addition process, namely, transformation of the studied monoterpene nitrosochlorides into α-substituted oximes proceeds stereoselectively to give the only stereoisomer, the structure of the latter corresponded to the attack of the azaheterocyclic anion from the less hindered side of the intermediate nitroso olefin generated from nitrosochloride under reaction conditions.[1] The only exception is the limonene indole derivative, which is a diastereomer mixture; the diastereomers can be separated by preparative column chromatography. In the case of the reaction of α-pinene with benzotriazole, formation of the unusual product arising from alkylation of the N(2)

Table 2. ^{13}C NMR spectra of (+)-3-carene derivatives **3**, **4**, and **5**

C Atom	δ_C (J_{C-H}/Hz)		
	3 ($CDCl_3$)	**4** (CCl_4—$CDCl_3$)	**5** ($CDCl_3$)
1	17.66 (J = 159.8)	18.57	19.40 (J = 158.8)
2	32.95 (2 C—H, J = 128.6)	33.89	33.61 (2 C—H, J = 128.3)
3	58.58	63.40	39.95
4	158.15	159.57	165.63
5	17.74 (J = 133.2, J = 127.5)	18.87	18.89 (J = 132.5, J = 126.3)
6	18.75 (J = 161.5)	19.43	20.06 (J = 161.1)
7	17.74	19.39	19.03
8	14.48 (3 C—H, J = 125.0)	14.95	14.63 (3 C—H, J = 126.0)
9	27.68 (3 C—H, J = 125.7)	27.85	27.97 (3 C—H, J = 125.5)
10	27.23 (3 C—H, J = 128.8)	24.38	26.26 (3 C—H, J = 128.0)
Ar	117.00 (d, J = 188.0, J = 16.0, J = 3.5); 128.52 (d, J = 189.0, J = 9.9, J = 9.9); 135.48 (d, J = 207.9, J = 10.0, J = 7.0)	110.76 (d); 120.12 (d); 123.59 (d); 127.13 (d); 132.48 (s); 146.34 (s)	111.08 (d, J = 155.1); 119.37 (d, J = 157.5); 119.93 (d, J = 160.0); 120.04 (s); 121.59 (d, J = 160.0); 121.70 (d, J = 182.5); 126.12 (s); 136.60 (s)

Table 3. ^{1}H NMR spectra ($CDCl_3$) of (+)-limonene derivatives **8**, **9**, **10a**, and **10b**

H Atom	δ_H (J/Hz)*			
	8	**9**	**10a**	**10b**
3 (*pro-R*)	1.47 (dd, J = 14.3, J = 13.1)	1.24 (dd, J = 13.1, J = 13.1)	1.66 (dd, J = 13.3, J = 12.9)	2.25 (dd, J = 11.0, J = 11.0)
3 (*pro-S*)	3.52 (ddd, J = 14.0, J = 3.5, J = 1.8)	3.51 (ddd, J = 13.5, J = 2.8, J = 1.5)	3.42 (ddd, J = 13.3, J = 3.3, J = 1.3)	2.99 (d.m, J = 11.0)
4	2.09 (dddd, J = 12.3, J = 12.3, J = 3.3, J = 3.3)	2.22 (dddd, J = 12.4, J = 12.4, J = 3.5, J = 3.5)	2.17 (m, $W_{1/2}$ = 25)	[2.28]
5 (*pro-R*)	[1.46]	[1.80—1.90]	[1.78]	[1.83] or [1.75]
5 (*pro-S*)	1.75 (d.m, J = 13.8)	[1.80—1.90]	[1.78]	[1.75] or [1.83]
6 (*pro-S*)	2.59 (ddd, J = 14.9, J = 3.3, J = 3.3)	3.58 (ddd, J = 14.5, J = 3.3, J = 3.3)	2.67 (m)	[1.75]
6 (*pro-R*)	1.88 (ddd, J = 14.9, J = 13.6, J = 3.7)	1.98 (ddd, J = 13.5, J = 13.5, J = 4.4)	[1.78]	2.41 (ddd, J = 14.1, J = 11.5, J = 3.5)
8 (H_a)	4.61 (br.s)	4.57 (br.s)	4.62 (br.s)	4.85 (br.s)
8 (H_b)	4.67 (br.s)	4.63 (br.s)	4.65 (br.s)	4.87 (br.s)
9	1.62 (br.s)	1.59 (br.s)	1.64 (br.s)	1.81 (br.s)
10	1.54 (s)	1.72 (s)	1.57 (s)	1.57 (s)
=NOH	11.9 (br)	9.61 (s)	9.24 (br)	8.5 (br)
NH			8.03 (br.s)	8.01 (br.s)
Ar<u>H</u>	6.93 (dd, J = 1.1, J = 1.1); 7.08 (dd, J = 1.1, J = 1.1); 7.61 (dd, J = 1.1, J = 1.1)	7.32 (dd, J = 8.2, J = 7.0); 7.38 (dd, J = 8.2, J = 7.0); 7.59 (d, J = 8.2); 8.08 (d, J = 8.2)	7.02 (d, J = 2.5); 7.10 (ddd, J = 8.1, J = 7.1, J = 1.1); 7.18 (ddd, J = 8.1, J = 7.1, J = 1.1); 7.34 (dddd.d, J = 8.1, J = 0.5, J = 0.5, J = 0.5), 7.81 (d, J = 8.0)	6.72 (d, J = 2.6); 7.10 (ddd, J = 8.1, J = 6.8, J = 1.1); 7.15 (ddd, J = 8.1, J = 7.5, J = 1.0); 7.20 (d, J = 7.9); 7.55 (d, J = 8.1)

* Chemical shifts for the overlapping multiplets determined from the 2D ^{13}C—^{1}H NMR experiments on direct couplings $^1J_{C-H}$ are given in brackets.

azole atom was detected. This is due apparently to the less steric hindrance upon formation of this product in contrast to the "normal" product. The specific behavior of α-pinene nitrosochloride associated with steric hindrance of the bicyclic pinane framework in the reactions with some nucleophiles is known. Thus, the reactions of

Table 4. ^{13}C NMR spectra ($CDCl_3$) of (+)-limonene derivatives **8**, **9**, **10a**, and **10b**

C Atom	δ_C			
	8	**9**	**10a**	**10b**
1	60.65	65.31	45.34	40.79
2	157.02	159.12	164.57	162.82
3	26.15	26.74	26.80	25.64
4	43.66	44.41	42.19	43.03
5	25.95	26.66	27.61	26.21
6	37.72	38.51	39.12	37.63
7	147.34	147.34	148.47	148.00
8	109.63	109.63	109.03	109.68
9	20.49	20.42	20.65	21.02
10	28.11	24.91	27.62	25.47

C Atom	δ_C			
	8	**9**	**10a**	**10b**
Ar	116.40 (d); 128.69 (d); 134.87 (d)	111.18 (d); 119.91 (d); 123.82 (d); 127.26 (d); 132.20 (s); 146.47 (s)	111.03 (d); 119.44 (d); 120.00 (s); 120.41 (d); 121.25 (d); 121.78 (d); 125.89 (s); 136.76 (s)	111.33 (d); 118.62 (d); 121.22 (d); 121.24 (d); 121.38 (s); 121.49 (d); 125.39 (s); 137.05 (s)

Table 5. ^{1}H NMR spectra of (−)-α-pinene derivatives **13**, **14a**, **14b**, and **15**

H Atom	δ_H (*J*/Hz)			
	13 (CCl_4—$CDCl_3$)	**14a** ($CDCl_3$—DMSO-d_6 (4 : 1, v/v))	**14b** ($CDCl_3$—DMSO-d_6 (4 : 1, v/v))	**15** (DMSO-d_6)
1	2.41 (dd, *J* = 5.5, *J* = 5.5)	2.81 (dd, *J* = 5.7, *J* = 5.7)	2.69 (dd, *J* = 5.7, *J* = 5.7)	2.55 (dd, *J* = 6.0, *J* = 6.0)
4 (*pro-R*)	3.02 (ddd, *J* = 18.8, *J* = 2.9, *J* = 2.6)	3.13 (ddd, *J* = 18.4, *J* = 3.0, *J* = 3.0)	3.11 (ddd, *J* = 18.2, *J* = 3.3, *J* = 3.3)	3.02 (ddd, (*J* = 18.5, *J* = 3.6, *J* = 2.8)
4 (*pro-S*)	2.57 (dd, *J* = 18.8, *J* = 2.6)	2.59 (dd, *J* = 18.4, *J* = 2.5)	2.63 (dd, *J* = 18.4, *J* = 2.2)	2.45 (dd, *J* = 18.5, *J* = 2.6)
5	2.03 (dddd, *J* = 6.3, *J* = 5.5, *J* = 2.9, *J* = 2.6)	2.01 (dddd, *J* = 5.8, *J* = 5.8, *J* = 3.3, *J* = 2.6)	1.97 (dddd, *J* = 5.9, *J* = 5.9, *J* = 3.3, *J* = 2.3)	1.86 (dddd, *J* = 5.8, *J* = 5.8, *J* = 3.2, *J* = 2.4)
7 (*pro-R*)	0.92 (d, *J* = 10.9)	0.50 (d, *J* = 10.5)	0.61 (d, *J* = 10.1)	0.94 (d, *J* = 10.5)
7 (*pro-S*)	2.31 (dddd, *J* = 10.9, *J* = 6.3, *J* = 6.3, *J* = 2.6)	2.05 (dddd, *J* = 10.5, *J* = 5.9, *J* = 5.9, *J* = 3.3)	2.00 (dddd, *J* = 10.1, *J* = 6.0, *J* = 6.0, *J* = 2.6)	1.98 (dddd, *J* = 10.5, *J* = 6.4, *J* = 6.4, *J* = 2.6)
8	1.01 (s)	1.02 (s)	0.99 (s)	0.98 (s)
9	1.37 (s)	1.31 (s)	1.29 (s)	1.27 (s)
10	1.73 (s)	2.09 (s)	2.04 (s)	1.70 (s)
=NOH	12.5 ($W_{1/2}$ = 700)	11.43 (br.s)	10.82 (br.s)	9.87 (br.s)
NH				10.08 (s)
Ar<u>H</u>	6.81 (dd, *J* = 1.1, *J* = 1.1); 6.99 (dd, *J* = 1.1, *J* = 1.1); 7.93 (dd, *J* = 1.1, *J* = 1.1)	7.27 (ddd, *J* = 8.5, *J* = 7.1, *J* = 1.0); 7.38 (ddd, *J* = 8.5, *J* = 6.9, *J* = 1.2); 7.50 (ddd, *J* = 8.7, *J* = 0.9, *J* = 0.9); 7.93 (ddd, *J* = 8.5, *J* = 0.9, *J* = 0.9)	7.26 (dd, *J* = 6.6, *J* = 3.0); 7.76 (dd, *J* = 6.6, *J* = 3.0)	6.80 (d, *J* = 2.6); 6.88 (ddd, *J* = 8.0, *J* = 7.2, *J* = 1.2); 6.98 (ddd, *J* = 8.0, *J* = 7.0, *J* = 1.0); 7.25 (ddd, *J* = 8.1, *J* = 0.8, *J* = 0.8); 7.58 (d, *J* = 8.0)

Table 6. ^{13}C NMR spectra of (−)-α-pinene derivatives **13**, **14a**, **14b**, and **15**

C Atom	δ_C (J_{C-H}/Hz)			
	13 (CCl_4—$CDCl_3$)	**14a** ($CDCl_3$—DMSO-d_6 (4 : 1, v/v))	**14b** ($CDCl_3$—DMSO-d_6 (4 : 1, v/v))	**15** (DMSO-d_6)
1	51.30	52.67 (*J* = 145.7)	53.13 (*J* = 148.9)	50.20
2	65.35	69.75	73.77	46.42
3	154.75	154.23	154.45	160.59
4	29.50	30.51 (2 C—H, *J* = 131.0)	29.41 (2 C—H, *J* = 130.8)	29.85
5	37.47	37.04 (*J* = 146.6)	37.34 (*J* = 143.5)	37.35
6	38.94	38.77	39.00	38.45
7	30.31	28.11 (2 C—H, *J* = 137.9)	27.76 (2 C—H, *J* = 140.3)	30.04
8	22.46	21.57 (3 C—H, *J* = 124.1)	21.42 (3 C—H, *J* = 124.4)	21.94
9	27.81	26.95 (3 C—H, *J* = 125.9)	27.00 (3 C—H, *J* = 125.4)	27.44
10	30.01	26.80 (3 C—H, *J* = 129.3)	26.59 (3 C—H, *J* = 130.0)	26.70
Ar	115.59 (d); 128.07 (d); 137.23 (d)	112.07 (d, *J* = 169.0); 119.12 (d, *J* = 163.8); 122.90 (d, *J* = 162.1); 126.55 (d, *J* = 162.1); 132.22 (s); 145.26 (s)	117.58 (d, 2 C, *J* = 165.5); 125.41 (d, 2 C, *J* = 160.1); 142.95 (s, 2 C)	111.10 (d); 117.54 (d); 120.06 (d); 120.13 (d); 122.52 (d); 123.62 (s); 124.57 (s); 136.84 (s)

nitrosochlorides of 3-carene and limonene with aniline gave the products of nucleophilic displacement of the chlorine to the amino group, while in the case of α-pinene nitrosochloride no products of such displacement formed.

Experimental

The following reactants were used: *S*-(−)-α-pinene (96% *ee*) (Fluka AG, cat. No. 80600), (*R*)-(+)-limonene (98% *ee*) (Ald-

rich, cat. No. 18.316-4), (+)-3-carene (≥99.5% *ee*) with $[\alpha]_{578}^{20}$ +16.0 (d_4^{20} = 0.863) obtained by distillation of turpentine of an ordinary pine; imidazole, benzotriazole, and indole (reagent grade, ReaKhim). Nitrosochlorides of (+)-3-carene and (−)-α-pinene were synthesized by passing gaseous nitrosyl chloride over a solution of terpene in dichloromethane.[1] *trans*-Nitrosochloride of *R*-(+)-limonene was prepared according to the standard procedure by treatment of a terpene solution with isoamyl nitrite.[1] All solvents were distilled prior to use. TLC were performed on an aluminum foil Sorbfil plates coated with silica gel. The spots were visualized by spaying the plates with developing solutions and further heating at 100—150 °C. The solutions of vanilin (1 g of vanilin + 5 mL of conc. H_2SO_4 + 100 mL of 95% EtOH) and iron chloride (10 g of $FeCl_3 \cdot 6H_2O$ + 100 mL of 95% EtOH) were used for the plates developing. The column chromatography was performed on a silica gel with the particle size 0.100—0.140 mm (grinding and fractionation were made in the Experimental Chemical Production of NIOCh SB RAS).

NMR spectra were recorded on a Bruker DRX-500 instrument (500.13 MHz for ^{1}H, 125.75 MHz for ^{13}C) for the solutions with concentrations 70—100 mg mL^{-1} at 25—27 °C. The solvent signals were used as internal standard: δ_H 7.24 and δ_C 76.90 for $CDCl_3$, δ_H 2.50 and δ_C 39.50 for DMSO-d_6. The signals were attributed using *J*-resolved ^{13}C NMR spectra (noise proton decoupling, the opposite phase for the signals of the atoms with even number of bonded protons with tuning on the constant J = 135 Hz), the homonuclear 2D ^{1}H—^{1}H and heteronuclear 2D ^{13}C—^{1}H NMR experiments on the direct couplings (J = 135 Hz) and heteronuclear 2D ^{13}C—^{1}H NMR experiments on the long-range couplings (J = 10 Hz). UV spectra were recorded on a HP 8453 UV/Vis spectrophotometer; IR spectra were run on a Bruker TENSOR 27 Fourier-transform IR spectrometer for the solutions in $CHCl_3$ (C = 0.5%) or in KBr pellets (C = 0.25%). Optical rotation was measured on a Polamat A polarimeter. Melting points were determined on a Koefler apparatus. Mass spectra were recorded on a Finnigan MAT-8200 mass spectrometer (EI, 70 eV). Elemental analyses were performed on Hewlett Packard 185 and Carlo Erba 1106 microanalysers.

Synthesis of imidazole derivatives 3, 8, and 13 (general procedure). To a solution of imidazole (1.36 g, 20 mmol) and NaOH (0.8 g, 20 mmol) in MeOH (50 mL), dimeric nitrosochloride of (+)-3-carene **2**, (+)-limonene **7** or (−)-α-pinene **12** (powdered, 2.00 g, 5 mmol) was added, and the reaction mixture was stirred at 30 °C for 15 h. The solvent was removed *in vacuo* (water-jet pump), the residue was mixed with water (30 mL), and extracted with EtOAc (3S30 mL). The combined organics were washed with brine (15 mL), dried with Na_2SO_4, and the solvent was removed *in vacuo*. Column chromatography (SiO_2, elution with hexane—EtOAc) and further recrystallization from MeCN afforded target product.

(1*R*,3*S*,6*R*)-3-(1*H*-Imidazol-1-yl)carnan-4-one (*E*)-oxime (3). Yield 50%, colorless crystals, m.p. 140—142 °C (from MeCN), $[\alpha]_{578}^{18}$ +181 (*c* 1.79, MeOH). Found (%): C, 66.6; H, 8.49; N, 17.7. $C_{13}H_{19}N_3O$. Calculated (%): C, 66.92; H, 8.21; N, 18.01. High resolution MS: found, m/z 233.15372 $[M]^+$. $C_{13}H_{19}N_3O$. Calculated: M = 233.15281. MS, m/z (I_{rel} (%)): 233 (17), 216 (10), 165 (28), 164 (100), 150 (15), 148 (13), 137 (30), 123 (16), 106 (23), 79 (23), 69 (77). IR ($CHCl_3$), ν/cm^{-1}: 3582 (O—H). IR (KBr), ν/cm^{-1}: 1636 (C=N), 980—920 (N—O).

(1*S*,4*R*)-1-(1*H*-Imidazol-1-yl)-*p*-menth-7-ene-2-one (*E*)-oxime (8). Yield 40%, colorless crystals, m.p. 160—162 °C (from MeCN), $[\alpha]_{578}^{18}$ +125 (*c* 2.64, MeOH). Found (%): C, 66.9; H, 8.58; N, 17.6. $C_{13}H_{15}N_3O$. Calculated: (%): C, 66.92; H, 8.21; N, 18.01. High resolution MS: found, m/z 233.15273 $[M]^+$. $C_{13}H_{19}N_3O$. Calculated: M = 233.15281. MS, m/z (I_{rel} (%)): 233 (17.08), 166 (10), 110 (15), 107 (19), 93 (22), 79 (14), 69 (100), 67 (10), 55 (17). IR ($CHCl_3$), ν/cm^{-1}: 3581 (O—H). IR (KBr), ν/cm^{-1}: 1641 (C=CH_2), 963 (N—O), 897 (C=CH_2).

(1*R*,2*R*,5*R*)-2-(1*H*-Imidazol-1-yl)pinan-3-one (*E*)-oxime (13). Yield 30%, colorless crystals, m.p. 172—173 °C (from MeCN), $[\alpha]_{578}^{18}$ −175 (*c* 2.17, MeOH). Found (%): C, 67.1; H, 8.65; N, 17.6. $C_{13}H_{19}N_3O$. Calculated (%): C, 66.92; H, 8.21; N, 18.01. High resolution MS: found, m/z 233.15378 $[M]^+$; $C_{13}H_{19}N_3O$. Calculated: M = 233.15281. MS, m/z (I_{rel} (%)): 233 (19.37), 166 (38), 165 (20), 124 (21), 110 (97), 107 (17), 106 (38), 79 (28), 69 (100), 53 (20). IR ($CHCl_3$), ν/cm^{-1}: 3580 (O—H). IR (KBr), ν/cm^{-1}: 1638 (C=N), 925 (N—O).

Synthesis of benzotriazole derivatives 4, 9, and 14 (general procedure). To a solution of benzotriazole (1.79 g, 15 mmol) in MeOH (50 mL), $Mg(ClO_4)_2$ (1.85 g, 15 mmol), K_2CO_3 (4.14 g, 30 mmol), and dimeric nitrosochloride of (+)-3-carene **2**, (+)-limonene **7** or (−)-α-pinene **12** (powdered, 2.00 g, 5 mmol) were added, and the reaction mixture was stirred at 35 °C for 10 h. The solvent was removed *in vacuo* (water-jet pump), the residue was mixed with water (30 mL) and extracted with EtOAc (3S30 mL). The combined organics were washed with brine (15 mL), dried with Na_2SO_4, and concentrated *in vacuo*. Purification of the residue (SiO_2, elution with hexane—EtOAc) and further recrystallization from MeCN afforded target products.

(1*R*,3*S*,6*R*)-3-(1*H*-Benzo[*d*][1,2,3]triazol-1-yl)caran-4-one (*E*)-oxime (4). Yield 47%, colorless crystals, m.p. 154—155 °C (decomp., from MeCN), $[\alpha]_{578}^{14}$ +116 (*c* 1.50, MeOH). Found (%): C, 67.2; H, 7.17; N, 19.8. $C_{16}H_{20}N_4O$. Calculated (%): C, 67.58; H, 7.09; N, 19.70. High resolution MS: found, m/z 284.16379 $[M]^+$. $C_{16}H_{20}N_4O$. Calculated: M = 284.16371. MS, m/z (I_{rel})): 284 (100), 267 (20), 150 (21), 148 (52), 120 (41), 91 (18), 78 (12), 77 (26), 69 (19), 41 (29). UV (EtOH), λ_{max}/nm (lg ε): 257 (3.84), 262 (3.83), 281 (3.62). IR ($CHCl_3$), ν/cm^{-1}: 3581 (O—H). IR (KBr), ν/cm^{-1}: 1632 (C=N), 957 (N—O), 750 (H—Ar).

(1*S*,4*R*)-1-(1*H*-Benzo[*d*][1,2,3]triazol-1-yl)-*p*-menth-7-ene-2-one (*E*)-oxime (9). Yield 50%, colorless crystals, m.p. 154—155 °C (decomp., from MeCN), $[\alpha]_{578}^{14}$ +134 (*c* 1.91, MeOH). Found (%): C, 67.3; H, 7.35; N, 19.3. $C_{16}H_{20}N_4O$. Calculated (%): C, 67.58; H, 7.09; N, 19.70. High resolution MS: found, m/z 284.16341 $[M]^+$. $C_{16}H_{20}N_4O$. Calculated: M = 284.16371. MS, m/z (I_{rel} (%)): 284 (2), 269 (27), 120 (21), 91 (11), 78 (12), 77 (10), 72 (37), 71 (34), 43 (24), 42 (100). UV (EtOH), λ_{max}/nm (lg ε): 256 (3.86), 262 (3.85), 281 (3.66). IR ($CHCl_3$), ν/cm^{-1}: 3582 (O—H). IR (KBr), ν/cm^{-1}: 1645 (C=CH_2), 958 (N—O), 896 (=CH_2), 748 (H—Ar).

(1*R*,2*R*,5*R*)-2-(1*H*-Benzo[*d*][1,2,3]triazol-1-yl)pinan-3-one (*E*)-oxime (14a). Yield 40%, colorless crystals, m.p. 154—155 °C (decomp., from MeCN), $[\alpha]_{578}^{14}$ −138 (*c* 1.37, MeOH). Found (%): C, 67.2; H, 7.17; N, 19.8. $C_{16}H_{20}N_4O$. Calculated (%): C, 67.58; H, 7.09; N, 19.70. High resolution MS: found, m/z 284.16379 $[M]^+$. $C_{16}H_{20}N_4O$. Calculated: M = 284.16371. MS, m/z (I_{rel})): 284 (100), 267 (20), 150 (21), 148 (52), 120 (41), 91 (18), 78 (12), 77 (26), 69 (19), 41 (29). UV (EtOH), λ_{max}/nm (lg ε): 257 (3.82), 263 (3.81), 282 (3.60). IR ($CHCl_3$), ν/cm^{-1}: 3581 (O—H). IR (KBr), ν/cm^{-1}: 1611 (C=N), 976 (N—O), 750 (H—Ar).

(2*H*-Benzo[*d*][1,2,3]triazol-2-yl)pinan-3-one (*E*)-oxime (14b). Yield 7%, colorless crystals, m.p. 154—155 °C (decomp., from MeCN), $[\alpha]_{578}^{14}$ −21.3 (*c* 0.66, MeOH). Found (%): C, 67.2; H, 7.17; N, 19.8. $C_{16}H_{20}N_4O$. Calculated (%): C, 67.58; H, 7.09; N, 19.70. High resolution MS: found, *m/z* 284.16373 $[M]^+$. $C_{16}H_{20}N_4O$. Calculated: *M* = 284.16371. MS, *m/z* (I_{rel} (%)): 284 (100), 267 (20), 150 (21), 148 (52), 120 (41), 91 (18), 78 (12), 77 (26), 69 (19), 41 (29). UV (EtOH), λ_{max}/nm (lg ε): 268 sh (4.04), 275 sh (4.14), 279 (4.17), 285 sh (4.10). IR ($CHCl_3$), ν/cm^{-1}: 3582 (O—H). IR (KBr), ν/cm^{-1}: 1620 (C=N), 971 (N—O), 760 (H—Ar).

Synthesis of indole derivatives 5, 10, and 15 (general procedure). To a solution of indole manganese salt (obtained from indole (2.34 g, 20 mmol) and EtMgBr (20 mmol) in Et_2O (50 mL)), dimeric nitrosochloride of (+)-3-carene **2**, (+)-limonene **7** or (−)-α-pinene **12** (powdered, 2.00 g, 5 mmol) was added, the reaction mixture was stirred at 15 °C for 10 h under nitrogen. The solvent was removed *in vacuo* (water-jet pump), the residue was mixed with 5% aqueous NH_4Cl (30 mL) and extracted with EtOAc (3S30 mL). The combined organics were washed with brine (15 mL), dried with Na_2SO_4, and concentrated *in vacuo*. Chromatography of the reddish oily residue (Al_2O_3, elution with CCl_4—methyl *tert*-butylate) afforded target product.

(1*R*,3*S*,6*R*)-3-(1*H*-Indol-3-yl)caran-4-one (*E*)-oxime (5). Yield 60%, yellowish crystals, m.p. 183—184 °C (from C_6H_6), $[\alpha]_{578}^{23}$ +131 (*c* 0.86, MeOH). Found (%): C, 76.7; H, 7.99; N, 9.52. $C_{18}H_{22}N_2O$. Calculated (%): C, 76.56; H, 7.85; N, 9.92. High resolution MS: found, *m/z* 282.17323 $[M]^+$. $C_{18}H_{22}N_2O$. Calculated: *M* = 282.17321. MS, *m/z* (I_{rel} (%)): 282 (4), 267 (43), 265 (46), 213 (36), 211 (55), 195 (18), 184 (100), 169 (31), 157 (11), 154 (16), 143 (44), 130 (34), 117 (30), 41 (17). IR ($CHCl_3$), ν/cm^{-1}: 3583 (O—H), 3480 (N—H). IR (KBr), ν/cm^{-1}: 1618 (C=N), 935 (N—O), 744 (H—Ar).

(1*R*,4*R*)-1-(1*H*-Indol-3-yl)-*p*-menth-7-ene-2-one (*E*)-oxime (10a). Yield 40%, yellowish crystals, m.p. 165—167 °C (from CCl_4), $[\alpha]_{578}^{14}$ +153 (*c* 0.89, MeOH). Found (%): C, 76.2; H, 7.80; N, 9.65. $C_{18}H_{22}N_2O$. Calculated (%): C, 76.56; H, 7.85; N, 9.92. High resolution MS: found, *m/z* 282.17294 $[M]^+$. $C_{18}H_{22}N_2O$. Calculated: *M* = 282.17321. MS, *m/z* (I_{rel} (%)): 282 (100), 264 (30), 265 (45), 249 (5), 170 (25), 142 (20), 130 (50), 117 (60), 105 (20), 43 (20), 41 (35). IR ($CHCl_3$), ν/cm^{-1}: 3583 (O—H), 3480 (N—H). IR (KBr), ν/cm^{-1}: 1644 (C=CH_2), 922 (N—O), 893 (=CH_2), 745 (H—Ar).

(1*S*,4*R*)-1-(1*H*-Indol-3-yl)-*p*-menth-7-ene-2-one (*E*)-oxime (10b). Yield 10%, colorless crystals, m.p. 165—167 °C (from MeCN), $[\alpha]_{578}^{15}$ +114 (*c* 3.03, MeOH). Found (%): C, 76.6; H, 7.50; N, 9.52. $C_{18}H_{22}N_2O$. Calculated (%): C, 76.56; H, 7.85; N, 9.92. High resolution MS: found, *m/z* 282.17388 $[M]^+$. $C_{18}H_{22}N_2O$. Calculated: *M* = 282.17321. MS, *m/z* (I_{rel} (%)): 282 (100), 267 (33), 265 (55), 182 (10), 170 (27), 165 (10), 148 (16), 118 (45), 117 (50), 115 (22), 43 (50), 41 (14). IR ($CHCl_3$), ν/cm^{-1}: 3582 (O—H), 3479 (N—H). IR (KBr), ν/cm^{-1}: 1645 (C=CH_2), 936 (N—O), 890 (=CH_2), 745 (H—Ar).

(1*R*,2*R*,5*R*)-2-(1*H*-Indol-3-yl)pinan-3-one (*E*)-oxime (15). Yield 54%, colorless crystals, m.p. 211—212 °C (from $CHCl_3$), $[\alpha]_{578}^{13}$ −92 (*c* 1.87, THF). Found (%): C, 76.8; H, 7.99; N, 9.62. $C_{18}H_{22}N_2O$. Calculated (%): C, 76.56; H, 7.85; N, 9.92. High resolution MS: found, *m/z* 282.17319 $[M]^+$. $C_{18}H_{22}N_2O$. Calculated: *M* = 282.17321. MS, *m/z* (I_{rel} (%)): 282 (4), 267 (43), 265 (46), 213 (36), 211 (55), 195 (18), 184 (100), 169 (31), 157 (11), 154 (16), 143 (44), 130 (34),117 (30), 41 (17). IR ($CHCl_3$), ν/cm^{-1}: 3582 (O—H), 3480 (N—H). IR (KBr), ν/cm^{-1}: 1618 (C=N), 935 (N—O), 741 (H—Ar).

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