Chemistry of *N,N*-bis(silyloxy)enamines
7.* Quaternization of tertiary amines and nitrogen-containing heterocycles by *N,N*-bis(silyloxy)enamines

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Coupling of *N,N*-bis(silyloxy)enamines with tertiary amines and nitrogen-containing heterocycles affording the corresponding functionalized ammonium or iminium salts was studied. The area of its application was determined, and optimal procedures for the synthesis of the target products were proposed. The mechanism including the formation of conjugated nitroso alkene or a silylnitrosonium cation as key intermediates is discussed.

Key words: aliphatic nitro compounds, *N,N*-bis(silyloxy)enamines, silylation, ammonium salts.

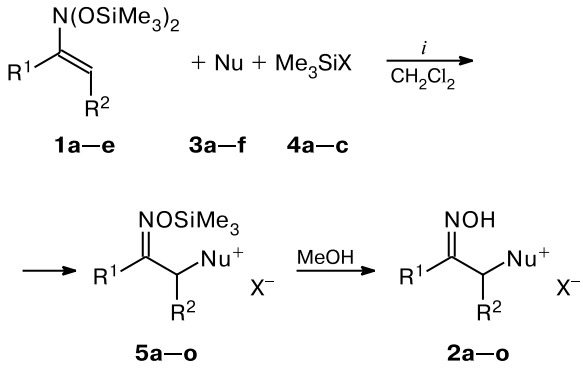
N,N-Bis(silyloxy)enamines (**1**) (BENA),[2,3] being the double silylation products of easily available aliphatic nitro compounds, are convenient reagents for coupling with different types of nucleophiles (for a review, see Ref. 4). Triethylamine is used as a base in the majority of syntheses of BENA. Sometimes, ammonium salts of a previously unknown type $[HON{=}CR^1CHR^2NEt_3]^+X^-$ are formed.[2,3] Normally, we undertook attempts at minimizing the amount of these salts. At the same time, they can be considered as useful products, *viz.*, as potential sources of stables ylides,[5] and as convenient precursors of α-functionalized oximes or heterocyclic systems. In addition, liquid salts can be of interest as modified ionic liquids.

In this connection, it seemed reasonable to optimize the synthesis of these salts. For this purpose, we studied the reactions of BENA **1** with some tertiary amines and nitrogen-containing heterocycles devoid of the NH fragments.

Results and Discussion

The optimal conditions for the synthesis of salts **2a—o** from BENA **1a—e** upon treatment with a nucleophile (**3**) (a tertiary amine or a nitrogen-containing heterocycle) in the presence of a silylating reagent Me_3SiX (**4**) in dichloromethane (Scheme 1) are listed in Table 1. The initially formed silylated salts **5a—o** produce the target products **2a—o** upon methanolysis. Our approach to the optimization of the synthesis of salts **5** is considered in more detail when discussing the mechanism of this reaction.

Scheme 1



X = Cl (**a**), OTf (**b**), Br (**c**)

BENA **1** with alkyl or functionalized substituents (R^1) react with various tertiary amines and nitrogen-containing heterocycles (**3**) devoid of NH groups. Evidently, the specific conditions of the process are determined by the nature of amine **3**. With highly nucleophilic amines **3a—d** and **3f**, the reactions occur smoothly at temperatures close to ambient using Me_3SiCl (**4a**) as the silylating reagent and afford target products **2** in high yields and almost without by-products. Reactions with amines with lower

* For Part 6, see Ref. 1.

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Table 1. Reactions of BENA with *N*-nucleophiles and Me_3SiX (conditions and products yields)

Entry	1	2	R^1	R^2	Nu	X	1 : 3 : 4	Conditions (*i*)		Yield of 2 (%)	*E*/*Z* for 2
								T/°C	τ/h		
1	**a**	**a**	H	H	*N*-methylimidazole (**3a**)	Cl	1 : 1.1 : 1.1	20—40	24	80	6 : 1
2	**a**	**b**	H	H	DMAP[a] (**3b**)	Cl	1 : 1.1 : 1.1	20	24	49	*E*
3	**b**	**c**	Me	H	*N*-methylimidazole (**3a**)	Cl	1 : 1.1 : 1	20—40	24	87	10 : 1
4	**b**	**d**	Me	H	DMAP (**3b**)	Cl	1 : 1.1 : 1.1	0—20	24	70	40 : 1
5	**c**	**e**	H	Me	*N*-methylimidazole (**3a**)	Cl	1 : 3 : 1.1	20—40	24	60	3 : 1
6	**d**	**f**	$(CH_2)_2CO_2Me$	H	*N*-methylimidazole (**3a**)	Cl	1 : 1.1 : 1.1	20—40	24	94	1 : 5
7	**d**	**g**	$(CH_2)_2CO_2Me$	H	DMAP (**3b**)	Cl	1 : 1.1 : 1.1	20	24	84	*E*
8	**e**	**h**	CO_2Et	H	*N*-methylimidazole (**3a**)	Cl	1 : 1.1 : 1.1	0—20	24	54	30 : 1
9	**b**	**i**	Me	H	Me_3N (**3c**)	Cl	1 : 5 : 1.1	0—20	1	72	*Z*
10	**b**	**j**[a]	Me	H	*N*-TMS-imidazole (**3d**)	Cl	2 : 1 : 1.1	0—20	24	83	*E*
11	**b**	**k**	Me	H	Pyridine (**3e**)	Cl	1 : 3 : 1.2	20	3	32	*E*
12	**b**	**l**	Me	H	Pyridine (**3e**)	OTf	1 : 3 : 1.05	−78	4	60	*E*
13	**e**	**m**[b]	CO_2Et	H	Et_3N (**3f**)	Br	—	−70	[c]	45	—
								−30	5		
								20	18		
14	**a**	**n**[d]	H	H	Et_3N (**3f**)	Cl	—	20	90	54	*E*
								60	60		
15	**d**	**o**[d]	$(CH_2)_2CO_2Me$	H	Et_3N (**3f**)	Cl	—	20	96	72	*Z*
								80	96		

[a] Product of the double alkylation of imidazole **3d** with BENA **1b**.
[b] Prepared from ethyl α-nitropropionate according to a known procedure.[3]
[c] 10 min.
[d] Prepared according to a known procedure[2] from nitroethane and γ-nitropropionate, respectively.

nucleophilicities, such as pyridine (**3e**), required that milder conditions and a more powerful silylating reagent, Me_3SiOTf (**4b**), were used. In this case, the formation of by-products could not be avoided.

The reaction of BENA **1b** with pyridine **3e** was studied in more detail (Scheme 2).

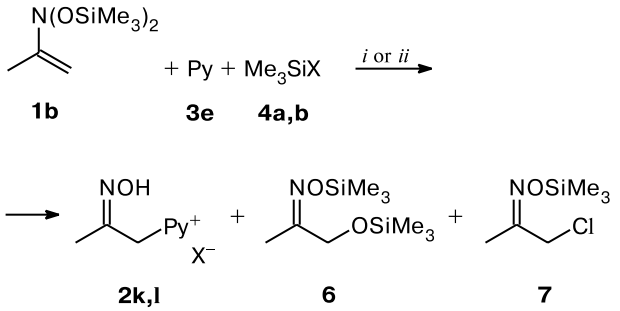
The well-known rearrangement product of BENA **1b** (a bissilyl derivative of α-hydroxy oxime (**6**))[6] and a silyl derivative of α-chloro oxime (**7**) are the by-products. The formation of the latter can be avoided if the silylating reagent **4a** is replaced by Me_3SiOTf (**4b**).

The initially formed silyl derivatives **5a—l** are, as a rule, oily products that are difficult to purify, which can be characterized only by spectroscopy (see, *e.g.*, data for **5c** in Experimental). Therefore, they were desilylated and transformed into crystalline salts **2a—l**, which were easily isolated from the reaction mixtures and additionally purified by recrystallization. Table 1 contains the data only for crystalline salts **2a—o**, although similar products can be obtained by the reactions of BENA with several other nucleophiles; however, since they are oils, we could not purify them and isolate as individual products. For example, these salts were detected by NMR spectroscopy in the reactions of BENA **1b** with *N*,*N*-dimethylformamide dimethyl acetal and DBU (purity >70%).

Table 1 also includes the published data[2,3] on the synthesis of salts **2m—o** by direct silylation of some aliphatic nitro compounds in the presence of Et_3N (entries *13—15*). Evidently, the corresponding BENA **1a,d,e** were intermediate products in these reactions.

The synthesis of salt **2j** from *N*-trimethylsilylimidazole **3d** should be considered in more detail (entry *10*, Table 1).

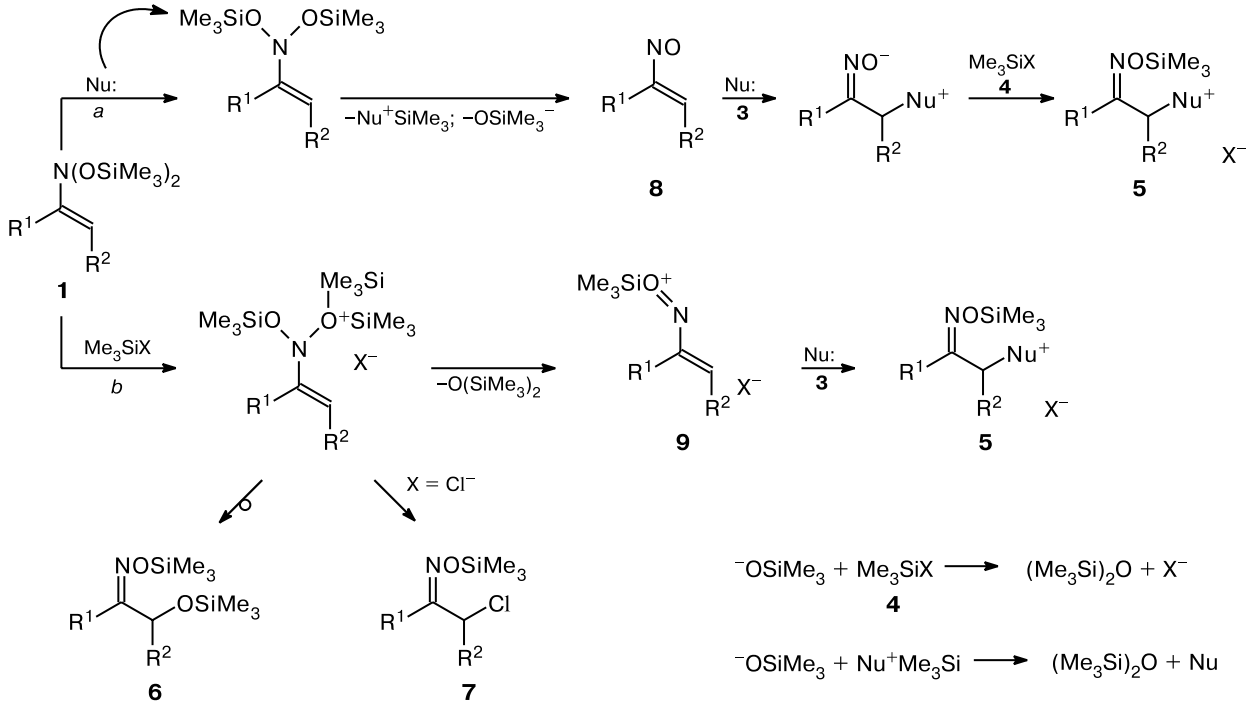
Scheme 2



X	1 : 3 : 4	Conditions*	Yield (%)		
			2	**6**	**7**
Cl	1 : 1.1 : 1.05	*i*	12	34	51
Cl	1 : 3 : 1.2	*i*	32	28	25
OTf	1 : 1.1 : 1.05	*ii*	45	51	—
OTf	1 : 3 : 1.05	*ii*	60	32	—

* *i*. CH_2Cl_2, 20 °C, 3 h. Mixture **6** + **7** was distilled off, and the residue was treated with MeOH for 4 h.
ii. CH_2Cl_2, −78 °C, 4 h; MeOH, 20 °C, 4 h.

Scheme 3



In this case, a twofold excess BENA **1b** was used, because the first equivalent of **1b** obviously alkylates the starting azole **3d**, after which the alkylation product (trimethylsilyl derivative of 1-(1*H*-imidazol-1-yl)acetone oxime) acts as a base in the formation of target salt **2j**. The synthesis of this derivative has recently[7] been studied in detail.

In this work, we did not intend to elucidate the mechanism of formation of salts **5**; however, the results obtained allow one to propose substantiated routes of formation of the target products.

We have previously shown[7] that amines react with BENA involving the silicon atom to give the respective conjugated nitroso alkenes **8** (Scheme 3). The trialkylsilyloxy anion that formed can "trigger" the chain process inducing the instant decomposition of BENA.

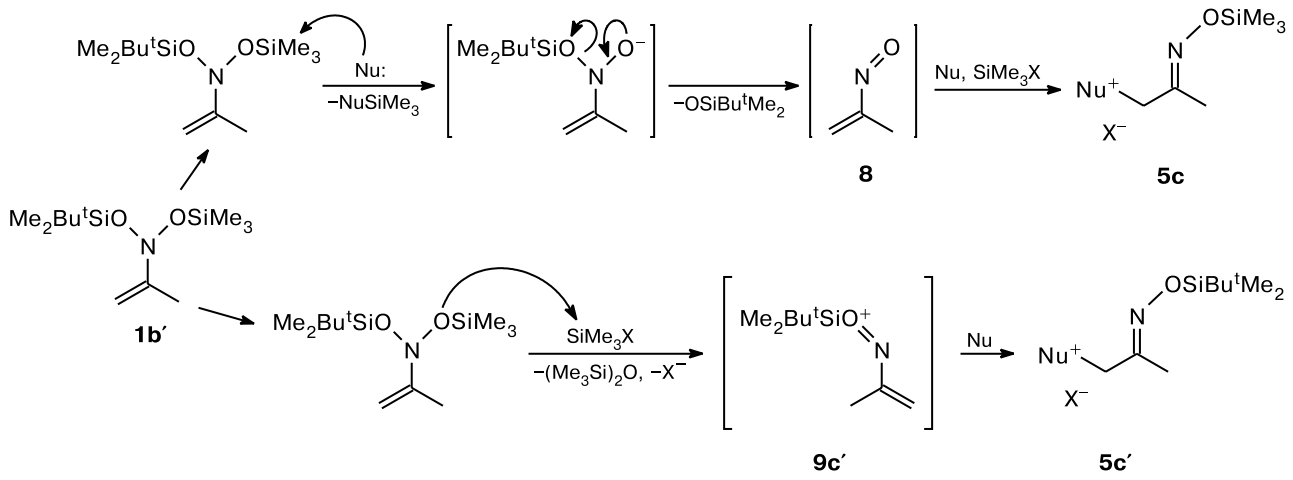
To prevent decomposition of BENA, we added the silylating reagent **4**, aimed at trapping the trialkylsilyloxy anion to form more stable anions (Cl^- or TfO^-), to the reaction mixture. As a result, the reaction of amines **3** (Nu) with nitroso intermediate **8** should produce silyl derivatives **5** (Scheme 3, route *a*).

At the same time, the silylating reagent **4** as an electrophile can interact with the oxygen atom of the O—N—O fragment of BENA to form nitrosonium cation **9** (Scheme 3, route *b*), which should be a more reactive electrophilic intermediate than conjugated nitroso alkene **8** mentioned above. The reaction of cation **9** with amine **3** should afford the target derivatives **5** as well (see Scheme 3, route *b*). However, by-products, namely, the rearrangement products **6** (see Ref. 6) and X-substituted oxime **7**, can be formed due to a high reactivity of intermediate **9**.* Evidently, an increase in the electrophilicity of the silylating reagent **4** favors an increase in the contribution of route (*b*) and, simultaneously, a decrease in the amount of oxime **7**. It is reasonable that an increase in the nucleophilicity of amine **3**, on the contrary, should increase the contribution of route (*a*) to the formation of the target salts **5**.

According to this interpretation, more "nucleophilic" amines **3**, such as tertiary amines, *N*-substituted imidazoles, or DMAP, can react with BENA **1** *via* route (*a*) to produce the corresponding salts **5** in high yields and without by-products. Route (*a*) was additionally confirmed for the reaction of *N*-methylimidazole **3a** with specially obtained "non-symmetrical" BENA **1b´** (Scheme 4). If the reaction proceeds *via* route (*b*), cation **9c´** and, correspondingly, salt **5c´** containing the Bu^tMe_2Si group would be formed due to steric hindrance in BENA **1b´**, while in fact salt **5c** with a less sterically hindered Me_3Si group is formed.

* Only single cases are known where α-halogeno oximes were isolated upon silylation of aliphatic nitro compounds.[8] At the same time, the reactions of 3-alkyl-substituted six-membered cyclic nitronates with Me_3SiHal in the presence of NEt_3 afford smoothly the corresponding 3-α-halogenoalkyl-substituted 5,6-dihydro-4*H*-oxazines.[9]

Scheme 4



On going to less nucleophilic pyridine **3c**, the contribution of route (*b*) (see Scheme 3) to the formation of the target salts **5** increases. This follows from the presence of the corresponding by-products, *viz.*, oximes **6** and **7**, in the reaction mixture (see Scheme 2). As already mentioned, the formation of oxime **7** can be prevented if a more electrophilic silylating reagent **4b** is used.

Note that α-halogeno oximes **7** could also alkylate nucleophiles **3** to form the target salts **5**. It is this route of the formation of salts **5** that we proposed earlier.[10] However, special experiments showed that the reaction **3** + **7** → **5** under the conditions presented in Table 1 and Scheme 2 occurs much more slowly than the formation of salts **5** and, hence, its contribution to the formation of the target products can be neglected.

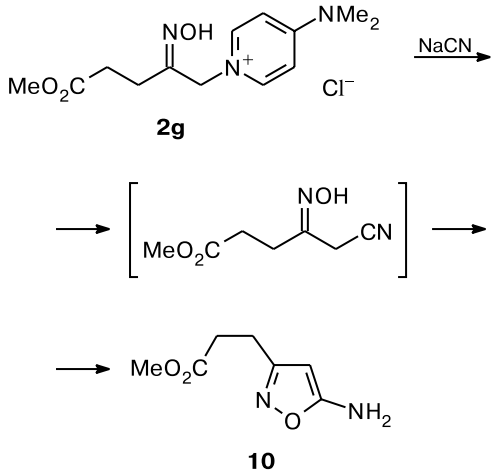
The structures of salts **2a—o** and silyl derivative **5c** were confirmed by the data from NMR spectroscopy* (see Experimental). The configuration of the hydroxyimino group was determined using the criteria already employed for this purpose in our previous works.[7,11]

We will consider elsewhere the application of salts **2** in organic synthesis. In the present work, we would like to demonstrate that these salts can react with nucleophiles by an example of the reaction of salt **2g** with the cyanide anion affording aminoisoxazole **10** (Scheme 5, see also Ref. 12).

Here, we showed that BENA **1** are convenient β-hydroxyiminoalkylating reagents for tertiary amines and nitrogen-containing heterocycles devoid of NH groups. Several functionalized salts **2** were synthesized.

* For salts **2b,d,g** obtained from DMAP, an alternative structure with the quaternary exocyclic nitrogen atom was rejected on the basis of analysis of the ^{1}H and ^{13}C NMR spectroscopic data and results of the NOE experiment (suppression of the protons of the CH_2 group brings about responses of the protons of the pyridine ring).

Scheme 5



Experimental

All reactions were carried out in dried (150 °C) glassware under dry argon. Solvents and reactants were additionally distilled over drying agents (presented in parentheses): pyridine (CaH_2), *N*-methylimidazole (CaH_2), trimethylchlorosilane (CaH_2), *tert*-butyldimethylsilyl triflate (CaH_2), trimethylsilyl triflate (CaH_2), and hexane (Na).

NMR spectra were recorded on a Bruker AM-300 spectrometer (^{1}H: 300.13 MHz, ^{13}C: 75.47 MHz, and ^{29}Si: 59.63 MHz). Chemical shifts are given in a δ scale relative to signals of the solvent (^{1}H and ^{13}C) and $SiMe_4$ (^{29}Si) used as an internal standard. Coupling constants, *J*, are presented in Hz.

Elemental analyses were carried out at the Laboratory of Microanalysis of the Institute of Organic Chemistry, RAS, and at the Analytical Center of the Chemical Lyceum.

Melting temperatures were determined on a Koffler hot stage and were not corrected.

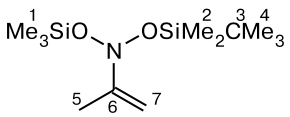
TLC analysis was carried out on Merck plates (SiO_2) with the QF-254 indicator using UV detection.

Preparative liquid chromatography was carried out on columns with silica gel Kieselgel 60 (230—400 mesh, Merck).

The following commercial reagents were used: trimethylchlorosilane (**4a**) (Aldrich), *tert*-butyldimethylchlorosilane (Aldrich), trifluoromethanesulfonic acid (Aldrich), sodium cyanide (Merck), 2-nitropropane (Aldrich), pyridine (**3e**) (Aldrich), *N*-methylimidazole (**3a**) (Aldrich), 4-(*N*,*N*-dimethylamino)pyridine (**3b**) (Aldrich), and trimethylamine.

Trimethylsilyl triflate **4b**,[13] BENA **1a—d**,[2] **1e**,[3] and *N*-trimethylsilylimidazole **3d** [14] were prepared according to the known procedures.

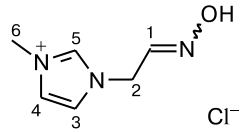
***N*-Trimethylsilyloxy-*N*-(*tert*-butyldimethylsilyloxy)isopropenylamine (1b´).** DBU (2.7 mL, 18 mmol) was added to a solution of 2-nitropropane (1.33 mL, 15 mmol) in CH_2Cl_2 (10 mL) at 0 °C, and after 5 min a solution of Bu^tMe_2SiCl (2.71 g, 18 mmol) in CH_2Cl_2 (10 mL) was added. The temperature of the reaction mixture was increased to 20 °C, and after 20 min the solution was concentrated at 0.1 Torr (20 °C). The residue was diluted with anhydrous light petroleum (20 mL) and filtered, the filtrate was concentrated at 0.1 Torr (20 °C), the residue was dissolved in CH_2Cl_2 (10 mL), and the resulting solution was cooled to 0 °C. At this temperature, NEt_3 (3.3 mL, 24 mmol) and then trimethylsilyl triflate (4.0 mL, 21 mmol) were added, and the mixture was kept for 1 h at 0 °C and partitioned between light petroleum (150 mL) and water (150 mL). The organic layer was washed with a solution of $NaHSO_4 \cdot H_2O$ (2 g, 14.5 mmol) in water (30 mL), water (30 mL), and brine (50 mL), dried with Na_2SO_4, and volatile components were distilled off *in vacuo*. The residue was distilled to give compound **1b´** (2.85 g, 69%) as a colorless oil, b.p. 53 °C (0.6 Torr). Found (%): C, 52.23; H, 10.76; N, 5.18. $C_{12}H_{29}NO_2Si_2$ (275.54). Calculated (%): C, 52.31; H, 10.61; N, 5.08.



^{1}H NMR ($CDCl_3$): 0.13 (s, 6 H, $H_3C(2)$); 0.16 (s, 9 H, $H_3C(1)$); 0.86 (s, 9 H, $H_3C(4)$); 1.84 (s, 3 H, $H_3C(5)$); 4.48 (s, 1 H, $H_2C(7)$); 4.87 (s, 1 H, $H_2C(7)$). ^{13}C NMR ($CDCl_3$): –4.5 (C(2)); 0.29 (C(1)); 13.5 (C(5)); 17.9 (C(3)); 25.8 (C(4)); 104.1 (C(7)); 155.6 (C(6)). ^{29}Si NMR ($CDCl_3$): 23.36 (TMS); 25.31 (TBS).

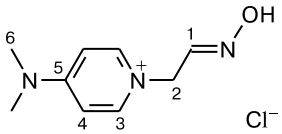
Synthesis of salts 2a—h (see Table 1). Trimethylchlorosilane **4a** was added to heterocycle **3a** or **3b** in CH_2Cl_2 (10 mL) at 20 °C, and then BENA **1a—e** (1 mmol) was added at 0 °C with vigorous stirring over 30 min.* The mixture was kept for 1 h, the temperature was raised to 20 °C, then the mixture was kept for 24 h and concentrated at 0.1 Torr (20 °C), and MeOH (10 mL) was added. After 24 h, the precipitated crystalline salt **2** was filtered off, and the filtrate was concentrated *in vacuo*. An additional amount of salt **2** was isolated from the residue by recrystallization from MeOH. The total yield of salt **2** (colorless crystals) is given in Table 1. Salt **2e** was isolated by column chromatography after the reaction mixture was concentrated *in vacuo* (eluent EtOH).

3-(2-Hydroxyiminoethyl)-1-methyl-3*H*-imidazolium chloride (2a). M.p. 188—189 °C (MeOH). Found (%): C, 41.18; H, 5.80; N, 24.11; Cl, 19.91. $C_6H_{10}N_3OCl$ (175.62). Calculated (%): C, 41.04; H, 5.74; N, 23.93; Cl, 20.19.



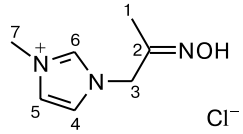
^{1}H NMR (DMSO-d_6) *E*-**2a**: 3.89 (s, 3 H, $H_3C(6)$); 5.08 (d, 2 H, $H_2C(2)$, J = 5.0 Hz); 7.54 (t, 1 H, HC(1), J = 5.0 Hz); 7.86 (s, 2 H, HC(3) and HC(4)); 9.55 (s, 1 H, HC(5)); 11.51 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2a**: 35.8 (C(6)); 47.4 (C(2)); 122.7, 123.6 (C(3), C(4)); 137.1 (C(5)); 143.6 (C(1)). ^{1}H NMR (DMSO-d_6) *Z*-**2a**: 3.89 (s, 3 H, $H_3C(6)$); 5.15 (d, 2 H, $H_2C(2)$, J = 4.4 Hz); 7.00 (t, 1 H, HC(1), J = 4.4 Hz); 7.86 (s, 2 H, HC(3) and HC(4)); 9.59 (s, 1 H, HC(5)); 11.94 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2a**: 35.8 (C(6)); 44.2 (C(2)); 122.7, 123.6 (C(3) and C(4)); 137.1 (C(5)); 148.6 (C(1)); *E*/*Z* = 6 : 1.

4-Dimethylamino-1-(2-hydroxyiminoethyl)pyridinium chloride (2b). M.p. > 350 °C (MeOH). Found (%): C, 50.17; H, 6.60; N, 19.35; Cl, 16.60. $C_9H_{14}N_3OCl$ (215.68). Calculated (%): C, 50.12; H, 6.54; N, 19.48; Cl, 16.44.



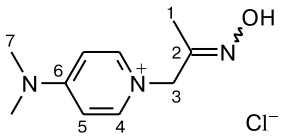
^{1}H NMR (DMSO-d_6) *E*-**2b**: 3.20 (s, 6 H, $H_3C(6)$); 5.08 (d, 2 H, $H_2C(2)$, J = 4.5 Hz); 7.07 (d, 2 H, HC(4), J = 7.3 Hz); 7.58 (t, 1 H, HC(1), J = 4.5 Hz); 8.32 (d, 2 H, HC(3), J = 7.3 Hz); 11.40 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2b**: 39.8 (C(6)); 54.8 (C(2)); 107.6 (C(4)); 142.6 (C(3)); 144.6 (C(1)); 155.9 (C(5)).

3-(2-Hydroxyiminopropyl)-1-methyl-3*H*-imidazolinium chloride (2c). M.p. 290—300 °C (MeOH). Found (%): C, 44.39; H, 6.48; N, 22.49; Cl, 19.00. $C_7H_{12}N_3OCl$ (189.64). Calculated (%): C, 44.33; H, 6.38; N, 22.16; Cl, 18.69.



^{1}H NMR (DMSO-d_6) *E*-**2c**: 1.77 (s, 3 H, $H_3C(1)$); 3.90 (s, 3 H, $H_3C(7)$); 5.04 (s, 2 H, $H_2C(3)$); 7.77, 7.84 (both s, 2 H each, HC(4), HC(5)); 9.45 (s, 1 H, HC(6)); 11.25 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2c**: 11.9 (C(1)); 35.8 (C(7)); 51.7 (C(3)); 123.0, 123.5 (C(4), C(5)); 137.3 (C(6)); 149.9 (C(2)). ^{1}H NMR (DMSO-d_6) *Z*-**2c**: 1.71 (s, 3 H, $H_3C(1)$); 3.90 (s, 3 H, $H_3C(7)$); 5.12 (s, 2 H, $H_2C(3)$); 7.77, 7.84 (both s, 2 H each, HC(4), HC(5)); 9.45 (s, 1 H, HC(6)); 11.37 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2c**: 17.2 (C(1)); 35.8 (C(7)); 45.8 (C(3)); 123.0, 123.5 (C(4), C(5)); 137.7 (C(6)); 148.8 (C(2)); *E*/*Z* = 10 : 1.

4-Dimethylamino-1-(2-hydroxyiminopropyl)pyridinium chloride (2d). M.p. 320—325 °C (MeOH). Found (%): C, 52.54; H, 7.10; N, 18.50; Cl, 15.41. $C_{10}H_{16}N_3OCl$ (229.71). Calculated (%): C, 52.29; H, 7.02; N, 18.29; Cl, 15.43.

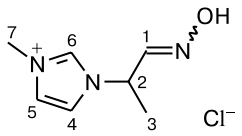


^{1}H NMR (DMSO-d_6) *E*-**2d**: 1.81 (s, 3 H, $H_3C(1)$); 3.24 (s, 6 H, $H_3C(7)$); 5.02 (s, 2 H, $H_2C(3)$); 7.10 (d, 2 H, HC(4), J = 7.3 Hz); 8.28 (d, 2 H, HC(5), J = 7.3 Hz); 11.17 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2d**: 12.0 (C(1)); 39.9 (C(7)); 59.0 (C(3)); 107.3 (C(5)); 142.6 (C(4)); 150.9 (C(2)); 155.9 (C(6)). ^{1}H NMR

* A brief temperature increase to 40 °C can occur during the addition of BENA.

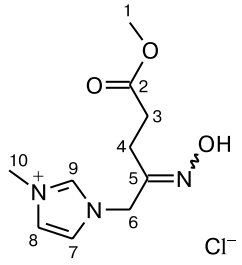
(DMSO-d_6) *Z*-**2d**: 1.70 (s, 3 H, $H_3C(1)$); 3.24 (s, 6 H, $H_3C(7)$); 5.12 (s, 2 H, $H_2C(3)$); 6.98 (d, 2 H, HC(4), J = 7.3 Hz); 8.21 (d, 2 H, HC(5), J = 7.3 Hz); 11.33 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2d**: 15.1 (C(1)); 39.9 (C(7)); 51.3 (C(3)); 106.9 (C(5)); 139.2 (C(4)); 150.9 (C(2)); 155.9 (C(6)); E/Z = 40 : 1.

3-(2-Hydroxyimino-1-methylethyl)-1-methyl-3*H*-imidazolium chloride (2e). M.p. 47—62 °C (MeOH), $R_{f,\ EtOH}$ = 0.76. Found (%): C, 44.89; H, 6.00; N, 22.65. $C_7H_{12}N_3OCl$ (189.64). Calculated (%): C, 44.33; H, 6.38; N, 22.16.



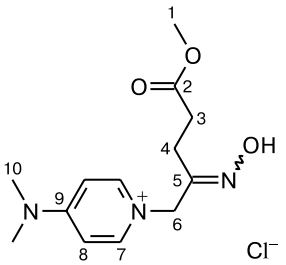
^{1}H NMR (DMSO-d_6) *E*-**2e**: 1.66 (d, 3 H, $H_3C(3)$, J = 6.6 Hz); 3.91 (s, 3 H, $H_3C(7)$); 5.40 (m, 1 H, HC(2)); 7.54 (d, 1 H, HC(1), J = 5.2 Hz); 7.81, 7.93 (both s, 2 H each, HC(4), HC(5)); 9.55 (s, 1 H, HC(6)); 11.4 (br.s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2e**: 18.3 (C(3)); 35.8 (C(7)); 54.6 (C(2)); 121.2, 123.7 (C(4), C(5)); 136.2 (C(6)); 147.2 (C(1)). ^{1}H NMR (DMSO-d_6) *Z*-**2e**: 1.66 (d, 3 H, $H_3C(3)$, J = 6.6 Hz); 3.91 (s, 3 H, $H_3C(7)$); 5.72 (m, 1 H, HC(2)); 7.20 (d, 1 H, HC(1), J = 5.9 Hz); 7.81, 7.96 (both s, 2 H each, HC(4), HC(5)); 9.58 (s, 1 H, HC(6)); 11.90 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2e**: 17.9 (C(3)); 35.8 (C(7)); 50.0 (C(2)); 121.0, 123.8 (C(4), C(5)); 136.4 (C(6)); 146.8 (C(1)); E/Z = 3 : 1.

3-[2-Hydroxyimino-4-(methoxycarbonyl)butyl]-1-methyl-3*H*-imidazolium chloride (2f). M.p. 220—221 °C (MeOH). Found (%): C, 45.67; H, 6.30; N, 16.35; Cl, 13.90. $C_{10}H_{16}N_3O_3Cl$ (261.71). Calculated (%): C, 45.89; H, 6.16; N, 16.06; Cl, 13.55.



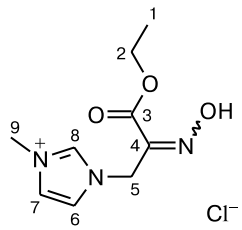
^{1}H NMR (DMSO-d_6) *E*-**2f**: 2.41, 2.55 (both t, 4 H each, $H_2C(3)$, $H_2C(4)$, J = 8.0 Hz); 3.52 (s, 3 H, $H_3C(1)$); 3.87 (s, 3 H, $H_3C(10)$); 5.11 (s, 2 H, $H_2C(6)$); 7.77, 7.87 (both s, 2 H each, HC(7), HC(8)); 9.48 (s, 1 H, HC(9)); 11.61 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2f**: 21.7 (C(4)); 28.8 (C(3)); 35.9 (C(10)); 50.5 (C(6)); 51.5 (C(1)); 123.1, 123.4 (C(7), C(8)); 137.4 (C(9)); 151.9 (C(5)); 172.4 (C(2)). ^{1}H NMR (DMSO-d_6) *Z*-**2f**: 2.47, 2.55 (both t, 4 H each, $H_2C(3)$, $H_2C(4)$, J = 8.0 Hz); 3.58 (s, 3 H, $H_3C(1)$); 3.91 (s, 3 H, $H_3C(10)$); 5.19 (s, 2 H, $H_2C(6)$); 7.75, 7.81 (both s, 2 H each, HC(7), HC(8)); 9.48 (s, 1 H, HC(9)); 11.40 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2f**: 26.5 (C(4)); 29.2 (C(3)); 34.9 (C(10)); 44.9 (C(6)); 51.3 (C(1)); 123.0, 123.6 (C(7), C(8)); 137.5 (C(9)); 150.0 (C(5)); 172.4 (C(2)); E/Z = 1 : 5.

1-(2-Hydroxyimino-4-methoxycarbonylbutyl)-4-dimethylaminopyridinium chloride (2g). M.p. 270—275 °C (MeOH). Found (%): C, 52.01; H, 6.78; N, 13.50; Cl, 12.17. $C_{13}H_{20}N_3O_3Cl$ (301.77). Calculated (%): C, 51.74; H, 6.68; N, 13.92; Cl, 11.75.



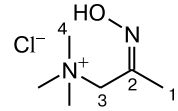
^{1}H NMR (DMSO-d_6) *E*-**2g**: 2.43, 2.62 (both m, 4 H each, $H_2C(3)$, $H_2C(4)$); 3.18 (s, 6 H, $H_3C(10)$); 3.61 (s, 3 H, $H_3C(1)$); 5.18 (s, 2 H, $H_2C(6)$); 7.04 (d, 2 H, HC(8), J = 7.3 Hz); 8.30 (d, 2 H, HC(8), J = 7.3 Hz); 11.30 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2g**: 21.9 (C(4)); 28.8 (C(3)); 40.8 (C(10)); 53.4 (C(1)); 58.8 (C(1)); 107.3 (C(8)); 142.9 (C(7); 152.9 (C(5)); 155.9 (C(9)); 172.5 (C(2)).

1-Methyl-3-(2-ethoxycarbonyl-2-hydroxyiminoethyl)-3*H*-imidazolium chloride (2h). M.p. > 350 °C (MeOH). Found (%): C, 43.70; H, 5.75; N, 16.64; Cl, l4.56. $C_9H_{14}N_3O_3Cl$ (247.68). Calculated (%): C, 43.64; H, 5.70; N, 16.97; Cl, 14.31.



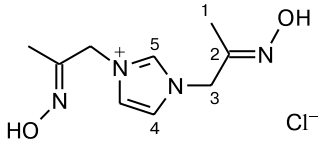
^{1}H NMR (DMSO-d_6) *E*-**2h**: 1.24 (t, 3 H, $H_3C(1)$, J = 7.3 Hz); 3.91 (s, 3 H, $H_3C(9)$); 4.23 (q, 2 H, $H_2C(2)$, J = 7.3 Hz); 5.33 (s, 2 H, $H_2C(5)$); 7.68, 7.82 (both s, 2 H each, HC(6), HC(7)); 9.50 (s, 1 H, HC(8)); 12.68 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2h**: 14.4 (C(1)); 35.8 (C(5)); 36.3 (C(9)); 62.0 (C(2)); 123.5, 124.1 (C(6) and C(7)); 137.7 (C(6)); 143.7 (C(4)); 161.0 (C(3)). ^{1}H NMR (DMSO-d_6) *Z*-**2h**: 1.24 (t, 3 H, $H_3C(1)$, J = 7.3 Hz); 3.91 (s, 3 H, $H_3C(9)$); 4.23 (q, 2 H, $H_2C(2)$, J = 7.3 Hz); 5.20 (s, 2 H, $H_2C(5)$); 7.68, 7.82 (both s, 2 H each, HC(6), HC(7)); 9.33 (s, 1 H, HC(8)); 13.79 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *Z*-**2h**: 14.4 (C(1)); 36.3 (C(7)); 41.5 (C(5)); 62.0 (C(2)); 123.3, 124.1 (C(6), C(7)); 137.7 (C(6)); 144.3 (C(4)); 163.0 (C(3)); E/Z = 30 : 1.

(2-Hydroxyiminopropyl)trimethylammonium chloride (2i). Trimethylchlorosilane **4a** (0.70 mL, 5.5 mmol) and then BENA **2b** (1.17 g, 5 mmol) were added to a solution of anhydrous trimethylamine **3c** (1.48 g, 25 mmol) in acetonitrile (2 mL) at 0 °C. The mixture was kept for 0.5 h at 0 °C, and the temperature was raised to 20 °C. After 1 h, the mixture was concentrated at 0.1 Torr (20 °C) and MeOH (10 mL) was added. After 24 h, the mixture was concentrated at 0.01 Torr and kept for 3 h at the same pressure, and the residue was washed with a large amount of ether. Salt **2i** was obtained in a yield of 0.6 g (72%), m.p. 230—235 °C (MeOH). Found (%): C, 43.35; H, 9.23; N, 17.06; Cl, 21.68. $C_6H_{15}N_2OCl$ (166.65). Calculated (%): C, 43.24; H, 9.07; N, 16.81; Cl, 21.27.



^{1}H NMR (DMSO-d_6): 1.88 (s, 3 H, $H_3C(1)$); 3.12 (s, 9 H, $H_3C(4)$); 4.22 (s, 2 H, $H_2C(3)$); 11.85 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6): 15.8 (C(1)); 52.4 (C(4)); 67.5 (C(3)); 147.3 (C(2)).

1,3-Bis(2-hydroxyiminopropyl)-3*H*-imidazolium chloride (2j). Trimethylchlorosilane **4a** (0.70 mL, 5.5 mmol) was added to a solution of azole **3d** (0.70 g, 5 mmol) in CH_2Cl_2 (2.5 mL) at 20 °C and then BENA **2b** (2.33 g, 10 mmol) was added over 30 min. After 24 h, volatile components were distilled off at 0.1 Torr (20 °C) and MeOH (10 mL) was added to the residue. After 24 h, the precipitated crystals of **2j** were filtered off, the filtrate was concentrated *in vacuo*, and the residue was recrystallized from MeOH. White crystals of **2j** were obtained in a yield of 1.03 g (83%). M.p. 265—270 °C (MeOH). Found (%):

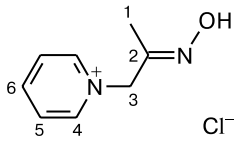


C, 43.74; H, 6.15; N, 22.74; Cl, 14.53. $C_9H_{15}N_4O_2Cl$ (246.69). Calculated (%): C, 43.82; H, 6.13; N, 22.71; Cl, 14.37.

^{1}H NMR (DMSO-d_6): 1.79 (s, 6 H, $H_3C(1)$); 5.09 (s, 4 H, $H_2C(3)$); 7.81 (s, 2 H, HC(4)); 9.51 (s, 1 H, HC(5)); 11.25 (c, 1 H, OH). ^{13}C NMR (DMSO-d_6): 12.2 (C(1)); 52.0 (C(3)); 123.4 (C(4)); 137.8 (C(5)); 150.2 (C(2)).

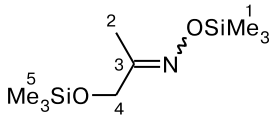
Reaction of BENA 1b with pyridine (3e) in the presence of trimethylchlorosilane (4a). BENA **1b** (1.17 g, 5 mmol) was added to a solution of pyridine (**3e**) and trimethylchlorosilane (**4a**) in CH_2Cl_2 (5 mL) for 10 min at 20 °C. After 3 h, volatiles were distilled off at 0.1 Torr (20 °C) and the distillate was fractionated to give a mixture of oxime **6** and chloro oxime **7**. Methanol (10 mL) was added to the residue. After 4 h, the mixture was concentrated, the resulting crystals were washed with CH_2Cl_2, and salt **2k** was filtered off.

1-(2-Hydroxyiminopropyl)pyridinium chloride (2k). M.p. 120—121 °C (EtOH). Found (%): C, 51.50; H, 5.96; N, 15.24; Cl, 18.71. $C_8H_{11}N_2OCl$ (186.64). Calculated (%): C, 51.48; H, 5.94; N, 15.01; Cl, 19.00.

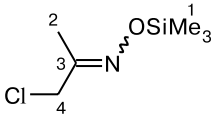


^{1}H NMR (DMSO-d_6) *E*-**2k**: 1.86 (s, 3 H, $H_3C(1)$); 5.61 (s, 2 H, $H_2C(3)$); 8.18 (dd, 2 H, HC(5), J = 7.3 Hz, J = 5.1 Hz); 8.66 (t, 1 H, HC(6), J = 7.3 Hz); 9.18 (d, 2 H, HC(4), J = 5.1 Hz); 11.25 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2k**: 12.4 (C(1)); 62.3 (C(3)); 127.8 (C(5)); 145.8, 146.0 (C(4), C(6)); 150.7 (C(2)).

1-Trimethylsilyloxypropan-2-one *O*-trimethylsilyloxime (6)[6] and 1-chloropropan-2-one *O*-trimethylsilyloxime (7). For mixture **6** : **7** = 1 : 1, b.p. 25—38 °C (0.4 Torr). For mixture **6** : **7** = 2 : 3, b.p. 21—33 °C (0.4 Torr).

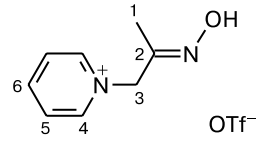


^{1}H NMR ($CDCl_3$) *E*-**6**: 0.12 (s, 9 H, $H_3C(5)$); 0.22 (s, 9 H, $H_3C(1)$); 1.89 (s, 3 H, $H_3C(2)$); 4.14 (s, 2 H, $H_2C(4)$). ^{13}C NMR ($CDCl_3$) *E*-**6**: −0.7, −0.6 (C(1), C(5)); 11.5 (C(2)); 64.9 (C(4)); 160.7 (C(2)). ^{29}Si NMR ($CDCl_3$) *E*-**6**: 20.31 (SiC(5)); 24.28 (SiC(1)). ^{1}H NMR ($CDCl_3$) *Z*-**6**: 0.14 (s, 9 H, $H_3C(5)$); 0.21 (s, 9 H, $H_3C(1)$); 1.92 (s, 3 H, $H_3C(2)$); 4.50 (s, 2 H, $H_2C(4)$). ^{13}C NMR ($CDCl_3$) *Z*-**6**: −0.7, −0.6 (C(1), C(5)); 12.1 (C(2)); 58.7 (C(4)); 160.5 (C(3)). ^{29}Si NMR ($CDCl_3$) *Z*-**6**: 19.74 (SiC(5)); 23.74 (SiC(1)); *E*/*Z* = 6 : 1.



^{1}H NMR ($CDCl_3$) *E*-**7**: 0.24 (s, 9 H, $H_3C(1)$); 1.98 (s, 3 H, $H_3C(2)$); 4.10 (s, 2 H, $H_2C(4)$). ^{13}C NMR ($CDCl_3$) *E*-**7**: −0.6 (C(1)); 16.5 (C(2)); 46.1 (C(4)); 157.5 (C(3)). ^{29}Si NMR ($CDCl_3$) *E*-**7**: 25.87. ^{1}H NMR ($CDCl_3$) *Z*-**7**: 0.22 (s, 9 H, $H_3C(1)$); 2.05 (s, 3 H, $H_3C(2)$); 4.29 (s, 2 H, $H_2C(4)$). ^{13}C NMR ($CDCl_3$) *Z*-**7**: −0.6 (C(1)); 18.0 (C(2)); 36.9 (C(4)); 156.8 (C(2)). ^{29}Si NMR ($CDCl_3$) *Z*-**7**: 25.61, *E*/*Z* = 8 : 1.

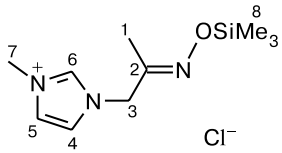
1-(2-Hydroxyiminopropyl)pyridinium trifluoromethanesulfonate (2l). BENA **1b** (1.17 g, 5 mmol) was added to a solution of pyridine **3e** (1.21 mL, 15 mmol) in CH_2Cl_2 (5 mL) at −78 °C, and then trimethylsilyl triflate **4b** (1.00 mL, 5.3 mmol) was added over 5 min. The reaction mixture was kept for 4 h at −78 °C, MeOH (1 mL) was added to the mixture, and after 1 min cooling was removed. The mixture was kept for 4 h at 20 °C and concentrated at 0.1 Torr (20 °C). The yields of salt **2l** and oxime **6** were determined in the residue after CH_2Cl_2 (0.1 mL) was added as an internal standard (see Table 2). The residue was washed with CH_2Cl_2 until pyridinium triflate was completely removed (^{1}H NMR monitoring). Salt **2l** was obtained in a yield of 0.17 g (11%). M.p. 76—78 °C (EtOH). Found (%): C, 36.34; H, 3.50; N, 8.95. $C_9H_{11}N_2O_4F_3S$ (300.26). Calculated (%): C, 36.00; H, 3.69; N, 9.33.



^{1}H NMR (DMSO-d_6) *E*-**2l**: 1.88 (s, 3 H, $H_3C(1)$); 5.43 (s, 2 H, $H_2C(3)$); 8.18 (dd, 2 H, HC(5), J = 7.3 Hz, J = 5.1 Hz); 8.66 (t, 1 H, HC(6), J = 7.3 Hz); 9.00 (d, 2 H, HC(4), J = 5.1 Hz); 11.16 (s, 1 H, OH). ^{13}C NMR (DMSO-d_6) *E*-**2l**: 12.4 (C(1)); 62.6 (C(3)); 127.8 (C(5)); 145.8, 146.0 (C(4), C(6)); 150.7 (C(2)).

Reaction of *N*-methylimidazole with BENA 1b´. The experimental procedure is similar to that described for BENA **1b** up to the step of preparation of derivative **5c**. Then toluene (0.1 mL) was added to the reaction mixture as an internal standard for quantitative NMR analysis, which revealed only product **5c**.

1-Methyl-3-(2-trimethylsilyloxyiminopropyl)-3*H*-imidazolium chloride (5c).



^{1}H NMR (DMSO-d_6) *E*-**5c**: 0.12 (s, 9 H, $H_3C(8)$); 1.89 (s, 3 H, $H_3C(1)$); 3.91 (s, 3 H, $H_3C(7)$); 5.19 (s, 2 H, $H_2C(3)$); 7.77, 7.80 (both s, 2 H each, HC(4), HC(5)); 9.52 (s, 1 H, HC(6)). ^{13}C NMR (DMSO-d_6) *E*-**5c**: −0.8 (C(8)); 12.4 (C(1)); 35.8 (C(7)); 51.4 (C(3)); 123.0, 123.4 (C(4), C(5)); 137.6 (C(6)); 156.2 (C(2)). ^{29}Si NMR (DMSO-d_6) *E*-**5c**: 25.73.

Reaction of salt 2g with sodium cyanide. Sodium cyanide (0.1 g, 2 mmol) was added to a solution of salt **2g** (0.3 g, 1 mmol) in DMF (3 mL), the mixture was stored for 3 h at 70 °C and concentrated *in vacuo*, and the residue was purified by column liquid chromatography (EtOAc—hexane, 1 : 5). Aminoisoxazole **10** was obtained in a yield of 0.14 g (79%) (R_f 0.36, EtOAc—hexane, 1 : 1), m.p. 63—67 °C (EtOAc—hexane) (see Ref. 12: 65—67 °C).

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