Reaction of 1-arylmethylidenepyrazolidin-1-azomethine imines with aryl ketenes

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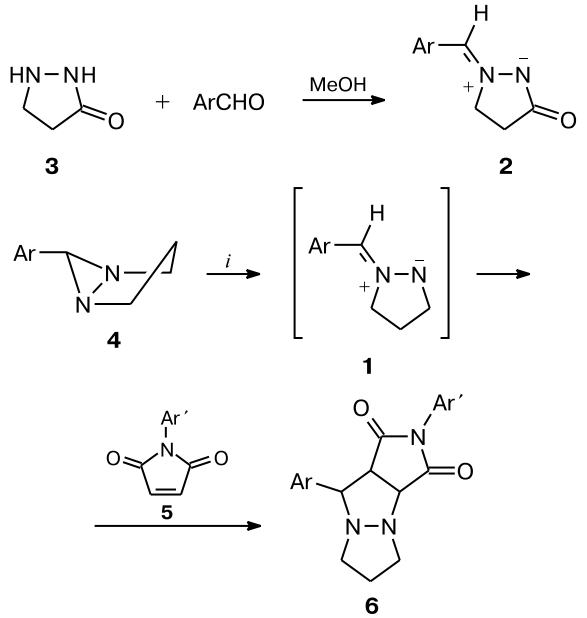
A reaction of aryl ketenes with 1-arylmethylidenepyrazolidin-1-azomethine imines, generated by the diaziridine ring opening in 6-aryl-1,5-diazabicyclo[3.1.0]hexanes catalyzed with $Et_2O \cdot BF_3$, leads to 1,2-bis(phenylacetyl)pyrazolidine, 2-arylacetyl-1-arylidenepyrazolidin-1-ium chlorides, or a representative of 1,5-diazabicyclo[3.3.0]octan-2-ones, *viz.*, 4-(4-ethoxyphenyl)-3,3-diphenyl-1,5-diazabicyclo[3.3.0]octan-2-one, depending on the reaction conditions and the structure of the starting compounds. A mechanism suggested earlier for the transformation of 1,5-diazabicyclo[3.1.0]hexanes in the reaction with ketenes was confirmed.

Key words: 6-aryl-1,5-diazabicyclo[3.1.0]hexanes, 1-arylmethylidenepyrazolidin-1-azomethine imines, ring expansion, ionic liquids, $BF_3 \cdot Et_2O$, aryl ketenes, 1,2-bis(phenylacetyl)pyrazolidine, 2-arylacetyl-1-arylidenepyrazolidin-1-ium chlorides, 1-(phenylacetyl)-pyrazolidine, 1-(phenylacetyl)-4,5-dihydro-1*H*-pyrazole, 2,2-diphenyl-3-(4-ethoxyphenyl)-tetrahydro-1*H*,5*H*-pyrazolo[1,2-*a*]pyrazol-1-one.

Azomethine imines are extremely reactive structures, which are widely used for the formation of nitrogen-containing heterocyclic systems based on [3+2] or [3+3] dipolar cycloaddition reactions to various dipolarophiles or 1,3-dipoles, respectively.[1—4] Especially intensive studies were devoted to azomethine imines derived from pyrazolidines, in particular, 1-arylmethylidenepyrazolidin-1-azomethine imines **1**, since they are used for the synthesis of biologically active γ-lactams derivatives, *i.e.*, 1,5-diazabicyclo[3.3.0]octan-2-ones.[5—7] For obtaining stable azomethine imines of this type, for example, compounds **2**, an aromatic substituent is incorporated into the molecule of **1** for the stabilization of the positively charged $C{=}N^+$ fragment and a C=O group for the stabilization of the negatively charged nitrogen atom. Structures **2** are obtained by the condensation of pyrazolidin-3-one **3** with aromatic aldehydes.[8,9] For the *in situ* generation of unstable under usual conditions azomethine imines **1** unsubstituted in the pyrazolidine ring, thermolysis of 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **4** in the presence of highly reactive dipolarophiles, for example, *N*-arylmaleimides **5**, is used at 130—140 °C (reflux in xylene).[10—14] In the work[15] of the same authors, it was shown that azomethine imines **1** can also be generated *in situ* from compounds **4** already at 20 °C using catalysis with Lewis acids ($BF_3 \cdot Et_2O$, $In(OTf)_3$) in acetonitrile. The reactions with compounds **5** in both cases led to the condensed heterocyclic systems **6** (Scheme 1).

Scheme 1



i. 130—140 °C/xylene, ($BF_3 \cdot Et_2O$/MeCN), 20 °C

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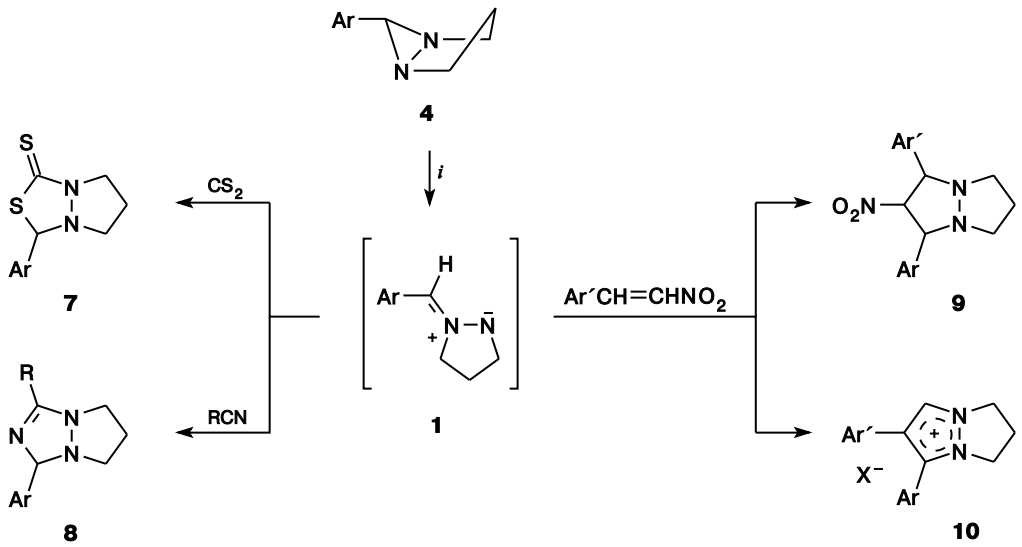
Scheme 2



i. [bmim][X] (X = BF_4^-, PF_6^-), $BF_3 \cdot Et_2O$, 20 °C

Ar = 4-$MeOC_6H_4$, 4-$EtOC_6H_4$, 4-$Pr^iOC_6H_4$, 4-MeC_6H_4; Ar´ = 3-$NO_2C_6H_4$; R = CCl_3, CO_2Et; [bmim] = 

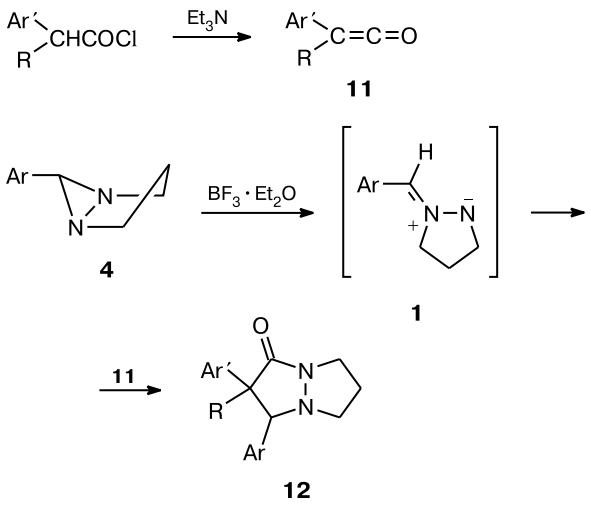
Studying behavior of azomethine imines **1** generated from bicyclic diaziridines **4** in common organic solvents in the presence of $BF_3 \cdot Et_2O$ as a catalyst at 20 °C, we showed[16—19] that under these conditions azomethine imines **1** do not react with less active dipolarophiles, such as carbon disulfide, nitriles, or other activated olefins, for example, β-nitrostyrenes. These reactions were successfully accomplished only in ionic liquids, that allowed us to develop simple methods for the preparation of a number of bicyclic structures **7—10** (Scheme 2).[16—19]

The present work is devoted to the study of a possibility of condensation of azomethine imines **1**, generated *in situ* from 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **4** under conditions found earlier,[15—19] with aryl ketenes **11** in order to obtain 3,4-diaryl(3,3,4-triaryl)-1,5-diazabicyclo[3.3.0]-octan-2-ones **12**, new γ-lactam azaanalogs (Scheme 3).

We expected that preliminary preparation of azomethine imines **1** from 6-aryl-1,5-diazabicyclo[3.1.0]hexanes **4** using $BF_3 \cdot Et_2O$ as a catalyst either in organic solvents or in ionic liquid under conditions developed by us earlier would allow us to accomplish their condensation with aryl ketenes **11** to form di(tri)aryl-substituted 1,5-diazabicyclo[3.3.0]octan-2-ones **12**. Aryl ketenes, as earlier, were supposed to be generated *in situ* from arylacetyl chlorides and Et_3N.

Earlier,[20] we have studied the reaction of other representatives of 1,5-diazabicyclo[3.1.0]hexanes, *viz.*, 6H-, 6-Alk-, and 6,6-Alk_2-derivatives **13**, with aryl ketenes **11** generated *in situ* from arylacetyl chlorides and Et_3N in benzene or diethyl ether at reduced temperature and showed that in this case the reaction proceeds with the

Scheme 3



formation of 1-acylpyrazolidines **14** in moderate yields. The following mechanism was suggested for this direction of the reaction: aryl ketene **11** attacks the starting bicycle **13** to form zwitterionic intermediate **15**, which is opened at the C—N bond of the diaziridine fragment to yield the second dipolar intermediate **16**. Being a stronger base than Et_3N, the enolate ion of intermediate **16** combines with HCl from $Et_3N \cdot HCl$, formed in the process of generation of ketene **11**, that leads to intermediate **17**. The contact of compound **17** with water in the process of isolation on a SiO_2 column resulted in its hydrolysis to 1-acylpyrazol-

idines **14** and the corresponding carbonyl compounds. The cyclization of intermediate **16** to bicyclic system **18** is restricted by the Baldwin´s rules and was successfully accomplished only for two examples on heating in low yields (Scheme 4).

In order to find conditions for the preparation of desired bicyclic compounds **12**, the reaction was initially performed in MeCN under conditions described in the work,[15] using 6-(4-methylphenyl)-1,5-diazabicyclo-[3.1.0]hexane **4a** and phenyl ketene **11a** (Ar = Ph, R^3 = H) as an example. However, the reaction was complicated and resulted in the formation of a mixture of products including polymeric, from which 1,2-bis(phenylacetyl)-pyrazolidine **19** was isolated by column chromatography in 12% yield instead of expected bicyclic compound **12** (Ar = 4-MeC_6H_4). Its structure was confirmed by a combination of the elemental analysis data, spectral characteristics (Scheme 5, Tables 1—4), and X-ray diffraction study. The latter showed that molecule **19** in the crystal is symmetric with respect to the axis going through the middle of the N—N bond (Fig. 1). The pyrazolidine ring has the *twist*-conformation; its geometrical parameters are within the range of the values characteristic of this class of compounds (see, for example, Refs 21—23).

Since, as it turned out, the reaction outcome does not depend on the bicyclic diaziridine used (in all the cases, 1,2-bis(phenylacetyl)pyrazolidine **19** was isolated in low yield), we decided to generate azomethine imine **1a** in ionic liquids [bmim][BF_4] and [bmim][PF_6] under conditions described in the works.[16—19] Azomethine imine **1a** was generated upon the action of $BF_3 \cdot Et_2O$ in catalytic amounts (0.1 mmol) on the starting compound **4a**

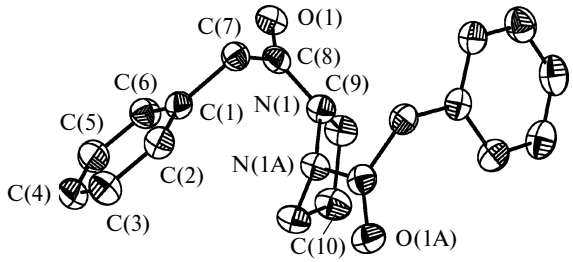
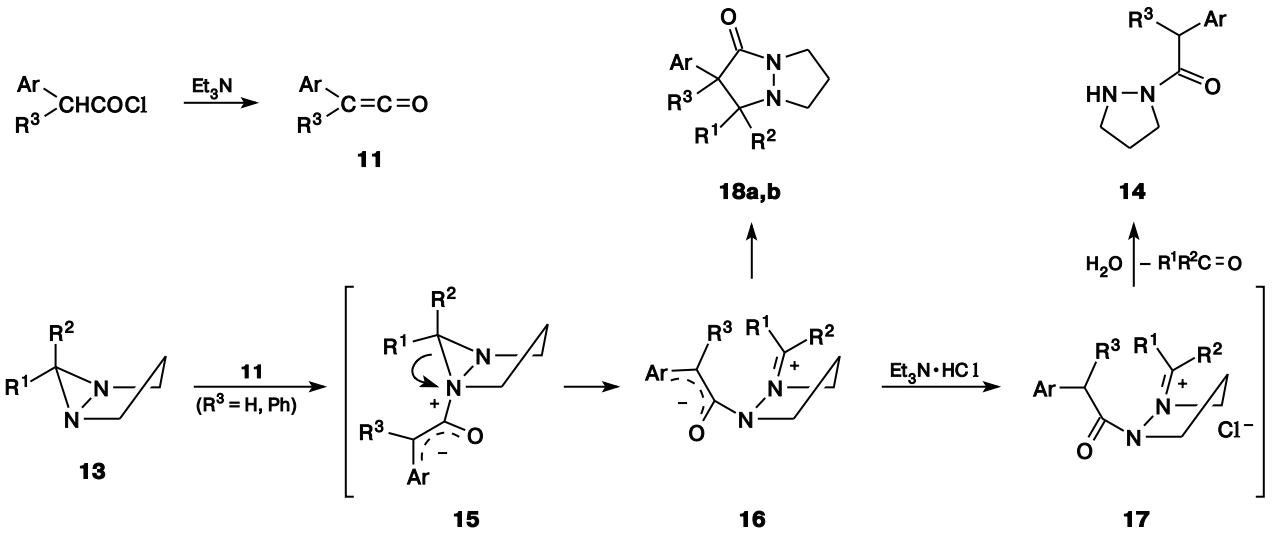


Fig. 1. General view of compound **19** in representation of atoms by probability ellipsoids of thermal vibrations (p = 50%).

(0.3 mmol) in MeCN or ionic liquid (IL), then phenylacetyl chloride and Et_3N were added simultaneously dropwise at reduced temperature. However, in this case too the reaction took similar direction only at considerably higher rate, and 1,2-bis(phenylacetyl)pyrazolidine **19** was isolated in low yield as the reaction product independent on the structure of compound **4a—c** involved into the reaction.

It may be supposed that in both MeCN and ionic liquids, phenyl ketene **11a** in the first step of the reaction attacks the negatively charged nitrogen atom of azomethine imines **1a—c** to form intermediates **20a—c**, close in their structure to intermediates **16**. Then, as in the reaction in Scheme 3, the enolate ions of intermediates **20** remove HCl from $Et_3N \cdot HCl$ to yield new intermediates **21**, analogs of intermediates **17**. But, since both MeCN and ionic liquids could contain certain amount of water, intermediates **21** were apparently hydrolyzed under the reaction conditions to 1-phenylacetylpyrazolidine **14a**, which reacted with the second molecule of ketene **11a** leading to 1,2-bis(phenylacetyl)pyrazolidine **19**. In all the

Scheme 4



13: R^1, R^2 = H, Alk
18: R^1 = R^2 = H; Ar = R^3 = Ph (**a**) (35%); Ar = 4-ClC_6H_4, R^3 = H (**b**) (14%)

Table 1. Some physico-chemical characteristics of compounds obtained

Compound	M.p./°C	R_f*	Found / Calculated (%)				Molecular formula
			C	H	N	Cl	
12a	152.0—152.5	0.17	78.35 78.36	6.59 6.58	7.01 7.03	—	$C_{26}H_{26}N_2O_2$
14a	Orange oil	0.11	69.40 69.45	7.49 7.42	14.76 14.73	—	$C_{11}H_{14}N_2O$
19	85.5—86.0	0.36	74.05 74.00	6.51 6.54	9.03 9.08	—	$C_{19}H_{20}N_2O_2$
21c	Orange oil	—	66.98 66.94	6.51 6.46	7.83 7.81	9.83 9.88	$C_{20}H_{23}ClN_2O_2$
23	Orange oil	0.23	70.21 70.19	6.41 6.43	14.84 14.88	—	$C_{11}H_{12}N_2O$

* *n*-Hexane—ethyl acetate (1 : 1 (v/v)) is the eluent, visualization with diphenylamine and under the UV light.

cases, the corresponding aromatic aldehydes were either isolated or characterized by NMR (see Scheme 5).

To avoid formation of compounds of the type **19** and synthesize desired bicyclic compounds **12**, we carried out the reaction of azomethine imine **1c** with phenyl ketene **11a** in anhydrous benzene in the flow of argon. In this case, after evaporation of benzene, by extraction with hot hexane, 1-(4-ethoxybenzylidene)-2-(phenylacetyl)pyrazolidin-1-ium chloride **21c** (analog of intermediates **17** in Scheme 4; Scheme 6) was isolated, which proved stable under usual conditions and, hence, was characterized by IR and NMR spectroscopy and mass spectrometry (see Tables 1—4). The IR spectrum exhibited an absorption band at 840 cm^{-1} corresponding to the stretching vibrations of the C—Cl bond, the mass spectrum contained a fragment ion corresponding to $[M^+ - Cl]$, the rest of the molecule fragmentation completely corresponded to the structure **21c**. The presence of the absorption band at 840 cm^{-1} in the IR spectrum is apparently due to the fact that, as it is known, α-chloromethylamines exist in the equilibrium mixture of the salts of the type **21** and covalent compounds of the type **22**. In our case, this equilibrium, by all accounts, is shifted to the side of the salt structures **21**. The NMR spectral data obtained using the $\{^1H—^1H\}$gNOESY, $\{^1H—^{13}C\}$HMBC, $\{^1H—^{15}N\}$HMBC, and $\{^1H—^{13}C\}$HSQC procedures on the ^1H, ^{13}C, ^{15}N nuclei were the most informative. Compound **21c** in its ^1H NMR spectrum is characterized by a low-field singlet at δ 9.86 (in the ^{13}C NMR spectrum, at δ 190.87) related to the $CH=N^+$ group, as well as by a broad singlet for the CH_2 group of the $COCH_2Ph$ fragment at δ 3.77 (in the ^{13}C NMR spectrum, at δ 40.01). The ^1H and ^{13}C NMR spectroscopic data for the reactions of azomethine imine **1c** with ketenes **11b,c** and azomethine imine **1b** with ketene **11a** showed formation of compounds **21b—e** in a mixture with other products (Table 5), however, we failed in their isolation in pure form (see Scheme 6).

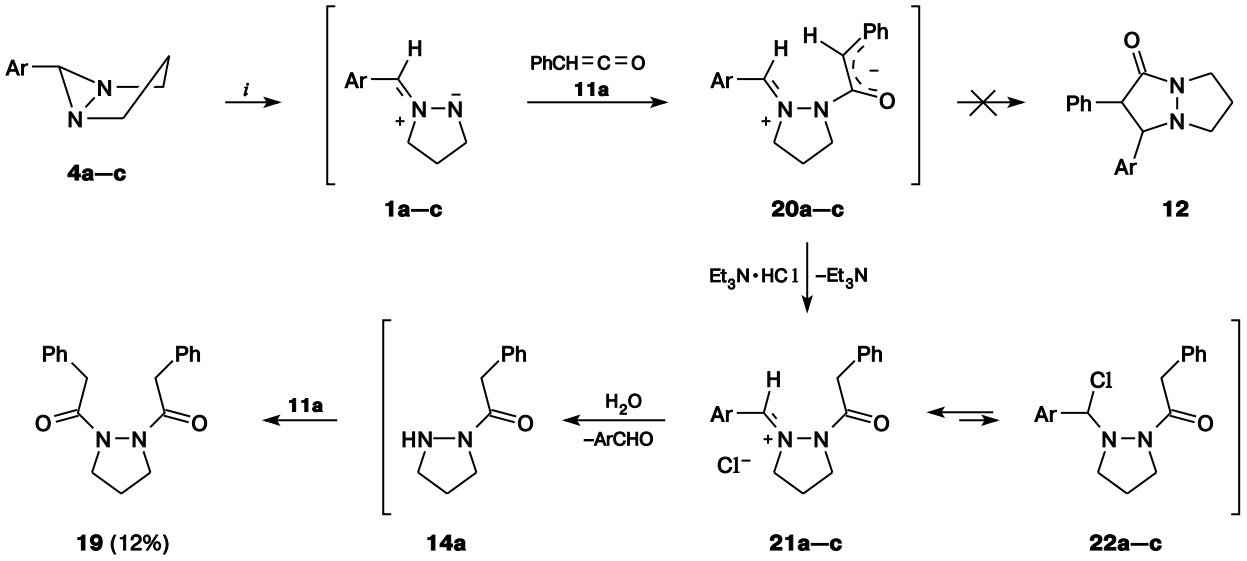
Table 2. IR spectra of compounds obtained

Compound	IR, ν/cm^{-1}
12a	640, 692, 700, 740, 840, 920, 1004, 1052, 1116, 1184, 1248, 1308, 1392, 1436, 1512, 1584, 1612, 1684, 2840, 2900, 2984, 3052
14a	668, 696, 720, 840, 892, 912, 972, 972, 1032, 1076, 1128, 1216, 1256, 1292, 1332, 1432, 1452, 1496, 1632, 1720, 2884, 2932, 2980, 3028, 3060, 3228
19	664, 700, 720, 752, 928, 1004, 1032, 1164, 1232, 1288, 1436, 1456, 1500, 1604, 1668, 1712, 2896, 2924, 2988, 3032, 3064, 3332
21c	520, 616, 696, 720, 808, 840, 920, 1044, 1116, 1160, 1256, 1304, 1396, 1432, 1472, 1496, 1508, 1576, 1600, 1680, 1700, 2744, 2932, 2980, 3028, 3060, 3240, 3448
23	668, 696, 720, 744, 928, 1032, 1076, 1124, 1176, 1288, 1432, 1456, 1496, 1512, 1600, 1652, 1728, 2856, 2928, 2960, 3028, 3064

Table 3. Mass-spectra of compounds **12a** and **21c**

Compound	MS, *m/z* (*I* (%))
12a	398 [M] (6), 327 [M – pyrazolidine] (2), 204 [M — Ph_2CCO] (100), 194 [Ph_2CCO] (9), 165 [Ph_2C] (43), 147 [$NCHC_6H_4OEt$] (14), 121 [C_6H_4OEt] (11), 77 [Ph] (15), 70 [pyrazolidine] (7)
21c	322 [M – Cl – H] (7), 282 [M – $(CH_2)_3$ + + H – Cl] (3), 203 [M – $PhCH_2CO$ – Cl] (18), 190 [M – $EtOC_6H_4CH$ – Cl] (9), 91 [$PhCH_2$] (100), 77 [Ph] (14), 70 [pyrazolidine] (72)

Scheme 5



i. $BF_3 \cdot Et_2O$, MeCN or ionic liquid

Ar = 4-MeC_6H_4 (**a**), 4-$MeOC_6H_4$ (**b**), 4-$EtOC_6H_4$ (**c**)

To sum up, we succeeded in obtaining compounds **21**, analogs of α-chlorobenzylamines, whose structure is close to the intermediates **17** suggested earlier (see Scheme 4), which undergo hydrolysis during isolation to yield 1-arylacetylpyrazolidine **14**. The higher stability of compounds **21** as compared to the intermediates **17** is apparently due

Table 4. ^{1}H and ^{13}C NMR spectra of compounds obtained*

Compound	δ, *J*/Hz ($CDCl_3$)	
	^{1}H NMR	^{13}C NMR
12a	1.38 (t, 3 H, $C\underline{H}_3CH_2O$, ^3J = 6.00); 2.47 (br.m, 2 H, $NCH_2C\underline{H}_2$); 2.48, 3.23 (both br.m, 2 H, $CHNC\underline{H}_2$, Δν = 150 Hz); 3.64, 3.91 (both br.m, 2 H, $CONC\underline{H}_2$, Δν = 54); 3.96 (q, 2 H, $CH_3C\underline{H}_2O$, ^3J = 6.00); 4.84 (br.s, 1 H, $C_6H_4C\underline{H}N$); 6.65, 7.55 (both d, 4 H, $EtOC_6\underline{H}_4$, ^3J = 7.00); 6.84, 7.29 (both m, 10 H, Ph) (Ar); 158.91 (CO)	14.78 ($\underline{C}H_3CH_2O$); 27.16 ($NCH_2\underline{C}H_2$); 39.72 ($CHN\underline{C}H_2$); 53.12 ($CON\underline{C}H_2$); 63.36 ($CH_3\underline{C}H_2O$); 78.50 ($C_6H_4\underline{C}HN$); 113.71 ($\underline{C}Ph_2$), 126.68, 126.95, 127.15, 127.48, 127.87, 128.39, 129.11, 129.22, 130.11, 130.25, 138.92, 165.38
14a	1.96 (m, 2 H, $NCH_2C\underline{H}_2$, ^3J = 8.00, ^3J = 6.00); 2.90 (t, 2 H, $HNC\underline{H}_2$, ^3J = 6.00); 3.46 (t, 2 H, $CONC\underline{H}_2$, ^3J = 8.00); 3.84 (s, 2 H, $COC\underline{H}_2Ph$); 4.37 (br.m, 1 H, NH); 7.26 (m, 5 H, Ph)	27.17 ($NCH_2\underline{C}H_2$); 40.92 ($HN\underline{C}H_2$); 43.91 ($CON\underline{C}H_2$); 47.83 ($CO\underline{C}H_2Ph$); 126.19, 128.16, 128.99, 135.88 (Ph); 171.34 (CO)
19	1.80 (m, 2 H, $NCH_2C\underline{H}_2$, ^3J = 6.88); 2.56, 4.13 (both br.m, 4 H, $NC\underline{H}_2CH_2$); 3.64 (q, 4 H, $COC\underline{H}_2Ph$, $^2J_{AB}$ = 12.79); 7.26 (m, 10 H, Ph)	24.95 ($NCH_2\underline{C}H_2$); 40.63 ($CO\underline{C}H_2Ph$); 41.04, 45.36 (both br, $N\underline{C}H_2CH_2$); 127.16, 128.57, 128.78, 129.09, 129.37, 139.66, 143.66 (Ph)
21s	1.36 (t, 3 H, $C\underline{H}_3CH_2O$, ^3J = 6.00); 1.93 (m, 2 H, $NCH_2C\underline{H}_2$, ^3J = 12.00); 2.82 (br.m, 2 H, $CHN^+C\underline{H}_2$); 3.33 (br.m, 2 H, $CONC\underline{H}_2$); 3.77 (br.s, 2 H, $COC\underline{H}_2Ph$); 4.14 (q, 2 H, $CH_3C\underline{H}_2O$, ^3J = 6.00); 7.10, 7.85 (both d, 4 H, $EtOC_6H_4$, ^3J = 6.00); 7.19 (t, 1 H, *p*-CH in Ph, ^3J = 6.00); 7.23 (t, 2 H, *m*-CH in Ph, ^3J = 6.00); 7.26, 7.28 (both d, *o*-CH in Ph, ^3J = 6.00); 9.86 (s, 1 H, $C\underline{H}N^+CH_2$)	14.36 ($CH_3\underline{C}H_2O$); 26.78 ($NCH_2\underline{C}H_2$); 40.01 ($CO\underline{C}H_2Ph$); 43.61 ($CHN^+\underline{C}H_2$); 47.26 ($CON\underline{C}H_2$); 63.68 ($CH_3\underline{C}H_2O$); 114.80, 129.47, 131.73, 169.98 ($\underline{C}_6H_4OEt$); 126.00, 127.73, 128.10, 129.09, 136.52 (Ph); 163.48 (CO); 190.87 ($CH{=}N^+$)
23	2.81 (td, 2 H, $NCH_2C\underline{H}_2$, ^3J = 10.10, ^3J = 1.50); 3.76 (t, 2 H, $NC\underline{H}_2$, ^3J = 10.10); 3.92 (s, 2 H, $COC\underline{H}_2Ph$); 6.88 (t, 1 H, NCH, ^3J = 1.50); 7.14 (t, 1 H, *p*-CH in Ph, ^3J = 8.31); 7.23 (t, 2 H, *m*-CH in Ph, ^3J = 8.31); 7.29 (d, 2 H, *o*-CH in Ph, ^3J = 8.31)	33.32 ($NCH_2\underline{C}H_2$); 40.81 ($CO\underline{C}H_2$); 42.02 ($CON\underline{C}H_2$); 126.75, 128.48, 129.52, 135.47 (Ph); 147.72 (NCH); 169.69 (CO)

* The ^{15}N NMR spectrum of compound **21c**: −53 ($CH\underline{N}^+$); −220 ($CO\underline{N}CH_2$).

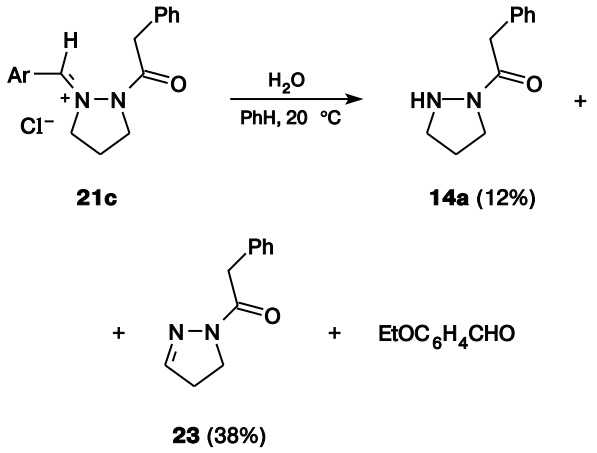
Table 5. The most characteristic signals in the ^1H and ^{13}C NMR spectra of compounds **21b—f**

Group	$^1H/^{13}C$ NMR				^1H NMR
	b	**c**	**d**	**f**	**e**
$NCH_2C\underline{H}_2$	1.80/24.98	1.93/26.78	1.88/29.38	1.96/27.01	1.91
$CHN^+C\underline{H}_2$	2.90/43.64	2.82/43.61	3.15/44.03	2.87/44.18	2.85
$CONC\underline{H}_2$	3.62/51.83	3.33/47.26	3.64/52.20	3.54/47.96	3.42
COHXAr′*	3.97/40.23	3.77/40.01	4.15/40.37	3.89/39.57	3.77
$C\underline{H}N^+CH_2$	9.89/190.89	9.86/190.87	9.90/190.78	9.88/190.60	9.79

* X = H (**b**—**e**), Ph (**f**).

to the replacement of aliphatic substituents on the imine fragment of these structures by the aromatic fragments with electron-donating substituents at position 4, which stabilize a positive charge in compounds **21**. To verify the mechanism suggested in Schemes 4 and 5 for the transformation of 1,5-diazabicyclo[3.1.0]hexane derivatives to 1-arylacetylpyrazolidines **14**, we treated compound **21c** with water in the two-phase system benzene—water at 20 °C and in fact obtained desired 1-phenylacetylpyrazolidine **14a**, that confirmed the reaction mechanism suggested in the work.[20] However, in addition to compound **14a**, 1-phenylacetylpyrazoline **23** was isolated as the reaction product as well, which is formed, by all accounts, through the oxidation of pyrazolidine **14a** with air oxygen under conditions of isolation. Such reactions are very characteristic of 1-substituted pyrazolidines.[24—26] Compounds **14a** and **23** were isolated by column chromatography on SiO_2. Their structures are confirmed by a combination of elemental analysis data and spectral characteristics (see Tables 1—4). 4-Ethoxybenzaldehyde was isolated in high yield as well (Scheme 7).

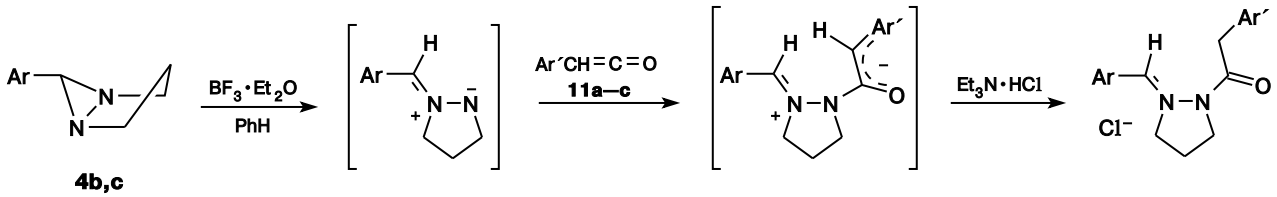
Scheme 7



Ar = 4-$EtOC_6H_4$

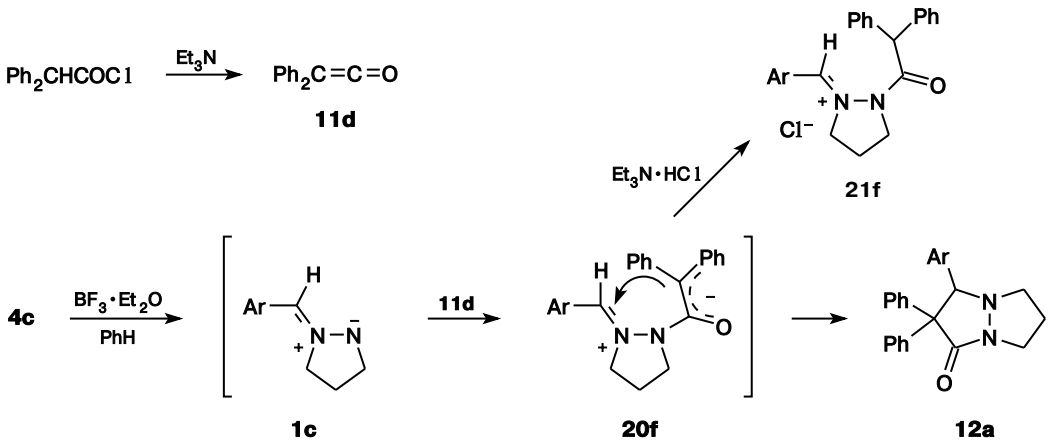
The synthesis of representative of compounds **12** based on the condensation of azomethine imines **1** and aryl ketenes **11** was successfully accomplished only for one example under the same conditions as the reaction of azomethine imine **1c** with diphenyl ketene **11d** in benzene and catalysis with $BF_3 \cdot Et_2O$ at 20 °C. Apparently, in this case the enolate ion in the intermediate **20f** is stabilized much stronger due to the conjugation with two phenyl groups than in the reactions with other aryl ketenes studied and, therefore, is predominantly involved into intramolecular cyclization to form 4-(4-ethoxyphenyl)-3,3-diphenyl-1,5-diazabicyclo[3.3.0]octan-2-one **12a** (see Table 1—4), however, the spectra showed the presence of compound **21f** in small amount as well (no more than 15%) (Scheme 8).

Scheme 6



Compound	Ar	Compound	Ar′	Compound	Ar	Ar′
1b	4-$MeOC_6H_4$	**11a**	Ph	**20b**, **21b**	4-$MeOC_6H_4$	Ph
1c	4-$EtOC_6H_4$	**11b**	4-MeC_6H_4	**20c**, **21c**	4-$EtOC_6H_4$	Ph
4b	4-$MeOC_6H_4$	**11c**	2,4-$(NO_2)_2C_6H_3$	**20d**, **21d**	4-$EtOC_6H_4$	4-MeC_6H_4
4c	4-$EtOC_6H_4$			**20e**, **21e**	4-$EtOC_6H_4$	2,4-$(NO_2)_2C_6H_3$

Scheme 8



The most characteristic chemical shifts in the NMR spectra of compounds **21b—f** are given in Table 5.

In conclusion, the synthesis of representatives of 1,5-diazabicyclo[3.3.0]octan-2-ones by the reaction of 6-aryl-1,5-diazabicyclo[3.1.0]hexanes with aryl ketenes, proceeding through the $Et_2O \cdot BF_3$-catalyzed intermediate formation of azomethine imines, was successfully accomplished only for diphenyl ketene by carrying out the reaction in anhydrous benzene. Analogous reaction with monoaryl ketenes in ionic liquids led to 1,2-bis(arylacetyl)pyrazolidines, whereas in benzene, to 1-arylidene-2-(arylacetyl)pyrazolidin-1-ium chlorides, one of which, *viz.*, 1-(4-ethoxyphenyl)-2-(phenylacetyl)pyrazolidin-1-ium chloride, was isolated and fully characterized. Hydrolysis of the latter during isolation yielded 1-phenylacetylpyrazolidine and its oxidation product with air oxygen, *viz.*, 1-phenylacetylpyrazoline, that confirmed the mechanism suggested earlier[20] for the transformation of 1,5-diazabicyclo[3.1.0]hexanes in the reactions with aryl ketenes.

Experimental

IR spectra were recorded on a UR-20 spectrometer in KBr pellets or for neat samples; ^1H and ^{13}C NMR spectra were recorded on a Bruker AM 300 spectrometer (75.5 MHz for ^{13}C NMR) in $CDCl_3$. The ^{13}C NMR spectra were obtained with proton decoupling. To confirm the structure of compound **21c**, its ^1H, ^{13}C, ^{15}N NMR spectra were recorded on a Bruker AV-600 spectrometer (600.13, 150.90, and 60.81 MHz for ^1H, ^{13}C, and ^{15}N, respectively). Nitromethane ($\delta_{15N} = 0$) was used as an external standard for recording ^{15}N NMR spectra. Assignment of signals in the NMR spectra of compound **21c** was performed using {^1H—^1H}gNOESY, {^1H—^{13}C}HMBC, {^1H—^{15}N}HMBC, and {^1H—^{13}C}HSQC techniques. All the 2D-spectra were obtained using the Bruker standard procedures with the Z-gradient. The spectra were recorded at 30 °C. Melting points were measured on a Gallenkamp (Sanyo). Mass spectra (EI) were measured on a Finnigan MAT INCOS-50 spectrometer. TLC monitoring of the reaction course was performed on Silufol UV-254 plates. The R_f values were determined in the *n*-hexane—ethyl acetate, 1 : 1 (v/v) solvent system.

X-ray diffraction data. Crystals of compound **19** ($C_{19}H_{20}N_2O_2$, M = 308.37) are orthorhombic, the space group is *Pbcn* at 120 K: a = 14.0802(8), b = 11.5168(7), c = 10.1006(6) Å, V = = 1637.90(17) Å^3, Z = 4 (Z' = 1/2), d_{calc} = 1.251 g cm^{-3}, μ(Mo-Kα) = 0.82 cm^{-1}, $F(000)$ = 656. Intensities of 16824 reflections were measured on a Bruker SMART 1000 CCD diffractometer (λ(Mo-Kα) = 0.71072 Å, ω-scanning, 2θ < 58°), and 2180 independent reflections (R_{int} = 0.0281) were used in further refinement. The structure was solved by the direct method and refined by the full-matrix least squares method on F^2 in anisotropic-isotropic approximation. Positions of hydrogen atoms were calculated geometrically. The final values of unreliability factors for **19**: wR_2 = 0.1400 and GOOF = 1.006 for all the independent reflections (R_1 = 0.0530 were calculated on F for 1568 observed reflections with $I > 2\sigma(I)$). All the calculations were performed using the SHELXTL PLUS 5.0 program package.

1,2-Bis(phenylacetyl)pyrazolidine (19). ***A.*** Solutions of phenylacetyl chloride (0.69 g, 4.5 mmol) obtained by a standard procedure[27,28] in anhydrous MeCN (3 mL) and anhydrous Et_3N (0.32 g, 3.0 mmol) in MeCN (5 mL) were added dropwise simultaneously with the addition of 2 drops (0.1 mmol) of boron trifluoride diethyl etherate to a solution of 6-(4-methylphenyl)-1,5-diazabicyclo[3.1.0]hexane (**4a**) (0.52 g, 3.0 mmol) obtained by a standard procedure[29] in anhydrous MeCN (10 mL) at 0÷—4 °C in the flow of Ar, the stirring at this temperature was continued for 30 min, then the reaction mixture was spontaneously heated to 44 °C and kept at this temperature for 2 h. The solvent was evaporated *in vacuo* of a water-jet pump. Compound **19** was isolated by column chromatography on SiO_2 (0.060—0.200 mm, 60 A, ACROS) using hexane—ethyl acetate = (2 : 1) → (0.3 : 5) as an eluent. The yield of 1,2-bis(phenylacetyl)pyrazolidine (**19**) was 0.11 g (12%).

Compound **19** was obtained similarly from 6-(4-methoxyphenyl)-1,5-diazabicyclo[3.1.0]hexane (**4b**) and 6-(4-ethoxy-

phenyl)-1,5-diazabicyclo[3.1.0]hexane (**4c**) in 8 and 13% yields, respectively.

B. Phenylacetyl chloride (0.35 g, 2.3 mmol) and anhydrous Et_3N (0.16 g, 1.5 mmol) were added dropwise simultaneously with the addition of 1 drop (0.05 mmol) of boron trifluoride diethyl etherate to a solution of 6-(4-methylphenyl)-1,5-diazabicyclo[3.1.0]hexane (**4a**) (0.26 g, 1.5 mmol) in ionic liquid [bmim][BF_4] at 18 °C, the stirring at this temperature was continued until the color of the reaction mixture stopped to change (from light yellow to bright orange), for about 30 min. The ionic liquid was three times extracted with the hexane—ethyl acetate (4 : 1) mixture, the extract was concentrated on a rotary evaporator at ~35—40 °C using a water bath. The residue was subjected to separation on a column similarly to method ***A*** yielding **19** (0.5 g, 16%).

Synthesis of 1-arylidene-2-(arylacetyl)pyrazolidin-1-ium chlorides 21b—e (general procedure). Solutions of arylacetyl chloride (2.5 mmol) in anhydrous benzene (3 mL) and anhydrous Et_3N (2.7 mmol) in anhydrous benzene (5 mL) were added dropwise simultaneously with addition of 2 drops (0.1 mmol) of boron trifluoride diethyl etherate to a solution of compounds **4** (2.5 mmol) in anhydrous benzene (10 mL) at 18 °C in the flow of Ar, the stirring at this temperature was continued for 40 h. The solvent was evaporated *in vacuo* of a water-jet pump. Compounds **21** were isolated by extraction with boiling hexane for 30 min. The solvent was evaporated *in vacuo* of a water-jet pump to obtain 1-(4-ethoxybenzylidene)-2-(phenylacetyl)pyrazolidin-1-ium chloride (**21c**) (0.4 g, 42%). 1-(4-Methoxybenzylidene)-2-(phenylacetyl)pyrazolidin-1-ium chloride (**21b**) (0.17 g, 18%), 1-(4-ethoxybenzylidene)-2-(4-methylphenylacetyl)pyrazolidin-1-ium chloride (**21d**) (0.14 g, 16%), and 1-(4-ethoxybenzylidene)-2-(2,4-dinitrophenylacetyl)pyrazolidin-1-ium chloride (**21e**) (0.16 g, 14%) were obtained similarly, but failed to be isolated in pure form and were characterized only with spectral data (see Table 5).

Hydrolysis of 1-(4-ethoxybenzylidene)-2-(phenylacetyl)pyrazolidin-1-ium chloride (21c). Water (5 mL) was added to a solution of 1-(4-ethoxybenzylidene)-2-(phenylacetyl)pyrazolidin-1-ium chloride (**21c**) (1.2 g, 3.3 mmol) in benzene (5 mL), the mixture was stirred for 2 h, followed by addition of 10% aq. $NaHCO_3$ (10 mL), and the stirring was continued for 2 h. The organic layer was separated, dried with $MgSO_4$. The residue was subjected to column chromatography on SiO_2 (0.060—0.200 mm, 60 A, ACROS) using ethyl acetate—hexane (2 : 1) → (1 : 0) as an eluent to obtain 1-phenylacetylpyrazolidine **14a** (0.08 g, 12%) as a yellow oil, 1-phenylacetyl-4,5-dihydropyrazole (**23**) (0.24 g, 38%), and 4-ethoxybenzaldehyde (0.3 g, 60%).

4-(4-Ethoxyphenyl)-3,3-diphenyl-1,5-diazabicyclo[3.3.0]octan-2-one (or 3-(4-ethoxyphenyl)-2,2-diphenyltetrahydro-1*H*,5*H*-pyrazolo[1,2-*a*]pyrazol-1-one) (**12a**). Solutions of diphenylacetyl chloride (0.58 g, 2.5 mmol) in anhydrous benzene (3 mL) and anhydrous Et_3N (2.7 mmol) in anhydrous benzene (5 mL) were added dropwise simultaneously with the addition of 2 drops (0.1 mmol) of boron triflouoride diethyl etherate to a solution of 6-(4-ethoxyphenyl)-1,5-diazabicyclo[3.1.0]hexane (**4c**) (0.51 g, 2.5 mmol) in anhydrous benzene (10 mL) at 18 °C in the flow of Ar, the mixture was stirred at this temperature for 48 h. The solvent was evaporated *in vacuo* of a water-jet pump. The residue was extracted with boiling hexane for 40 min. Upon cooling the solution obtained, a precipitate of compound (**12a**) was formed, which was purified by recrystallization from acetone, the yield was 0.1 g (10%). Concentration of the mother liquor gave the residue, which according to the ^1H and ^{13}C NMR spectral data contained 2-(diphenylacetyl)-1-(4-ethoxybenzylidene)-pyrazolidin-1-ium chloride **21f** in the mixture with **12a**.

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