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Synthesis and Dehydration of *endo*-2-(3-R-Isoxazol-5-yl)-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-2-ols

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Abstract—*endo*-2-Ethynyl-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-2-ol reacts with nitrile oxides, yielding *endo*-2-(3-R-isoxazol-5-yl)-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-2-ols. Treatment of the latter with methanesulfonyl chloride in pyridine leads to dehydration and formation of mixtures of the corresponding 1-(3-R-isoxazol-5-yl)-3,3-dimethyl-2-methylenebicyclo[2.2.1]heptanes and 2-(3-R-isoxazol-5-yl)-1,7,7-trimethylbicyclo[2.2.1]hept-2-enes at a ratio of 2:1.

In the last decades terpenoid compounds with a bicyclo[2.2.1]heptane skeleton have received application in the synthesis of biologically active substances and their precursors. Researcher's interest is stimulated by the possibility of obtaining enantiomerically pure products on the basis of optically active initial compounds and by the fact that compounds possessing a natural terpene skeleton well "fit" a number of biochemical processes in living bodies [1–3].

We previously developed a procedure for preparation of carbocyclic analogs of prostaglandin endoperoxides (PGH) on the basis of bicyclo[2.2.1]heptene using the nitrile oxide technique. The PGH analogs thus obtained showed high pharmacological activity [4, 5]. In continuation of our studies on synthons for prostaglandins, the present communication describes a new approach to prostanoids starting from camphor. We examined the possibility for introducing prostaglandin side chains into the camphor molecule by the nitrile oxide (isoxazole) technique. The initial compound was *endo*-2-ethynyl-1,7,7-trimethylbicyclo-[2.2.1]hept-*exo*-2-ol (**II**) which was in turn prepared by the action of lithium acetylide on camphor (**I**) [6]. 1,3-Dipolar cycloaddition of nitrile oxides, generated *in situ* from the corresponding nitroso compounds and phenyl isocyanate in the presence of a catalytic amount of triethylamine, to the triple bond of **II** regioselectively yielded isoxazole derivatives **IIIa** and **IIIb** (Scheme 1). The structure of products **IIIa** and **IIIb** was confirmed by spectral data. Their IR spectra contained a band at 1600 cm^{-1} belonging to stretching vibrations of the C=N bond in the isoxazole ring; compound **IIIb** also showed in the spectrum ester carbonyl band at 1746 cm^{-1}. In the ^1H NMR spectra of **IIIa** and **IIIb** protons of the bicyclo[2.2.1]heptane skeleton, located in the vicinity of the isoxazole ring, suffer its anisotropic effect. As a result, the chemical shifts of the *endo*- and *exo*-protons show considerable differences, which facilitate interpretation of the spectral data. In the ^1H NMR spectrum of initial alcohol **I** signals from four protons at C^5 and C^6 appear in a weaker field than those from the methyl protons. In the spectrum of isoxazolyl derivative **IIIa** the most upfield signal is that from the *endo*-6-H proton which is located most closely to the heteroring (δ 0.78 ppm, d.d.d, ^2J = 12.5 Hz, $^3J_{endo,endo}$ = 8.5 Hz, $^3J_{exo,endo}$ = 4.0 Hz). The *endo*-5-H signal is also displaced upfield (δ 1.12 ppm) and is overlapped by the 7-CH_3 signals. By contrast, the *endo*-3-H signal is located in a weaker field (δ 2.12 ppm), as compared to alclhol **I** (δ 1.87 ppm), for it falls into the area deshielded by the oxazole ring. These data indicate that the heteroring lies in the plane formed by the C^2-C^3, C^3-*endo*-H, and $C^2-C^{5'}$ bonds. Just this orientation of the heterocycle is consistent with shielding of the *endo*-6-H proton and, to a lesser extent, of *endo*-5-H [7]. The *exo*-3-H proton gives a doublet of triplets at δ 2.24 ppm; the coupling con-

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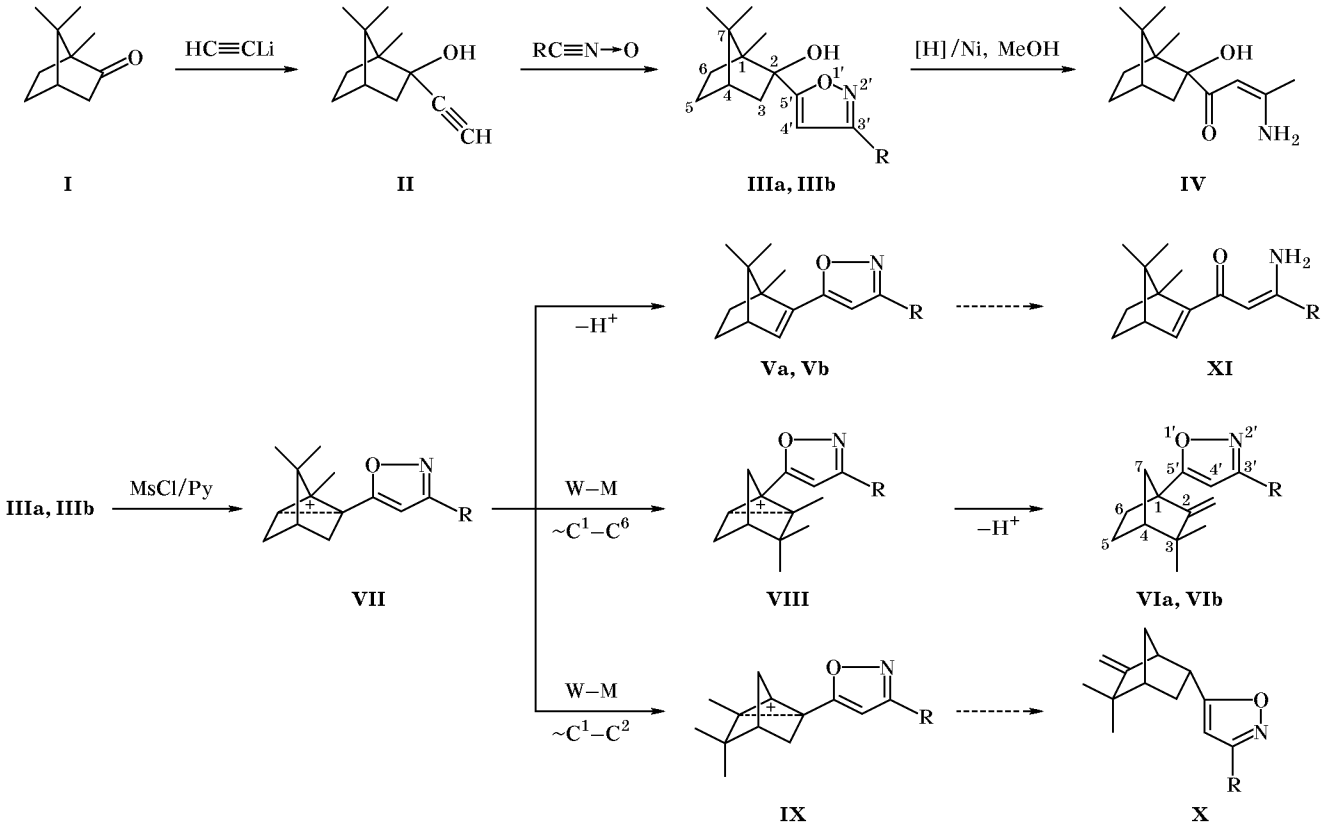
Scheme 1.



R = CH_3 (**a**), $MeOCOCH_2CH_2$ (**b**).

stant 13.5 Hz corresponds to geminal interaction with *endo*-3-H (δ 2.12 ppm), and two constants equal to 4.0 Hz characterize vicinal coupling with 4-H (triplet at δ 1.86 ppm) and *syn*-periplanar interaction with the hydroxy proton. The small difference in the chemical shifts of protons on C^3 makes the pattern similar to that typical of an *AB* spin system.

The isoxazole ring in compounds **IIIa** and **IIIb** can be converted into open chain by one of the known methods. For example, catalytic hydrogenation of **IIIa** (R = CH_3) over Raney nickel in methanol leads to formation of enaminoketone **IV**. The IR spectrum of **IV** contains absorption bands at 3380 and 3200 cm^{-1} typical of the amino group and a band at 1620 cm^{-1}, which belongs to stretching vibrations of the conjugated ketone carbonyl group. In the ^1H NMR spectrum of **IV** we observed a signal at δ 5.36 ppm from the side-chain olefinic proton and two broadened singlets at δ 5.23 and 9.85 ppm, which arise from the chelated and free protons of the amino group. Thus, one prostaglandin side chain can be attached to the bicyclic camphor skeleton via isoxazole technique. In this case, the structure of the initial nitrile oxide determines functionalities of the resulting side chain.

We presumed that the second side chain can be built up through intermediate 1,7,7-trimethylbicyclo-[2.2.1]hept-2-enes in which the endocyclic double bond is highly reactive due to considerable strain of the bicyclic skeleton. It is known that direct dehydration of bornane alcohols is generally accompanied by the Wagner–Meerwein rearrangement with formation of olefins with a semicyclic double bond [8–11]. As we showed in [6], alcohol **II** in acid medium also undergoes a multistep skeletal rearrangement.

Transformation of an initial bicyclic alcohol into a derivative containing a good leaving group, such as methanesulfonate, *p*-toluenesulfonate, etc., which can be removed by the action of bases in some cases allows one to avoid acid catalysis and hence undesirable skeletal rearrangement. However, our attempt to obtain the corresponding methanesulfonate from *endo*-2-ethynyl derivative **II** under standard conditions resulted in tarring.

By contrast, treatment of isoxazolyl-substituted compounds **IIIa** and **IIIb** with methanesulfonyl chloride in pyridine caused their direct dehydration without formation of the corresponding methanesulfonates. We thus isolated mixtures of 2-isoxazolyl-1,7,7-trimethylbicyclo[2.2.1]hept-2-enes **Va** and **Vb** and rearranged products with a semicyclic double bond, 1-(3-R-isoxazol-5-yl)-3,3-dimethyl-2-methylenebicyclo[2.2.1]heptanes **VIa** and **VIb**; the product ratio **V**:**VI** was 1:2. They were separated by column chromatography on silica gel (see Experimental).

The structure of compounds **V** and **VI** was derived from the IR, ^{1}H NMR, and mass spectra. The IR spectrum of **Va** lacked a band assignable to stretching vibrations of hydroxy group (3450 cm^{-1}) but contained bands at 3140 and 3080 cm^{-1} typical of vibrations of olefinic C–H bonds and a band at 1650 cm^{-1} characteristic of endocyclic double bond. The molecular ion peak M^+ (*m*/*z* 217) in the mass spectrum of **Va** had an intensity of 18% relative to the base peak. In the ^{1}H NMR spectrum, the 4′-H proton of the isoxazole ring appeared as a singlet at δ 6.0 ppm. A three-proton singlet at δ 2.27 ppm was assigned to the methyl group attached to the heteroring, and a doublet at δ 6.62 ppm, to the olefinic 3-H proton in the bicyclic core. The observed coupling constant J = 4.0 corresponds to interaction between 3-H and 4-H. The positions and multiplicities of the other signals are consistent with the bornane structure (see Experimental).

In the IR spectrum of compound **VIa** we observed bands at 1615 cm^{-1} due to stretching vibrations of the C=N bond in the isoxazole ring and at 1670 cm^{-1} from the exocyclic C=C bond. The mass spectrum of **VIa** contained the molecular ion peak M^+, *m*/*z* 217 (I_{rel} 25%). Singlets at δ 5.90 ppm (1H) and 2.28 ppm (3H) in the ^{1}H NMR spectrum were assigned to the olefinic (4′-H) and 3′-CH_3 protons of the isoxazole ring (see above). Two singlets at δ 4.67 and 5.51 ppm belong to the exocyclic methylene protons. Two geminal methyl groups on C^3 give a six-proton singlet at δ 1.14 ppm. A doublet at δ 2.04 ppm (J = 4.0 Hz) corresponds to the 4-H proton in the bridgehead position; its multiplicity (only one vicinal coupling constant) suggests the presence of only one *exo*-proton on the adjacent carbon atoms. The multiplicities of signals located at δ 2.22 (d.q) and 1.60 ppm (d.d) are typical of the bridging C^7H_2 moiety. The coupling constant equal to 11.0 Hz corresponds to geminal *syn*–*anti*-interaction. The *syn*-7-H proton (δ 2.22 ppm) also shows three small coupling constants (1.5–1.8 Hz) characterizing its iteraction with 4-H and *W*-coupling with *endo*-oriented protons. The absence of a signal from proton at the second bridgehead carbon atom, as well as of a signal typical of a proton neighboring to isoxazole ring (δ 3.4–3.5 ppm), indicates that the heteroring is attached to C^1. The other protons (5-H and 6-H) give a four-proton multiplet at δ 1.64–2.02 ppm. This spectral pattern is consistent only with structure **VIa**.

Likewise, the IR, ^{1}H NMR, and mass spectra support the structure of products **Vb** and **VIb** obtained by reaction of *endo*-2-[3-(2-methoxycarbonylethyl)-isoxazol-5-yl]-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-2-ol (**IIIb**) with methanesulfonyl chloride (see Experimental). A possible mechanism of formation of compounds **V** and **VI** is shown in Scheme 1.

Taking into account that steric structure of initial alcohol **III** does not favor formation of the corresponding *O*-methylsulfonyl derivative, methanesulfonyl chloride is likely to act as a weak Lewis acid which promotes elimination of the hydroxy group from **III** to give nonclassical carbocation **VII**. The latter can be stabilized through elimination of proton, yielding bornene derivative **V**. Another pathway is Wagner–Meerwein rearrangement (W–M) of cation **VII**, which is accompanied by cleavage of the C^1–C^6 bond; proton abstraction from cation **VIII** yields compound **VI** with bulky isoxazolyl substituent in the bridgehead position. This result is surprising, for the alternative Wagner–Meerwein rearrangement involving cleavage of the C^1–C^2 bond could give cation **IX** and then (via proton elimination) compound **X** with more spatially favorable arrangement of the isoxazole group. However, no product **X** was detected in the reaction mixture. This may be associated with a specific steric structure of the transition state. Cleavage of the C^1–C^2 bond implies 6,2-hydride shift; in this case, the isoxazole ring in cation **IX** would appear in the *pseudoendo* position so that the conjugation between the heteroring and the cation would be lost. Hence cation **IX** should be less stable than **VIII**, and the reaction follows the pathway involving formation of thermodynamically more stable species, leading to product **VI**.

The formation of an analogous product was observed in the dehydration of structurally related *endo*-2-phenylisoborneol [12]; here, the only product was 1-phenylcamphene (3,3-dimethyl-2-methylene-1-phenylbicyclo[2.2.1]heptane). The formation of bornene derivatives **V** with endocyclic double bond in such reactions was observed by us for the first time.

Presumably, the determining factor is the nature of the catalyst. Insofar as elimination of hydroxy group by the action of a weak Lewis acid is a slow process, bornene **V** is likely to be formed by transformation of the primary polarized complex of the alcohol with methanesulfonyl chloride rather than by stabilization of ion **VII** as shown in Scheme 1.

Thus we have synthesized two kinds of bicyclo-[2.2.1]heptane derivatives containing both double bond and isoxazole ring. Compounds **Va** and **Vb** can be converted into prostanoids by previously known methods: opening of the isoxazole ring in such products will give rise to compounds **XI** in which the endocyclic double bond is activated due to conjugation with the side-chain carbonyl group. The second prostanoid side chain can readily be introduced, e.g., by Michael addition.

As concerns compounds **VIa** and **IVb**, opening of the isoxazole ring will lead to products in which one side chain is attached to the bridgehead carbon atom Moreover, the exocyclic double bond in **VIa** and **IVb** is not conjugated with the heteroring; therefore, it may be difficult to transform the double bond into the second prostanoid side chain using previously developed procedures. Nevertheless, the methylene group and isoxazole ring in **VI** are attached to the neighboring carbon atoms, and they can be regarded as potential precursors of vicinal prostaglandin chains, but the transformation of compounds **VI** into PG analogs requires development of synthetic approaches which may be different from those currently used in the synthesis of prostanoids.

EXPERIMENTAL

The ^{1}H NMR spectra were recorded on a Bruker AC-200 spectrometer (200 MHz) in $CDCl_3$. The IR spectra (films) were obtained on a UR-20 instrument. The mass spectra were run on a Hewlett–Packard 5890–5972 GC–MS system (electron impact, 70 eV, HP-5 column). The progress of reactions was monitored, and the purity of products was checked, by TLC on Silufol UV-254 plates (Serva). Column chromatography was performed on silica gel 100/160 μ (Czechia). Kieselgel L 5/40 μ applied to glass plates was used for preparative thin-layer chromatography; eluent hexane–ether, 1:1.

***endo*-2-Ethynyl-1,7,7-trimethylbicyclo[2.2.1]-heptan-*exo*-2-ol (II)** was synthesized by reaction of camphor with lithium acetylide according to [7]. mp. 92–94°C. IR spectrum, ν, cm^{-1}: 3450 (OH); 3310 (≡C−H); 2950, 2930, 2820 (C−H, aliph.); 2100 v.w (C≡C). ^{1}H NMR spectrum, δ, ppm: 0.88 s (3H, 1-CH_3), 0.96 s (3H, *anti*-7-CH_3), 1.06 s (3H, *syn*-7-CH_3), 1.14 d.d.d (1H, *endo*-6-H, ^2J = 12.5, $^3J_{endo,endo}$ = 8.5, $^3J_{endo,exo}$ = 5.0 Hz), 1.50 d.d.d (1H, *exo*-6-H, ^2J = 12.5, $^3J_{exo,exo}$ = 11.0, $^3J_{exo,endo}$ = 5.0 Hz), 1.73 m (2H, 5-H), 1.78 t (1H, 4-H, ^3J = 4.5 Hz), 1.87 d (1H, *endo*-3-H, ^2J = 13.0 Hz), 1.98 br.s (OH), 2.24 d.t (1H, *exo*-3-H, ^2J = 13.0, $^3J_{3,4}$ = 4.5, $J_{3,OH}$ = 4.5 Hz), 2.46 s (1H, C≡CH). Mass spectrum, *m*/*z*: 178 (M^+, I_{rel} 7%), 163, 145, 135, 122, 117, 110 (100%), 95, 55, 41.

1,7,7-Trimethyl-*endo*-2-(3-methylisoxazol-5-yl)-bicyclo[2.2.1]heptan-*exo*-2-ol (IIIa) and *endo*-2-[3-(2-methoxycarbonylethyl)isoxazol-5-yl]-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-ol (IIIb). Triethylamine, 1 ml, was added to a mixture of 0.01 mol of acetylenic alcohol **II**, 0.01 mol of nitroethane or methyl 4-nitrobutanoate, and 0.01 mol of phenyl isocyanate in 50 ml of dry benzene. After 10 min, a solid precipitated. The mixture was stirred for 24 h at room temperature, the precipitate was filtered off, and the filtrate was evaporated under reduced pressure. The product was isolated by column chromatography on silica gel.

Compound **IIIa**. Yield 0.21 g (85%). Colorless crystals, mp. 101–103°C. IR spectrum, ν, cm^{-1}: 3500 (OH); 3140 (C−H, olefin.); 2960, 2880 (C−H, aliph.); 1595 (C=N). ^{1}H NMR spectrum, δ, ppm: 0.78 d.d.d (1H, *endo*-6-H, ^2J = 12.5, $^3J_{endo,endo}$ = 8.5, $^3J_{endo,exo}$ = 4.0 Hz), 0.90 s (3H, 1-CH_3), 1.06 s (3H, *anti*-7-CH_3), 1.12 m (1H, *endo*-5-H; the signal is overlapped by those of the neighboring methyl groups), 1.18 s (3H, *syn*-7-CH_3), 1.34 d.d.d (1H, *exo*-6-H, ^2J = 12.5, $^3J_{exo,exo}$ = 11.0, $^3J_{endo,exo}$ = 4.0 Hz), 1.72 m (1H, *exo*-5-H, ^2J = 12.5, $^3J_{exo,exo}$ = 11.0, $^3J_{endo,exo}$ = $^3J_{4,5}$ = 4.0 Hz), 1.86 t (1H, 4-H, ^3J = 4.0 Hz), 2.12 d (1H, *endo*-3-H, ^2J = 13.5 Hz), 2.24 d.t (1H, *exo*-3-H, ^2J = 13.5, $^3J_{3,4}$ = $^3J_{3,OH}$ = 4.0 Hz), 2.28 s (3H, 3′-CH_3), 2.46 br.s (OH), 6.01 s (1H, 4′-H). Mass spectrum, *m*/z: 235 (M^+, I_{rel} 10%), 218, 208, 160, 148, 146, 119, 105, 93, 91, 77, 65, 53, 49.

Compound **IIIb** was isolated as a viscous oily substance, yield 85%. IR spectrum, ν, cm^{-1}: 3500 (OH); 3140 (C−H, olefin.); 2960, 2920, 2880 (C−H, aliph.); 1745 (C=O); 1600 (C=N); 1590 (C=C). ^{1}H NMR spectrum, δ, ppm: 0.78 d.d.d (1H, *endo*-6-H, ^2J = 12.5, $^3J_{endo,endo}$ = 8.5, $^3J_{endo,exo}$ = 4.0 Hz), 0.88 s (3H, 3-CH_3), 1.06 s (3H, *anti*-7-CH_3), 1.12 m (1H, *endo*-5-H; the signal is overlapped by those of the

neighboring methyl groups), 1.18 s (3H, *syn*-7-CH_3), 1.34 d.d.d (1H, *exo*-6-H, ^2J = 12.5, $^3J_{exo,exo}$ = 11.0, $^3J_{endo,exo}$ = 4.0 Hz), 1.72 m (1H, *exo*-5-H, ^2J = 12.5, $^3J_{exo,exo}$ = 11.0, $^3J_{endo,exo}$ = $^3J_{5,4}$ = 4.0 Hz), 1.84 t (1H, 4-H, J = 4.0 Hz), 2.12 d (1H, *endo*-3-H, ^2J = 13.5 Hz), 2.24 d.t (1H, *exo*-3-H, ^2J = 13.5, $^3J_{3,4}$ = $^3J_{3,OH}$ = 4.0 Hz), 2.50 br.s (OH), 2.74 t (2H, CH_2, ^3J = 7.0 Hz), 3.01 t (2H, CH_2, ^3J = 7.0 Hz), 3.70 s (3H, CH_3O), 6.01 s (1H, 4′-H). Mass spectrum, *m*/*z*: 313 (M^+, I_{rel} 11%), 296, 286, 266, 236, 208, 148, 146, 119, 105, 93, 91, 77, 65, 53, 49.

***endo*-2-[(2*Z*)-3-Amino-1-oxo-2-butenyl]-1,7,7-trimethylbicyclo[2.2.1]heptan-*exo*-2-ol (IV).** A solution of 0.165 g (0.0007 mol) of isoxazole derivative **IIIa** in 20 ml of methanol was added to 0.25 g of Raney nickel wetted with methanol. The mixture was stirred in a hydrogen atmosphere; the progress of the reaction was monitored by TLC, following the disappearance of the initial isoxazole derivative. The solution was separated by decanting, the catalyst was washed with methanol, and the solvent was distilled off under reduced pressure. Hydroxyenaminoketone **IV** was isolated as a viscous oil. Yield 0.158 g (95%). IR spectrum, ν, cm^{-1}: 3380, 3200 (NH); 2960, 2920 (C−H, aliph.); 1620 (C=O); 1530 (C=C). ^{1}H NMR spectrum, δ, ppm: 0.86 s (6H, 1-CH_3, *anti*-7-CH_3), 1.14 s (3H, *syn*-7-CH_3), 1.18–2.46 m (6H), 2.0 s (3H, C=CCH_3), 5.23 br.s (1H, NH), 5.36 s (1H, C=CH), 8.94 s (1H, OH), 9.85 br.s (1H, NH). Mass spectrum, *m*/*z*: 237 (M^+, I_{rel} 8%), 220, 210, 160, 148, 146, 119, 105, 93, 91, 77, 65, 53, 49.

Reaction of isoxazolyl derivatives IIIa and IIIb with methanesulfonyl chloride. Methanesulfonyl chloride, 1.2 mmol, was added to 1 mmol of compound **IIIa** or **IIIb** in 8 ml of pyridine. A solid precipitated from the solution. The mixture was stirred for 24 h. The formation of two products was observed by TLC. The solvent was removed under reduced pressure, and the products were separated by preparative thin-layer chromatography on silica gel using 1:1 hexane–ether as eluent.

1,7,7-Trimethyl-2-(3-methylisoxazol-5-yl)bicyclo-[2.2.1]hept-2-ene (Va) and 3,3-dimethyl-2-methylene-1-(3-methylisoxazol-5-yl)bicyclo[2.2.1]heptane (VIa) were isolated in an overall yield of 65% (ratio 1:2). Compound **Va**. IR spectrum, ν, cm^{-1}: 3140, 3080 (C−H, olefin.); 2965, 2935, 2880 (C−H, aliph.); 1630 (C=N, C=C). ^{1}H NMR spectrum, δ, ppm: 0.84 s (6H, 1-CH_3, *anti*-7-CH_3), 1.22 s (3H, *syn*-7-CH_3), 1.62–2.02 m (4H), 2.27 s (3H, CH_3), 2.46 t (1H, 4-H, ^3J = 4.0 Hz), 6.00 s (1H, 4′-H), 6.60 d (1H, 3-H, ^3J = 4.0 Hz). Mass spectrum, *m*/*z* (I_{rel}, %): 217 (M^+, 18), 202, 188, 175, 174 (100), 160, 148, 146, 119, 105, 93, 91, 77, 65, 53, 49.

Compound **VIa**. IR spectrum, ν, cm^{-1}: 3140, 3080 (C−H, olefin.); 2970, 2940, 2885 (C−H, aliph.); 1670 (C=C); 1615 (C=N). ^{1}H NMR spectrum, δ, ppm: 1.14 s [6H, 3-$(CH_3)_2$], 1.60 d.d (1H, *anti*-7-H, ^2J = 11.0, $^3J_{anti\text{-}7,4}$ = 1.2 Hz), 1.64–2.02 m (4H), 2.04 br.d (1H, 4-H, $^3J_{4,exo\text{-}5}$ = 4.0, $^3J_{4,7}$ = 1.2 Hz), 2.22 d.q (1H, *syn*-7-H, ^2J = 11.0, $^WJ_{syn\text{-}7,endo\text{-}5}$ = $^WJ_{syn\text{-}7,endo\text{-}6}$ = $^3J_{syn\text{-}7,4}$ = 1.2 Hz), 2.28 s (3H, 3′-CH_3), 4.51 s (1H, =CH), 4.67 s (1H, =CH), 5.90 s (1H, 4′-H). Mass spectrum, *m*/*z* (I_{rel}, %): 217 (M^+, 25), 202, 189, 174 (100), 161, 148, 146, 119, 115, 105, 91, 77, 65, 53, 49.

2-[3-(2-Methoxycarbonylethyl)isoxazol-5-yl]-1,7,7-trimethylbicyclo[2.2.1]hept-2-ene (Vb) and 1-[3-(2-methoxycarbonylethyl)isoxazol-5-yl]-3,3-dimethyl-2-methylenebicyclo[2.2.1]heptane (VIb) were isolated in an overall yield of 60% (ratio 1:2). Compound **VIa**. IR spectrum, ν, cm^{-1}: 3140, 3080 (C−H, olefin.); 2965, 2935, 2880 (C−H, aliph.); 1740 (C=O); 1630 (C=N, C=C). ^{1}H NMR spectrum, δ, ppm: 0.83 s (6H, 1-CH_3, *anti*-7-CH_3), 1.14 s (3H, *syn*-7-CH_3), 1.60–2.10 m (4H), 2.48 t (1H, 4-H, ^3J = 3.5 Hz), 2.74 t (2H, side-chain CH_2, ^3J = 7.0 Hz), 3.01 t (2H, side-chain CH_2, ^3J = 7.0 Hz), 3.70 s (3H, CH_3O), 6.04 s (1H, 4′-H), 6.61 d (1H, 3-H, ^3J = 3.5 Hz).

Compound **VIb**. IR spectrum, ν, cm^{-1}: 3140, 3080 (C−H, olefin.); 2965, 2935, 2880 (C−H, aliph.); 1740 (C=O); 1630 (C=N, C=C). ^{1}H NMR spectrum, δ, ppm: 1.10 s [6H, 3-$(CH_3)_2$], 1.14 s (3H, *syn*-7-CH_3), 1.58 br.d (1H, *anti*-7-H, ^3J = 10.0 Hz), 1.60–2.10 m (5H), 2.74 t (2H, CH_2, ^3J = 7.0 Hz), 3.01 t (2H, CH_2, ^3J = 7.0 Hz), 3.70 s (3H, CH_3O), 4.48 s (1H, =CH), 4.64 s (1H, =CH), 5.96 s (1H, 4′-H).

REFERENCES

1. Noe, C.R., Knollmüller, M., Gärtner, P., Mereiter, K., and Steinbauer, G., *Justus Liebigs Ann. Chem.*, 1996, no. 11, pp. 1015–1021.
2. Noe, C.R., Knollmüller, M., and Ettmayer, P., *Justus Liebigs Ann. Chem.*, 1991, no. 5, pp. 417–424.
3. Oppolzer, W., *Tetrahedron*, 1987, vol. 43, no. 9, pp. 1969–2004.
4. Bondar', N.F., Skupskaya, R.V., Levchenko, V.K., and Lakhvich, F.A., *Izv. Akad. Nauk BSSR, Ser. Khim.*, 1991, no. 3, pp. 48–52.

5. Malaeva, L.P., Bondar', N.F., and Kuz'mitskii, B.B., *Izv. Akad. Nauk BSSR, Ser. Khim.*, 1991, no. 3, pp. 52–56.
6. Koval'skaya, S.S., Kozlov, N.G., and Dikusar, E.A., *Russ. J. Org. Chem.*, 2000, vol. 36, no. 3, pp. 379–385.
7. Dyer, J.R., *Applications of Absorption Spectroscopy of Organic Compounds*, Englewood Cliffs: Prentice–Hall, 1965. Translated under the title *Prilozheniya absorbtsionnoi spektroskopii organicheskikh soedinenii*, Moscow: Khimiya, 1970, pp. 87–96.
8. Barkhash, V.A., *Neklassicheskie karbkationy* (Nonclassical Carbocations), Novosibirsk: Nauka, Sibirsk. Otd., 1984, pp. 10–102.
9. Ingold, C.K., *Structure and Mechanism in Organic Chemistry*, Ithaca: Cornell Univ., 1969, 2nd ed. Translated under the title *Teoreticheskie osnovy organicheskoi khimii*, Moscow: Mir, 1973, pp. 611–612.
10. Pigulevskii, G.V., *Khimiya terpenov*, (Chemistry of Terpenes), Leningrad: Leningr. Gos. Univ., 1949, pp. 175–176.
11. Nikitin, V.M., *Khimiya terpenov i smolyanykh kislot* (Chemistry of Terpenes and Rosin Acids), Moscow: Goslesbumizdat, 1952, pp. 196–230.
12. Coxon, J.M., Jones, A.J., and Beeman, C.P., *Tetrahedron Lett.*, 1975, no. 8, pp. 577–580.