Tetrahedron 65 (2009) 7662–7672

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

3-Alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)-acrylonitriles as masked 1,3-dipoles

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ARTICLE INFO

Article history:
Received 10 March 2009
Received in revised form 9 June 2009
Accepted 25 June 2009
Available online 2 July 2009

Keywords:
1,2-Diazadiene
Thioaminal
Azomethine ylides
Dipolarophile

ABSTRACT

Reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles with maleimides, dimethyl maleate and dimethylacetylene dicarboxylate were carried out to give octahydro-pyrrolo[3,4-*a*]pyrrolizin-4-ylidenes, hexahydro-pyrrolizines and 6,7-dihydro-5*H*-pyrrolizines. The formation of the synthesized compounds is explained by a 1,3-dipolar cycloaddition of an in situ generated azomethine ylide. The mechanisms of the formation of these active intermediates were discussed with the aid of density functional theory methods with the B3LYP functional 6-31G$^+$ calculations using the STQN method and chemical experiments.

1. Introduction

1,2-Diazabutadienes are very useful reagents in organic synthesis. The chemistry of the 1,2-diazabutadiene system mainly deals with the nucleophilic interaction of the terminal carbon atom with a large series of C- and hetero-nucleophiles.[1] In the case of the reactions of functionalized azadienes, the formation of various types of heterocyclic compounds occurs via a Michael type addition followed by cyclization with participation of either one of the nitrogen atoms of the diene system or of the functional group.[2] A variety of azoles (pyrroles, pyrazoles, imidazoles, thiazoles, thiadiazoles) and azines (pyrazines, piperazines and triazines) were prepared based on the reactions of 1,2-diazadienes.[1,2] Tetrahydropyridazines and *N*-aminopyrroles were synthesized by [4+2] cycloadition of diazadienes with alkenes and enamines.[3] Before our preliminary report there were no data in the literature on the chemical properties of 1,2-diazadienes bearing an *S*,*N*-acetal group.[4] It was shown there that these compounds reacted with *N*-phenyl- and *N*-methyl maleimides to form [3+2] adducts via initally formed azomethine ylides.

It is worth noting that the chemistry of azomethine ylides remains the subject of intensive research of organic chemists for the preparation of various heterocyclic compounds including those that contain fragments of natural products[5] and other bioactive molecules,[6] that have found wide applications as chiral ligands and organocatalysts in asymmetric synthesis[7] and for the construction of new materials in nanoscience and nanotechnology.[8] Several methods have been developed for the synthesis of azomethine ylides: ring opening of aziridines,[9] decarboxylation of arylidene α-amino acids,[10] 1,2-prototropy[11] or metallotropy[12] of iminoesters, deprotonation of iminium salts,[13] desilylation of imines[14] or destannylation of (2-azaallyl)stannates.[15] At the same time, the use of diazabutadienes with a terminal conjugated *S*,*N*-thioaminal function as starting compounds to generate azomethine ylides was not known except for our preliminary publication.[4]

We report here the study of the mechanism of generation of azomethine ylides from 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles and their interaction with dipolarophiles.

2. Results and discussion

In terms of frontier molecular orbital (FMO) theory, in which a reaction takes place by maximizing overlap of the HOMO and the LUMO, azomethine ylides can be considered to be electron-rich, and the dominant interaction involves the HOMO of the azomethine ylide with the LUMO of the dipolarophile. This is borne out by the general preference for the reaction of azomethine ylides with electron-poor alkenes and alkynes. Thus, we investigated the cycloaddition of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1** and **2** with substituted maleimides, dimethyl maleate and dimethyl acetylenedicarboxylate (DMAD).

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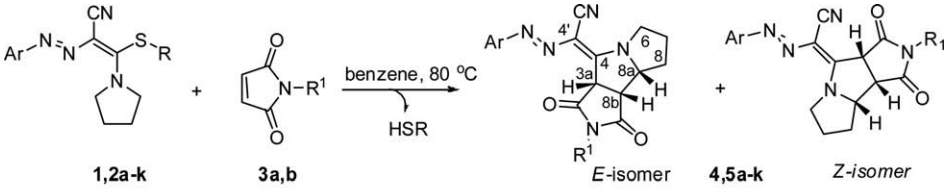
doi:10.1016/j.tet.2009.06.114

2.1. Reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles with maleimides

The starting *S*,*N*-ketenacetals **1**,**2a**–**k** were obtained by the reaction of arylhydrazonoacetothioamides with the corresponding haloalkanes as reported earlier.[4] Reactions of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1**,**2 a**–**k** with *N*-methyl- and *N*-phenylmaleimides **3a**–**b** have been carried out in benzene at reflux in the presence of 5 equiv of dipolarophile for 0.5–10 h resulting in solid products in good yields (71–98%) (Scheme 1, Table 1). The IR-, mass-, ^{1}H and ^{13}C NMR spectra are in good agreement with the structures of the tricyclic pyrrolo[3,4-*a*]pyrrolizines **4** and **5** and refute the structure of the initially proposed pyridazines.[4a] The IR spectra of all prepared compounds exhibit an absorption band corresponding to the cyano group at 2200 cm^{-1}.



3 R^1 = Me (**a**), Ph (**b**)
4 R^1 = Me Ar = 4-$NO_2C_6H_4$ (**a**), 4-$CF_3C_6H_4$ (**b**), 4-EtOOCC_6H_4 (**c**), 2-$CF_3C_6H_4$ (**d**), 2,4-$Cl_2C_6H_3$ (**e**), 4-ClC_6H_4 (**f**), 2-Cl-4-MeC_6H_3 (**g**), C_6H_5 (**h**), 4-MeC_6H_4 (**i**), 4-EtOC_6H_4 (**j**), 4-MeOC_6H_4 (**k**)
5 R^1 = Ph Ar = 4-$NO_2C_6H_4$ (**a**), 4-$CF_3C_6H_4$ (**b**), 4-EtOOCC_6H_4 (**c**), 2-$CF_3C_6H_4$ (**d**), 2,4-$Cl_2C_6H_3$ (**e**), 4-ClC_6H_4 (**f**), 2-Cl-4-MeC_6H_3 (**g**), C_6H_5 (**h**), 4-MeC_6H_4 (**i**), 4-EtOC_6H_4 (**j**), 4-MeOC_6H_4(**k**)

Scheme 1.

Table 1
The time of conversion and yields of cycloadducts **4** and **5** for the reaction cycloaddition of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1** and **2** with *N*-methyl- and *N*-phenylmaleimides **3**

Entry	Compounds **1** and **2**			Reaction with **3a** (R^1=Me)		Reaction with **3b** (R^1=Ph)	
	N	Ar	R	Time of conversion **1** and **2** (h)	Yield[a] of cycloadduct **4** (%)	Time of conversion **1** and **2** (h)	Yield[a] of cycloadduct **5** (%)
1	**1a**	4-$NO_2C_6H_4$	Me	0.5	85	0.5	90
2	**2a**		Allyl	0.3	92	0.3	85
3	**1b**	4-$CF_3C_6H_4$	Me	1.0	99	1.0	98
4	**2b**		Allyl	0.5	95	0.5	95
5	**1c**	4-EtOOCC_6H_4	Me	1.0	90	1.1	87
6	**2c**		Allyl	0.5	89	0.5	95
7	**1d**	2-$CF_3C_6H_4$	Me	2.0	65	2.0	78
8	**2d**		Allyl	1.5	68	1.5	83
9	**1e**	2,4-$Cl_2C_6H_3$	Me	0.7	75	1.5	81
10	**2e**		Allyl	0.5	95	0.5	78
11	**1f**	4-ClC_6H_4	Me	3.0	97	2.5	84
12	**2f**		Allyl	0.5	95	0.7	80
13	**1g**	2-Cl-4-MeC_6H_3	Me	3.5	80	2.5	90
14	**2g**		Allyl	1.0	75	1.0	85
15	**1h**	Ph	Me	3.0	83	3.0	80
16	**2h**		Allyl	1.1	78	1.0	85
17	**1i**	4-MeC_6H_4	Me	5.5	85	5.0	75
18	**2i**		Allyl	4.0	75	4.0	71
19	**1j**	4-EtOC_6H_4	Me	10.0	73	10.0	78
20	**2j**		Allyl	6.5	71	6.0	80
20	**1k**	4-MeOC_6H_4	Me	10.0	83	10.0	78
22	**2k**		Allyl	7.0	80	7.0	71

[a] Yield after isolation and putification.

It should be noted that compounds **4** and **5** are present as a mixture of two isomers due to the fact that the intermediate azomethine ylides can isomerize. Indeed, two sets of signals are present in the NMR spectra. The most typical for the structures of pyrrolopyrrolizine-4-ylidines is the presence of two doublets at 4.7–5.10 ppm corresponding to the **3a** proton with $^3J_{3a-8b}$=8.2–8.9 Hz and two doublet of doublet signals with $^3J_{8b-3a}$=8.2–8.9; $^3J_{8b-8a}$=9.8–10.5 Hz and the shift of the doublet of multiplet signal of H8a (4.5–4.7 ppm) for 0.6–0.8 ppm downfield in comparison with the starting material. We can assume the all-*cis*-H structure by analogy with similar tricyclic compounds reported by Viehe et al.[16] that have coupling constants in the same range. Thus, cycloaddition of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1** and **2** with maleimides **3** takes place in a stereoselective manner to form *endo*-products.

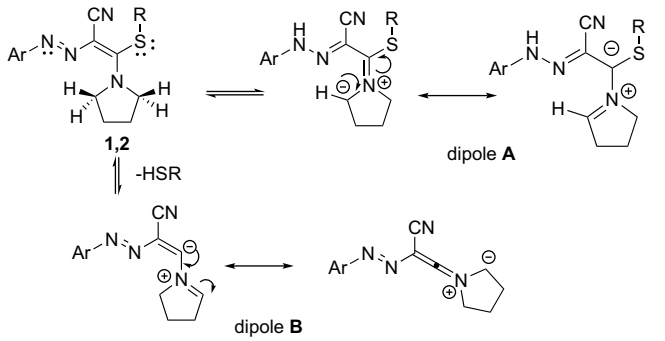
The assignment of the signals in the ^{1}H and ^{13}C NMR spectra was made on the base of DEPT, 2D COSY, HSQC, HMBC, NOESY experiments. Cross-peaks between the aromatic proton and the C3a proton in the *E*-isomer and the aromatic proton with the proton at position C6 are found in the NOESY spectra. The spin–spin couplings of C4 and C4′ with the C3a proton were confirmed by 2D COSY experiments. The signals of C4′ are displayed at 102.8 and 103.9 ppm as two doublets with coupling constants ^3J=1.3 and 0.6 Hz, and the signals of C4 at 158.9 and 154.3 ppm with coupling constants with H3a ^2J=6.4 and 3.4 Hz. The data of the NMR spectra confirm the formation of two new bonds, namely, C4–C3a and C8b–C8a.

It is interesting to note that the measurement of the ^{1}H NMR spectra of compounds **4a** has shown the degeneration of two doublets for proton **3a** and for the *ortho*-proton of the aromatics; first they became wider and closer and then coalescence was achieved for the compound **4a** at 120 °C. This confirms the existence of two isomers in equilibrium. The ratio of isomers at 25 °C depends on the nature of the substituent at the aromatic ring (Supplementary data). The equilibrium is shifted in favor of the *Z*-isomer for compounds with electron-withdrawing substituents and it is in favor of the *E*-isomer for compounds with electron-releasing substituents.

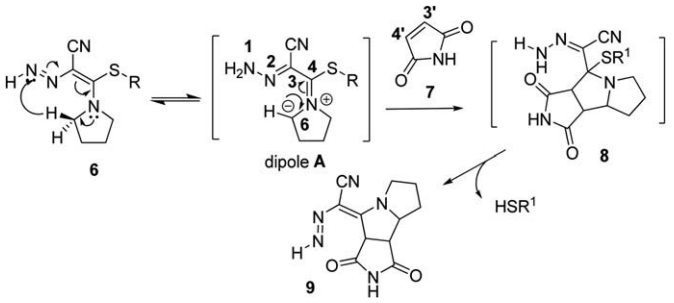
2.2. Theoretical study of interaction of *S*,*N*-ketene acetals 1 and 2 with maleimide: generation of azomethine ylide and its cycloaddition

Depending on whether elimination of thiols take place either from cycloaddition products or from starting compounds, intermediates for the reactions of thioaminals **1** and **2** with maleimides can be presented as ylides **A** or **B**, respectively (Scheme 2). Other mechanisms initiated by electrophilic/nucleophilic attack were rejected since observed reaction proceeds in non-polar benzene media.

In path 1 the first step is a 1,6-hydrogen shift occuring in compounds **1** and **2** yielding the intermediate **A**. In path 2 the formation of the azomethine ylide is accomplished by elimination of HSR. Using the B3LYP density functional[17] within a 6-31G* basis set we explored two possible mechanisms of generation of azomethine ylides **A** and **B**. The structure of substrates was simplified: no aryl substituent on nitrogen was taken into account (Scheme 3).



Scheme 2. The two proposed mechanisms for the generation of azomethine ylides.



Scheme 3. The mechanism of cycloaddition via the dipole **A.**

According to calculations, the formation of dipole **A** is thermodynamically more preferable than formation of dipole **B**. Dipole **B** was located 31.8 kcal/mol above the dipole **A** (Supplementary data). Therefore we concentrated our further efforts on the way leading to ylide **A** only.

The transition state of the hydrogen transfer TS_{Hshift} from carbon to nitrogen was successfully located at the B3LYP/6-31G* level of theory using the STQN method[18] (Fig. 1). Distances between reaction centers were r(C6···H7)=1.497 Å and r(N1···H7)=1.169 Å. The activation barrier for the process of dipole formation was calculated to be 14.9 kcal/mol.

This located transition state has attracted our special attention. Previously it was proposed by Lemal and later developed by a number of authors, that if there is a lone pair of electrons in the plane orthogonal to the π-system, the reaction mechanism for a sigmatropic shift and other pericyclic reactions can switch from pericyclic to pseudopericyclic.[19]

So the reaction can proceed comparably easy due to reduction of electron–electron repulsion thus lowering the activation barrier. A number of references with a detailed explanation of this concept is available elsewhere.[20] To answer the question if there is a change of mechanism one has to monitor the evolution of electron density localization within the reaction coordinate interval. Moreover, the aromaticity of the transition state should be determined, since pseudopericyclic transition states should not exhibit any aromaticity oppositely to the pericyclic transition states.

The evolution of the orbitals interaction with the flow of the reaction coordinate was done within a natural bond orbital (NBO) localization scheme. This method in regard to this problem was extensively tested and recognized as a powerful tool to distinguish the participation of orbitals. NBO analysis was performed for the points along the reaction pathway from **6** to dipole **A**. The pathway was reconstructed in both directions starting at TS_{Hshift} by instrict reaction coordinate (IRC) methodology. The screenshot presented in Figure 2 depicts the involvement of LP(N1) and π(N1=N2) into simultaneous of the new σ(N1–H7)-bond. The second order perturbation theory analysis of the Fock matrix in the NBO basis has shown that both orbitals, the lone pair of electrons of nitrogen LP(N1) and π(N1=N2), interact with the σ*(C6–H7) orbital, but the contribution of LP(N1) was somewhat more significant. Also, the decrease of orbital occupancy for the lone pair of electrons LP(N1) was more than the lack of electron occupancy from the π(N1=N2) orbital (1.972→1.857 vs 1.964→1.877).

Although a number of aromaticity criteria has been described in the literature,[21] the screening of anisotropy of the induced current density (ACID)[21a,22] should be the preferred one in this case due to the nonplanar geometry of the transition state. The calculated ACID profile gave some more insights into the nature of the located transition state for the transfer of hydrogen atom. This profile visually supports the evidence of the pericyclic nature of the transition state since the disconnection in the cyclic loop of the ACID function was located only at the isocontour line of 0.061 a.u. (Fig. 3) and not at the critical isocontour value less than 0.002 a.u. The absence of a disconnection confirms the pericyclic nature of the transition states as predicted for pseudopericyclic reactions by Herges et al.[21a]

The cycloaddition transition state $TS_{cycloadd}$ of maleimide **7** to dipole **A** was located 1.35 kcal/mol above the reactants energy level (Fig. 1); distances between reaction centers were r(C6C3′)=2.251 Å and (C4C4′)=2.745 Å. NBO analysis of $TS_{cycloadd}$ confirms that in that point two separate fragments are presented. The bonds C4C4′ and C6C3′ are not formed yet. The stabilization provided by π(C3′C4′)→π*(N5C6) interaction is more than the one given by the LP(C4)→π*(C3′C4′) electron density shift, 16.66 kcal/mol versus 9.09 kcal/mol. No other remarkable secondary interactions were listed.

Concerning the energetics of this reaction, the cycloaddition of maleimide **7** to 3-methylsulfanyl-2-azo-pyrrolidin-1-yl-acrylonitrile

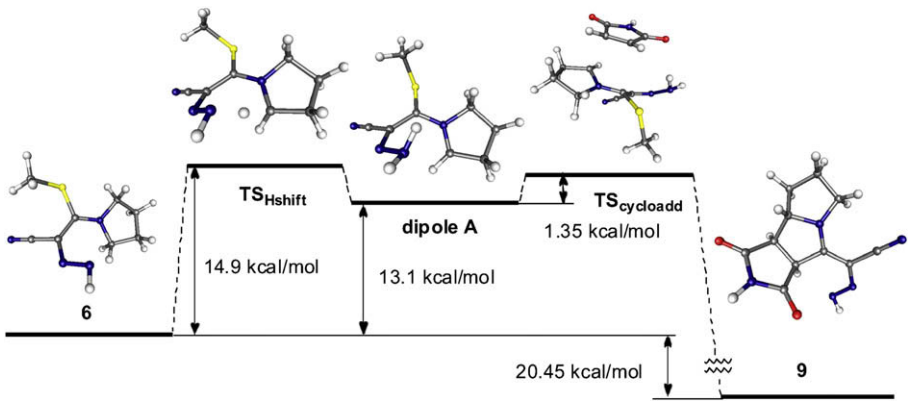


Figure 1. Stationary points **6**, TS_{Hshift}, dipole **A**, $TS_{cycloadd}$, **9** and energy profile for the reaction of 3-methylsulfanyl-2-azo-(pyrrolidin-1-yl)acrylonitrile **6** with maleimide **7** at the B3LYP level.

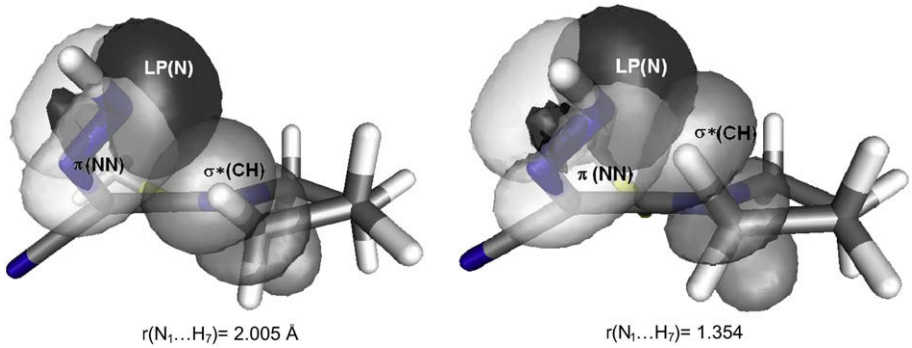


Figure 2. The screenshot for orbital picture based on NBO analisis during the hydrogen shift.

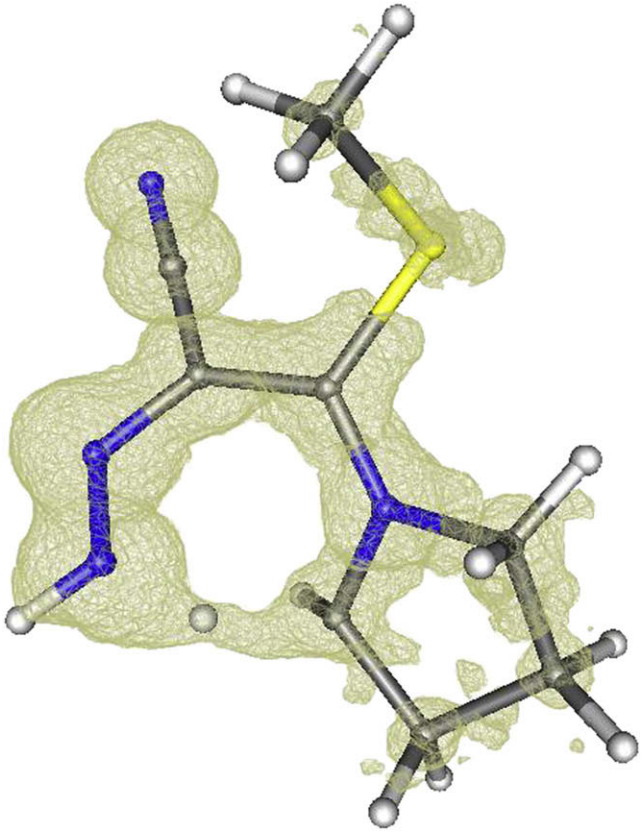
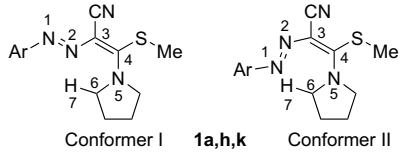


Figure 3. The ACID profile for transition state TS_{Hshift} at the CIV=0.050 a.u.



Scheme 4.

6 was calculated to be exothermic by 20.45 kcal/mol (B3LYP/6-31G*). The activation energy for the general process calculated in the gas phase, is about 15 kcal/mol, which is consistent with experimental conditions for the reaction of compounds **1** and **2** with maleimides **3** in benzene at 80 °C.

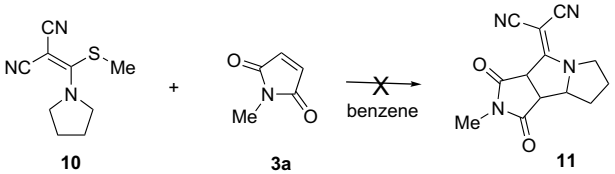
Experiments have shown that the time of conversion for compounds **1** and **2** mainly depends on their structure (Table 1). The introduction of electron-withdrawing substituents to the aryl group and replacement of methyl by allyl in the alkylsulfanyl moiety increase the rate of reaction.

We have carried out a number of estimations of the relative stability of two of the possible conformers for compounds **1** (Scheme 4). A 1,6 hydrogen-shift can take place only in conformer II. According to calculations in vacuum the difference in energy of the conformers decreases in the following order: **1k**(Ar=4-$MeOC_6H_4$)>**1h**(Ar=Ph)>**1a**(Ar=4-$NO_2C_6H_4$) (Supplementary data). In part, decreasing the relative stability of conformers is in accordance with the experimental data for the time of conversion of starting compounds **1** and **2** to final compounds **4** and **5**.

We propose that the introduction of electron-withdrawing substituents to the aromatic ring enhances the 1,6-proton shift. This is in accordance with a 0.1 ppm downfield α-CH_2 shift of in the ^1H NMR spectra that should enhance its dissociation, when the methoxy group at the aryl was replaced by nitro group. Within our theoretical study we have determined atom charges, bond lenghts of the azadiene system and occupancies of bonds in electrons together with the charges on the nitrogen atom and α-carbon atom of the pyrrolidine ring in compounds **1a**,**h**,**k** by the NBO method (MP2/6-31G*) (Supplementary data). According to these data the charge on the nitrogen atom of the azo group N1 turns more negative in the series of substituents at the aromatic ring **1a**(4-$NO_2C_6H_4$)>**1h**(Ph)>**1k**(4-$MeOC_6H_4$). Hence, the hydrogen shift should be enhanced in the same order.

As it is outlined above (Fig. 1) the activation barrier for hydrogen shift is higher than for cycloaddition step. So any factor like decrease of relative thermodynamic stability of starting compounds and increasing electron density, e.g., negative charge on N1 would increase the rate of this reaction. This supports our theory that the introduction of electron-withdrawing groups increases the conjugation of the nitrogen electron pair of the pyrrolidine ring with the aromatic ring via the diene system. Remarkably, the N1–H7 bond distance is shorter for the compounds that react faster (Supplementary data).

To determine the role of the azo group in the interaction process of *S*,*N*-acetals with maleimides, we have studied interaction of ketene *S*,*N*-acetal **10**, where the azo group is absent, with *N*-methylmaleimide **3a** (Scheme 5). We have shown that compound **10** does not react with maleimide under any conditions studied. It confirms the participation of the azo group in the generation process of the azomethine ylides from 1,2-diazadienes.



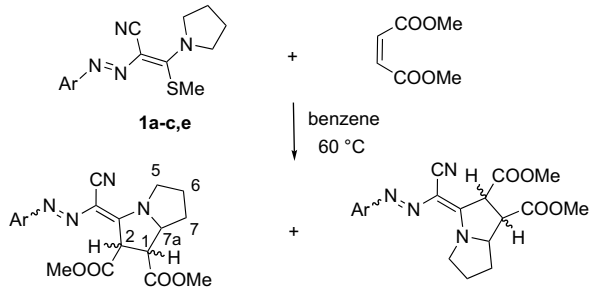
Scheme 5.

Indeed, the experimental and theoretical studies for the reaction of thioaminals **1** and **2** with maleimides **3** is consistent with the mechanism outlined in the Scheme 2. First the generation of azomethine ylide **A** occurs via 1,6-sigmatropic shift of hydrogen from pyrrolidine ring to N1 of the azo group. During the second step, ylide **A** reacts with the double bond of the maleimides to give cycloadducts **8**. The latter looses a thiole molecule to give final products **4** or **5**.

The process proceeds stereoselectively via an *endo*-transition state and the formation of two isomers can be explained by stereomutation of the 1,3-dipole.

2.3. Reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles with dimethyl maleate and dimethyl acetylenedicarboxylate

Heating of ketene-*S*,*N*-acetals **1** with dimethyl maleate in benzene followed by column chromatograpy allowed us to prepare hexahydro-pyrrolizines **12** as an inseparable mixture of four stereoisomers that are crystalline compounds of yellow or orange color (Scheme 6).



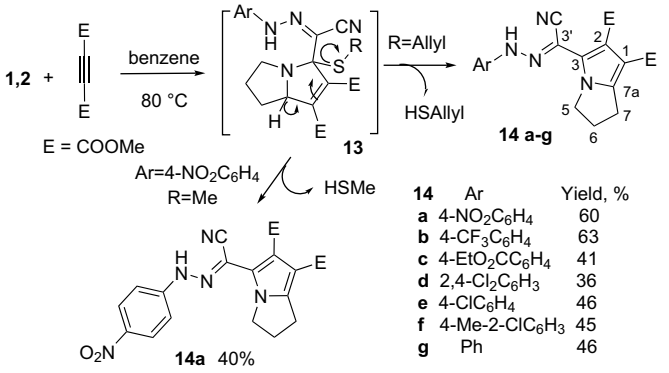
12	a	b	c	d
Ar	4-$NO_2C_6H_4$	4-$CF_3C_6H_4$	4-$EtOOCC_6H_4$	2,4-$Cl_2C_6H_3$
Yield,%	88	51	68	35

Scheme 6.

Their structures are consistent with their elemental analysis and spectroscopic data. Thus mass-spectra of the prepared compounds **12** contain peaks corresponding to their molecular masses. IR spectra of all prepared compounds exhibit an broad absorption bands corresponding to the cyano groups at 2200 cm^{-1} and broad absorption bands at 1715 and 1710 cm^{-1} corresponding to carbonyl groups. The ^1H NMR and ^{13}C NMR spectra are complicated. Several signals were combined, which hampered their assignment. At the same time we have registered four doublet signals in the range of 4.6–5 ppm corresponding to C2H with coupling constants $^3J_{1-2}$=8.5–9.5 Hz in the ^1H NMR spectra and four singlets of C7a at 70 ppm in the ^{13}C NMR spectra **12**. 2D TOCSY and 1D TOCSY with selective excitation allowed us to separate the 4 sets of signals for protons of bicyclical fragments of four stereo isomers. Those are resulted from the cis-, trans-isomerism for two double bonds (C=C and N=N) combined with inversion occurred on the N1 atom.

Although relatively large coupling constants were observed between H2 and H1, H1 and H7a (J=8.3–10.5 Hz), the formation of the *exo*/*endo* isomers should be taken into account. We admit that all sets of signals are not typical for protons in *trans* position, though analogously large coupling constants have also been observed between a *trans* hydrogen atom in cyclopentane derivatives bearing an electron-deficient substituent.[23] The observed lack of stereoselectivity for the cycloaddition with dimethyl maleate in comparison to the same reaction with maleimide might be due to the increased dipolarophile activity of dimethyl maleate and the spatial hindrance between two $COOCH_3$-groups in transition state.

The cycloaddition of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)-acrylonitriles **1** with DMAD was carried out in benzene at reflux (Scheme 7). It should be noted that the complete conversion of reaction is reached after 0.5–2.0 h and accompanied by the formation of a mixture of quite a few products that were difficult to separate to single components. Only in the case of compound **1a**, we managed to isolate a single product that was identified by spectroscopic data as 6,7-dihydro-5*H*-pyrrolizine **14a**.



14	Ar	Yield, %
a	4-$NO_2C_6H_4$	60
b	4-$CF_3C_6H_4$	63
c	4-$EtO_2CC_6H_4$	41
d	2,4-$Cl_2C_6H_3$	36
e	4-ClC_6H_4	46
f	4-Me-2-ClC_6H_3	45
g	Ph	46

Scheme 7.

The use of compounds **2** bearing an *S*-allyl group allowed us to prepare other derivatives of this series, compounds **14 a–g.** The mass-spectra of dihydropyrrolizines **14** exhibit peaks of molecular ions with intensity of 9–36%.

IR spectra of these compounds contain bands at 2220, 1700 and 1740 cm^{-1} corresponding to the cyano and two carbonyl groups, respectively (Fig. 4).

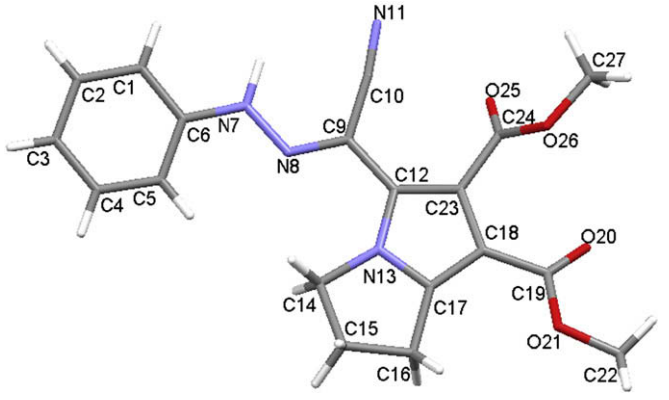


Figure 4. The X-ray data of 3-[cyano-(phenylhydrazono)methyl]-6,7-dihydro-5*H*-pyrrolizine-1,2-dicarboxylic acid dimethyl ester **14g**.

The formation of pyrrolizidines **14** was proposed to be a three-step process. Firstly, the generation of azomethine ylides of dipole **A** type occurred, followed by cycloaddition with DMAD. The elimination of methyl- or allylthiol from adducts **13** finalized the whole process.

3. Conclusion

In conclusion, we have demonstrated a new approach leading to the generation of azomethine ylides under mild conditions. A series of new pyrrolo[3,4-*a*]pyrrolizin-4-ylidenes **4** and **5** were

synthesized efficiently by 1,3-dipolar cycloaddition of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1** and **2** with maleimides. Experimental and theoretical investigation of the mechanisms of these reactions by DFT calculations allowed us to conclude that although the azo group is not included into the cyclic products it effects the mechanism of the generation of the azomethine ylides. The process depends on the type of the structural fragments on the sulfur and at the aromatic ring. The 1,3-dipolar cycloaddition reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles could be expanded to other electron-poor dipolarophiles such as dimethyl maleate and dimethyl acetylenedicarboxylate. 3-Alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles **1** and **2** are shown to be masked azomethine ylides that react with dipolarophiles via a concerted mechanism. Investigations of the scope of these reactions are in progress.

4. Experimental

4.1. General considerations

The IR data (potassium bromide) were obtained with an UR-20 spectrometer. The ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker DRX-400 instrument (400 MHz for ^{1}H and 100 MHz for ^{13}C) in DMSO-d_6 solvent with TMS as a standard. Chemical shifts and coupling constants were expressed in ppm and Hz. Mass spectra were recorded on a Varian MAT 311A mass spectrometer using the electron impact ionization technique (40–200 °C, 70 eV). Single crystal X-ray diffraction analyses were performed on a Bruker SMART APEXIICCD area-detector diffractometer.

Column chromatography was performed on silica gel (0.035–0.070, 60 Å) with chloroform/acetone (30:1). Routine monitoring of reactions was made using thin layer chromatography monitored by TLC was performed on Sorbfil UV–254. Solvents were dried and distilled according to the common procedure.

3-Alkylsulfanyl-2-arylazo-3-pyrrolidin-1-yl-acrylo-nitriles **1** and **2** were prepared by the procedure reported in our previous articles.[4]

4.1.1. Computational details

All calculations were carried out using the Gaussian03W package.[24] Geometries were completely optimized using Becke's hybrid HF density functional theory method[17] with the Lee–Yang–Parr correlation functional[25] and the 6-31G(d) basis set [B3LYP/6-31G(d)]. The nature of the various critical points was established by performing frequency computations. IRC calculations[24] were also performed for transition-state structures. The NBO analysis[25] was performed to explore the electronic structure of located stationary points [MP2/6-31G(d)]. ACID calculations were performed at B3LYP/6-31G(d) level. To estimate the energetic of isomerism for of **1a**,**h**,**k**, both possible conformers have optimized at MP2/6-31G(d) level of theory. All visualization was done with the gOpenMol program.[26]

4.2. Reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles with maleimides

General procedure: A solution of 0.5 mmol **1** or **2** and 2.5 mmol corresponding maleimide **3a**,**b** was refluxed in 5 mL benzene (TLC). The reaction mixture was evaporated and purified by column chromatography.

4.2.1. (4-Nitrophenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4a**)

Yellow crystals; yield 162 mg (85%) from **1a** and 175 mg (92%) from **2b**; yield 162 mg (85%); mp 278–280 °C; IR (KBr) ν_{max} 2965 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^{1}H NMR δ_H 1.34–1.62 (m, 1H, CH), 1.92–2.13 (m, 1H, CH_2), 2.14–2.40 (m, 2H, CH_2), 2.88 and 2.90 (s and s, 3H, NMe), 3.75 (dd, 1H, J=8.5, 9.9 Hz, CH), 3.77–3.89 (m, 2H, CH_2), 4.51–4.82 (m, 1H, CH_2), 4.87 and 5.17 (d and d, 1H, J=8.5 Hz, CH), 7.68 and 7.94 and 8.25 (AA′XX′ and AA′XX′, 4H, J=9.1 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 58:42). MS *m*/*z* (%) 380 (M$^+$, 51). Anal. Calcd for $C_{18}H_{16}N_6O_4$: C, 56.84; H, 4.24; N, 22.09. Found: C, 56.72; H, 4.19; N, 21.97%.

4.2.2. (4-Trifluoromethylphenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4b**)

Yellow powder; yield 200 mg (99%) from **1b** and 191 mg (92%) from **2b**; mp 313–315 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^{1}H NMR δ_H 1.37–1.49 (m, 1H, CH), 1.94–2.05 (m, 1H, CH_2), 1.12–2.25 (m, 2H, CH_2), 2.85 and 2.87 (s and s, 3H, Me), 3.70–3.88 (m, 3H, CH), 4.55–4.64 (m, 1H, CH), 4.85 and 5.18 (d and d, 1H, J=8.6 Hz, CH), 7.69 (d, 1H, J=8.1 Hz, Ar), 7.79 (d, 2H, J=7.6 Hz, Ar), 7.93 (d, 1H, J=8.1 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 57:43). MS *m*/*z* (%) 403 (M$^+$, 20.4). Anal. Calcd for $C_{19}H_{16}F_3N_5O_2$: C, 56.58; H, 4.00; N, 17.36. Found: C, 56.52; H, 3.96; N, 17.29%.

4.2.3. 4-[Cyano-(2-methyl-1,3-dioxooctahydropyrrolo-[3,4-a]pyrrolizin-4-ylidene)-methyl]-azobenzoic acid ethyl ester (**4c**)

Yellow powder; yield 183 mg (90%) from **1c** and 181 mg (89%) from **1c**; mp 255–257 °C; IR (KBr) ν_{max} 2950 (CH_2), 2200 (CN), 1705 (CO) cm^{-1}; ^{1}H NMR δ_H 1.37 and 1.38 (t and t, 3H, J=7.0 Hz, Me), 1.43–1.59 (m, 1H, CH_2), 1.97–2.12 (m, 1H, CH_2), 2.15–2.36 (m, 2H, CH_2), 2.89 and 2.91 (s and s, 3H, Me), 3.63–3.92 (m, 3H, CH_2), 4.32 and 4.33 (q and q, 2H, J=7.0 Hz, CH_2), 4.48–4.67 (m, 1H, CH_2), 4.83 and 5.14 (d and d, 1H, J=8.5 Hz, CH), 7.58 (d, 1H, J=8.8 Hz, Ar), 7.83 (d, 1H, J=8.8 Hz, Ar), 8.0 (d, 2H, J=8.8 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 57:43). MS *m*/*z* (%) 407 (M$^+$, 35.9). Anal. Calcd for $C_{21}H_{21}N_5O_4$: C, 61.91; H, 5.20; N, 17.19. Found: C, 61.85; H, 5.16; N, 17.03%.

4.2.4. (2-Trifluoromethylphenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4d**)

Dark yellow powder; yield 131 mg (65%) from **1d** and 137 mg (68%) from **2d**; mp 245–247 °C; IR (KBr) ν_{max} 2980 (CH2), 2200 (CN), 1710 (CO) cm^{-1}; ^{1}H NMR δ_H 1.36–1.50 (m, 1H, CH_2), 1.94–2.04 (m, 1H, CH_2), 1.13–2.25 (m, 2H, CH_2), 2.85 and 2.87 (s and s, 3H, Me), 3.68–3.85 (m, 3H, CH), 4.54–4.63 (m, 1H, CH), 4.84 and 5.19 (d and d, 1H, J=8.3 Hz, CH), 7.42–7.48 (m, 1H, Ar), 7.68 (dd, 1H, J=7.7, 0.8 Hz, Ar), 7.77 (dd, 1H, J=7.7, 0.8 Hz, Ar), 7.51 and 8.03 (d and d, 1H, J=8.1 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 60:40). MS *m*/*z* (%) 403 (M$^+$, 17.9). Anal. Calcd for $C_{19}H_{16}F_3N_5O_2$: C, 56.58; H, 4.00; N, 17.36. Found: C, 56.55; H, 3.94; N, 17.14%.

4.2.5. (2,4-Dichlorophenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4e**)

Yellow powder; yield 151 mg (75%) from **1e** and 175 mg (92%) from **2e**; mp 304–306 °C; IR (KBr) ν_{max} 2965 (CH_2), 2190 (CN), 1700 (CO) cm^{-1}; ^{1}H NMR δ_H 1.53–1.40 (m, 1H, CH), 1.99–2.07 (m, 1H, CH_2), 2.08–2.38 (m, 2H, CH_2), 2.89 and 2.92 (s and s, 3H, Me), 3.62–3.83 (m, 3H, CH), 4.51–4.67 (m, 1H, CH_2), 4.83 and 5.13 (d and d, 1H, J=8.2 Hz, CH), 7.22–7.32 (m, 2H, Ar), 7.48 (dd, 1H, J=7.1, 2.4 Hz, Ar), 7.91 (d, 1H, J=8.7 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 66:34). MS *m*/*z* (%) 403 (M$^+$, 33.2). Anal. Calcd for $C_{18}H_{15}Cl_2N_5O_2$: C, 53.48; H, 3.74; N, 17.32. Found: C, 53.41; H, 3.68; N, 17.30%.

4.2.6. (4-Chlorophenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4f**)

Yellow powder; yield 178 mg (97%) from **1f** and 175 mg (95%) from **2f**; mp 278–180 °C; IR (KBr) ν_{max} 2960 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^{1}H NMR δ_H 1.32–1.55 (m, 1H, CH_2), 1.94–2.11 (m, 1H,

CH_2), 2.12–2.31 (m, 2H, CH_2), 2.88 and 2.90 (s and s, 3H, Me), 3.61–3.88 (m, 3H, CH), 4.45–4.63 (m, 1H, CH), 4.78 and 5.11 (d and d, 1H, J=8.4 Hz, CH), 7.39 and 7.52 and 7.75 (AA′XX′, 4H, J=8.8 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 57:43). MS *m*/*z* 368 (M^+, 27.1). Anal. Calcd for $C_{18}H_{16}ClN_5O$: C, 58.62; H, 4.10; N, 18.94. Found: C, 58.57; H, 4.08; N, 18.83%.

4.2.7. (2-Chloro-4-methylphenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4g**)

Yellow powder; yield 153 mg (80%) from **1g** and 144 mg (75%) from **2g**; mp 301–303 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 1.35–1.55 (m, 1H, CH_2), 1.97–2.13 (m, 1H, CH_2), 2.15–2.2 (m, 2H, CH_2), 2.36 (s, 3H, Me), 2.89 and 2.92 (s and s, 3H, Me), 3.7–3.8 (m, 3H, CH_2), 4.48–4.63 (m, 1H, CH), 4.80 and 5.12 (d and d, 1H, J=8.4 Hz, CH), 7.07 (d, 1H, J=7.7 Hz, Ar), 7.18–7.30 (m, 1.5H, Ar), 7.77 (d, 0.5H, J=8.1 Hz, Ar); ^{13}C NMR δ_C 20.3, 25.2, 25.3, 26.2, 26.4, 26.7, 26.9, 40.0, 40.4, 45.9, 48.9, 55.1, 57.2, 69.9, 70.3, 103.3, 104.6, 114.3, 114.7, 117.3, 118.7, 128.1, 128.5, 130.0, 130.4, 130.5, 130.8, 138.8, 139.2, 146.6, 146.8, 154.7, 159.2, 172.5, 171.9, 174.4, 174.5 (mixture of *Z*- and *E*-isomers in ratio 56:44). MS *m*/*z* (%) 383 (M^+, 25.8). Anal. Calcd for $C_{19}H_{18}ClN_5O_2$: C, 59.45; H, 4.73; N, 17.51. Found: C, 59.37; H, 4.64; N, 17.47%.

4.2.8. Phenylazo-(2-methyl-1,3-dioxo-octahydropyrrolo-[3,4-a]pyrrolizin-4-ylidene)acetonitrile (**4h**)

Yellow powder; yield 140 g (83%) from **1h** and 131 mg (78%) from **2h**; mp 314–316 °C; IR (KBr) ν_{max} 2965 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 1.30–1.52 (m, 1H, CH), 1.94–2.10 (m, 1H, CH), 2.12–2.30 (m, 2H, CH_2), 2.88 and 2.90 (s and s, 3H, N–Me), 3.62–3.92 (m, 3H, CH and CH_2), 4.45–4.62 (m, 1H, CH), 4.78 and 5.13 (d and d, 1H, J=8.8 Hz, CH), 7.21–7.32 (m, 1H, Ar), 7.35–7.45 (m, 2H, Ar), 7.40 (d, 4H, 1H, J=7.8 Hz, Ar), 7.55 (d, 4H, 1H, J=7.8 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 50:50). MS *m*/*z* (%) 335 (M^+, 25). Anal. Calcd for $C_{18}H_{17}N_5O_2$: C, 64.47; H, 5.11; N, 20.88. Found: C, 64.26; H, 5.05; N, 20.96%.

4.2.9. (2-Methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-p-tolylazoacetonitrile (**4i**)

Yellow powder; yield 148 g (85%) from **1i** and 130 mg (75%) from **2i**; mp 305–307 °C; IR (KBr) ν_{max} 2955 (CH_2), 2190 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 1.30–1.52 (m, 1H, CH_2), 1.93–2.11 (m, 1H, CH_2), 2.12–2.31 (m, 2H, CH_2), 2.37 (s, 3H, Me), 2.88 and 2.91 (s and s, 3H, Me), 3.60–3.93 (m, 3H, CH), 4.40–4.62 (m, 1H, CH), 4.76 and 5.10 (d and d, 1H, J=8.6 Hz, CH), 7.19 and 7.42 and 7.20 and 7.65 (AA′′XX′, 4H, J=8.4 Hz, Ar); ^{13}C NMR δ_C 20.8, 25.2, 25.3, 26.4, 26.6, 26.8, 26.9, 39.9, 40.1, 46.1, 48.9, 56.9, 57.0, 69.5, 70.0, 102.5, 103.6, 114.8, 115.1, 121.2, 121.6, 129.4, 129.7, 137.5, 137.9, 150.6, 150.9, 154.1, 158.7, 172.0, 172.8, 174.6, 174.7 (mixture of *Z*- and *E*-isomers in ratio 48:52). MS *m*/*z* (%) 349 (M^+, 20.9). Anal. Calcd for $C_{19}H_{19}N_5O_2$: C, 65.32; H, 5.48; N, 20.04. Found: C, 65.25; H, 5.43; N, 19.89%.

4.2.10. (4-Ethoxyphenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4j**)

Yellow powder; yield 138 g (73%) from **1j** and 135 mg (71%) from **2j**; mp 259–261 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 1.29–1.43 (m, 1H, CH_2), 1.35 and 1.34 (t and t, 3H, J=7.0 Hz, Me), 1.90–2.01 (m, 1H, CH), 2.09–2.23 (m, 2H, CH), 2.84 and 2.86 (s and s, 3H, Me), 3.61–3.84 (m, 3H, CH), 4.06 and 4.07 (q and q, 2H, J=7.0 Hz, CH_2), 4.46–4.55 (m, 1H, CH), 4.75 and 5.11 (d and d, 1H, J=8.7 Hz, CH), 6.93 and 6.98 (d and d, 2H, J=8.8 Hz, Ar), 7.51 and 7.71 (d and d, 2H, J=8.8 Hz, Ar); ^{13}C NMR δ_C 14.59, 14.6, 25.2, 25.3, 26.4, 26.6, 26.8, 26.9, 40.3, 40.6, 46.1, 48.9, 56.7, 56.8, 63.2, 63.3, 69.4, 69.8, 102.4, 103.5, 114.5, 114.8, 114.9, 115.2, 122.8, 123.1, 146.6, 146.9, 153.5, 158.2, 158.6, 158.8, 172.1, 172.9, 174.6, 174.7 (mixture of *Z*- and *E*-isomers in ratio 35:65). MS *m*/*z* (%) 379 (M^+, 17.9). Anal. Calcd for $C_{20}H_{21}N_5O_3$: C, 63.31; H, 5.58; N, 18.46. Found: 63.27; H, 5.52; N, 18.42%.

4.2.11. (4-Methoxyphenylazo)-(2-methyl-1,3-dioxo-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**4k**)

Yellow powder; yield 151 mg (83%) from **1k** and 146 mg (80%) from **2k**; mp 259–261 °C; IR (KBr) ν_{max} 2965 (CH_2), 2195 (CN), 1705 (CO) cm^{-1}; ^1H NMR δ_H 1.27–1.52 (m, 1H, CH), 1.95–2.11 (m, 1H, CH), 2.12–2.32 (m, 2H, CH_2), 2.89 and 2.91 (s, 3H, NMe), 3.62–3.93 (m, 3H, CH and CH_2), 3.82 (s, 3H, OMe), 4.43–4.58 (m, 1H, CH), 4.74 and 5.10 (d and d, 1H, J=8.8 Hz, CH), 7.70 and 7.92 (AA′XX′, 4H, J=8.8 Hz, Ar); ^{13}C NMR δ_C 25.15, 25.2, 26.4, 26.6, 26.7, 26.9, 40.3, 40.5, 46.1, 48.9, 55.3, 56.7, 56.8, 69.3, 69.8, 102.4, 103.4, 114.0, 114.4, 114.8, 115.1, 122.7, 123.1, 146.7, 147.0, 153.4, 158.2, 159.2, 159.4, 172.0, 172.8, 174.5, 174.6 (mixture of *Z*- and *E*-isomers in ratio 46:54). MS *m*/*z* (%) 365 (M^+, 17.9). Anal. Calcd for $C_{19}H_{19}N_5O_3$: C, 62.46; H, 5.24; N, 19.17. Found: C, 62.39; H, 5.32; N, 19.09%.

4.2.12. (4-Nitrophenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**5a**)

Yellow powder; yield 198 mg (90%) from **1a** and 188 mg (85%) from **1b**; mp 273–275 °C; IR (KBr) ν_{max} 2950 (CH_2), 2200 (CN), 1720 (CO) cm^{-1}; ^1H NMR δ_H 1.53–1.69 (m, 1H, CH_2), 2.13–1.99 (m, 1H, CH_2), 2.40–2.16 (m, 2H, CH_2), 4.06–3.73 (m, 3H, CH and CH_2), 4.79–4.66 (m, 1H, CH), 5.04 and 5.36 (d and d, 1H, J=8.4 Hz, CH), 7.28–7.59 (m, 5H, Ar), 7.72 (d, 1H, J=8.8 Hz, Ar), 7.89 (d, 1H, J=8.7 Hz, Ar), 8.27 (d, 1H, J=8.7 Hz, Ar), 8.29 (d, 1H, J=8.7 Hz, Ar); ^{13}C NMR δ_C 26.2, 26.4, 26.8, 27.0, 30.7, 35.7, 46.2, 49.5, 57.8, 57.9, 70.9, 71.4, 104.0, 105.3, 114.1, 114.4, 121.8, 122.1, 124.8, 125.0, 127.3, 127.5, 128.7, 128.8, 132.2, 132.5, 145.5, 145.6, 156.3, 156.8, 157.2, 160.5, 162.3, 170.8, 171.5, 173.6, 173.7 (mixture of *Z*- and *E*-isomers in ratio 59:41). MS *m*/*z* (%) 442 (M^+, 95.2). Anal. Calcd for $C_{23}H_{18}N_6O_4$: C, 62.44; H, 4.10; N, 18.99. Found: C, 62.36; H, 4.00; N, 18.76%.

4.2.13. (4-Trifluorophenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)acetonitrile (**5b**)

Yellow powder; yield 228 mg (98%) from **1b** and 220 mg (95%) from **2b**; mp 281–283 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 1.55–1.65 (m, 1H, CH), 1.99–2.08 (m, 1H, CH), 2.17–2.34 (m, 2H, CH_2), 3.75–3.97 (m, 3H, CH), 4.63–4.74 (m, 1H, CH), 5.0 and 5.34 (d and d, 1H, J=8.6 Hz, CH), 7.34 (dd, 2H, J=6.3, 8.2 Hz, Ar), 7.40–7.55 (m, 3H, Ar), 7.69–7.83 (m, 3H, Ar), 7.88 (d, 1H, J=8.9 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 58:42). MS *m*/*z* (%) 465 (M^+, 23.9). Anal. Calcd for $C_{24}H_{18}F_3N_5O_2$: C, 61.93; H, 3.90; N, 15.05. Found: C, 61.86; H, 3.86; N, 14.96%.

4.2.14. 4-{[Cyano-(1,3-dioxo-2-phenyl-octahydro-pyrrolo[3,4-a]pyrrolizin-4-ylidene)-methyl]-azo}-benzoic acid ethyl ester (**5c**)

Yellow powder; yield 205 mg (87%) from **1c** and 223 mg (95%) from **1c**; mp 235–237 °C; IR (KBr) ν_{max} 2950 (CH_2), 2200 (CN), 1715 (CO) cm^{-1}; ^1H NMR δ_H 1.36 and 1.38 (t and t, 3H, J=7.3 Hz, Me), 1.51–1.73 (m, 1H, CH_2), 2.02–2.17 (m, 1H, CH_2), 2.17–2.41 (m, 2H, CH_2), 3.83 (dd, 1H, J=8.8, 10.5 Hz, CH), 3.85–4.03 (m, 2H, CH_2), 4.30 and 4.32 (q and q, 2H, J=7.3 Hz, CH_2), 4.57–4.75 (m, 1H, CH_2), 4.98 and 5.29 (d and d, 1H, J=8.8 Hz, CH), 7.24–7.54 (m, 5H, Ar), 7.60 (d, 1H, J=8.7 Hz, Ar), 7.79 (d, 1H, J=8.7 Hz, Ar), 7.98 (d, 1H, J=8.7 Hz, Ar), 8.02 (d, 1H, J=8.7 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 60:40). MS *m*/*z* (%) 469 (M^+, 63.7). Anal. Calcd for $C_{26}H_{23}N_5O_4$: C, 66.51; H, 4.94; N, 14.92. Found: C, 66.48; H, 4.89; N, 14.86%.

4.2.15. (2-Trifluoromethylphenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**5d**)

Orange powder; yield 181 mg (78%) from **1d** and 193 mg (83%) from **1d**; mp 258–260 °C; IR (KBr) ν_{max} 2980 (CH_2), 2200 (CN), 1720 (CO) cm^{-1}; ^1H NMR δ_H 1.51–1.63 (m, 1H, CH), 1.99–2.08 (m, 1H, CH),

2.17–2.34 (m, 2H, CH_2), 3.75–3.98 (m, 3H, CH), 4.63–4.72 (m, 1H, CH), 4.99 and 5.35 (d and d, 1H, J=8.9 Hz, CH), 7.34 (dd, 2H, J=6.4, 7.6 Hz, Ar), 7.39–7.56 (m, 4.4H, Ar), 7.62–7.81 (m, 2H, Ar), 7.94 (d, J=8.3 Hz, 0.6H, Ar) (mixture of *Z*- and *E*-isomers in ratio 61:39). MS *m*/*z* (%) 465 (M^+, 20.8). Anal. Calcd for $C_{24}H_{18}F_3N_5O_2$: C, 61.93; H, 3.90; N, 15.05. Found: C, 61.88; H, 3.87; N, 14.89%.

4.2.16. (2,4-Dichlorophenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)acetonitrile (**5e**)

Yellow powder; yield 189 mg (81%) from **1e** and 182 mg (78%) from **2e**; mp 243–245 °C; IR (KBr) ν_{max} 2960 (CH_2), 2215 (CN), 1725 (CO) cm^{-1}; ^1H NMR δ_H 1.58–1.69 (m, 1H, CH_2), 2.05–2.17 (m, 1H, CH), 2.17–2.38 (m, 2H, CH_2), 3.80–3.99 (m, 3H, CH_2), 4.72–4.60 (m, 1H, CH), 4.98 and 5.28 (d and d, 1H, J=8.9 Hz, CH), 7.22–7.50 (m, 7H, Ar), 7.84 (d, 1H, J=8.6 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 70:30). MS *m*/*z* (%) 466 (M+, 10.1). Anal. Calcd for $C_{23}H_{17}Cl_2N_5O_2$: C, 59.24; H, 3.67; N, 17.19. Found: C, 59.19; H, 3.61; N, 17.03%.

4.2.17. (4-Chlorophenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)acetonitrile (**5f**)

Yellow powder; yield 181 mg (84%) from **1f** and 172 mg (80%) from **2f**; mp 217–219 °C; IR (KBr) ν_{max} 2955 (CH_2), 2195 (CN), 1718 (CO) cm^{-1}; ^1H NMR δ_H 1.49–1.62 (m, 1H, CH_2), 1.98–2.07 (m, 1H, CH_2), 2.14–2.31 (m, 2H, CH_2), 3.90 and 3.94 (dd and dd, 1H, J=8.7, 9.8 Hz, CH), 3.73–3.87 (m, 2H, CH_2), 4.59–4.69 (m, 1H, CH), 4.98 and 5.29 (d and d, 1H, J=8.7 Hz, CH), 7.30–7.36 (m, 2H, Ar), 7.42–7.53 (m, 2H, Ar), 7.47 (d, 1H, J=8.8 Hz, Ar), 7.50 (d, 1H, J=8.8 Hz, Ar), 7.57 (d, 1H, J=8.8 Hz, Ar), 7.73 (d, 1H, J=8.8 Hz, Ar). MS *m*/*z* (%) 431 (M^+, 32.4). Anal. Calcd for $C_{23}H_{18}ClN_5O_2$: C, 63.97; H, 4.20; N, 16.22. Found: C, 63.92; H, 4.17; N, 16.14%.

4.2.18. (2-Chloro-4-methylphenylazo)-(1,3-dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-acetonitrile (**5g**)

Yellow powder; yield 200 mg (90%) from **1g** and 189 mg (85%) from **2g**; mp 281–283 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1720 (CO) cm^{-1}; ^1H NMR δ_H 1.51–1.70 (m, 1H, CH), 2.03–2.16 (m, 1H, CH), 2.18–2.34 (m, 2H, CH_2), 2.34 and 2.36 (s and s, 3H, Me), 3.76–3.99 (m, 3H, CH), 4.96 and 5.28 (d and d, 1H, J=8.6 Hz, CH), 7.06 (dd, 1H, J=7.3, 7.8 Hz, Ar), 7.20–7.37 (m, 3H, Ar), 7.37–7.54 (m, 2.4H, Ar), 7.57–7.72 (m, 1H, CH), 7.70 (d, 0.6H, J=7.8 Hz, Ar) (mixture of *Z*- and *E*-isomers in ratio 58:42). MS *m*/*z* (%) 445 (M^+, 26.2). Anal. Calcd for $C_{24}H_{20}ClN_5O_2$: C, 64.65; H, 4.52; N, 15.71. Found: C, 64.61; H, 4.48; N, 15.68%.

4.2.19. (1,3-Dioxo-2-phenyloctahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-phenylazoacetonitrile (**5h**)

Dark yellow powder; yield 159 mg (80%) from **1h** and 169 mg (85%) from **2h**; mp 202–204 °C; IR (KBr) ν_{max} 2950 (CH_2), 2200 (CN), 1715 (CO) cm^{-1}; ^1H NMR δ_H 1.49–1.61 (m, 1H, CH), 1.98–2.07 (m, 1H, CH), 2.14–2.30 (m, 2H, CH_2), 3.71–3.90 (m, 2H, CH), 3.90 and 3.94 (dd and dd, 1H, J=8.7, 10.5 Hz, CH), 4.58–4.69 (m, 1H, CH), 4.95 and 5.31 (d and d, 1H, J=8.7 Hz, CH), 7.25–7.36 (m, 3H,Ar), 7.38–7.54 (m, 5H, Ar), 7.76 and 7.57 (d and d, 1H, J=8.2 Hz, Ar), 7.71 and 7.72 (d and d, 1H, J=8.2 Hz, Ar); ^{13}C NMR δ_C 26.5, 26.7, 26.8, 26.9, 46.3, 49.3, 57.1, 57.2, 69.9, 70.4, 102.9, 103.9, 114.7, 115.0, 121.3, 121.6, 126.8, 127.3, 127.5, 127.7, 127.8, 128.2, 128.3, 128.6, 128.7, 128.8, 129.1, 132.2, 132.5, 134.6, 152.6, 152.9, 154.7, 159.3, 169.9, 171.1, 171.9, 173.9 (mixture of *Z*- and *E*-isomers in ratio 51:49). MS *m*/*z* (%) 397 (M^+, 24.7). Anal. Calcd for $C_{24}H_{21}N_5O_2$: C, 69.51; H, 4.82; N, 17.02. Found: C, 69.47; H, 4.78; N, 16.96%.

4.2.20. (1,3-Dioxo-2-phenyl-octahydropyrrolo[3,4-a]-pyrrolizin-4-ylidene)-p-tolylazo-acetonitrile (**5i**)

Yellow powder; yield 154 mg (75%) from **1i** and 146 mg (71%) from **2i**; mp 224–226 °C; IR (KBr) ν_{max} 2950 (CH_2), 2195 (CN), 1715 (CO) cm^{-1}; ^1H NMR δ_H 1.49–1.61 (m, 1H, CH), 1.98–2.07 (m, 1H, CH), 2.14–2.30 (m, 2H, CH_2), 2.33 and 2.32 (s, 3H, Me), 3.71–3.90 (m, 2H, CH), 3.90 and 3.94 (dd and dd, 1H, J=8.7, 10.5 Hz, CH), 4.58–4.69 (m, 1H, CH), 4.95 and 5.31 (d and d, 1H, J=8.7 Hz, CH), 7.25–7.36 (m, 3H,Ar), 7.38–7.54 (m, 5H, Ar), 7.76 and 7.57 (d and d, 1H, J=8.2 Hz, Ar), 7.51 and 7.21 (AA′XX′, 2H, J=8.1 Hz, Ar); ^{13}C NMR δ_C 20.7 (dt, J=126.4, 4.3 Hz, Me), 20.8 (dt, J=126.6, 4.4 Hz, Me), 26.7 (m, C(8)), 26.5 (m, C(8)), 26.9 (m, C(7)), 26.8 (m, C(7)), 40.6 (m, C(8b)), 40.3 (m, C(8b)), 46.4 (t, C(6), J=146.3 Hz), 49.2 (t, C(6), J=147.5 Hz), 56.9 (dd, C(3a), J=148.6, 2.1 Hz), 57.1 (dd, C(3a), J=147.1, 2.1 Hz), 69.8 (d, C(8a), J=150.1 Hz), 70.3 (d, C(8a), J=150.7 Hz), 102.8 (d, C(4), J=0.6 Hz), 103.9 (d, C(4′), J=1.2 Hz), 114.8 (CN), 115.2 (CN), 121.2 (dd, J=161.0, 5.1 Hz, C(Ar)), 121.6 (dd, J=161.0, 5.4 Hz, C(Ar)), 127.3 (d, J=163.1 Hz, C(Ar)), 127.5 (d, J=163.6 Hz, C(Ar)), 128.6 (d, J=158.3 Hz, C(Ar)), 128.7 (d, J=158.0 Hz, C(Ar)), 128.8 (d, J=157.1 Hz, C(Ar)), 128.8 (d, J=157.3 Hz, C(Ar)), 129.4 (d, J=158.0 Hz, C(Ar)), 129.7 (d, J=158.1 Hz, C(Ar)), 132.2 (dd, J=10.1, 9.2 Hz, C(Ar)), 132.5 (ddd, J=9.3, 7.7, 1.5 Hz, C(Ar)), 137.46 (dddd, J=8.9, 6.8, 5.2, 4.1 Hz, C(Ar)), 137.9 (ddd, J=6.5, 7.7, 6.5 Hz, C(Ar)), 150.6 (C(Ar)), 150.9 (C(Ar)), 154.3 (ddd, J=3.4, 1.7, 1.7 Hz, C(4)), 158.9 (d, J=6.4 Hz, C(4)), 171.9 (dd, J=7.5, 4.1 Hz, CO), 171.1 (dd, J=7.4, 4.3 Hz, CO), 173.8 (m, CO), 173.9 (m, CO) (mixture of *Z*- and *E*-isomers in ratio 46:54). MS: *m*/*z* (%) 411 (M^+, 21). Anal. Calcd for $C_{24}H_{21}N_5O_2$: C, 70.06; H, 5.14; N, 17.02. Found: C, 69.91; H, 5.05; N, 16.84%.

4.2.21. (1,3-Dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-(4-ethoxyphenylazo)acetonitrile (**5j**)

Yellow powder; yield 172 mg (78%) from **1j** and 176 mg (80%) from **2j**; mp 254–256 °C; IR (KBr) ν_{max} 2955 (CH_2), 2200 (CN), 1720 (CO) cm^{-1}; ^1H NMR δ_H 1.33 and 1.34 (t and t, 3H, J=7.0 Hz, Me), 1.45–1.59 (m, 1H, CH_2), 1.95–2.06 (m, 1H, CH_2), 2.10–2.31 (m, 2H, CH_2), 3.70–3.86 (m, 2H, CH_2), 3.89 and 3.93 (dd and dd, 1H, J=8.5, 10.6 Hz, CH), 4.05 and 4.07 (q and q, 2H, J=7.0 Hz, CH_2), 4.56–4.67 (m, 1H, CH), 4.93 and 5.28 (d and d, 1H, J=8.5 Hz, CH), 7.30–7.36 (m, 2H, Ar), 7.42–7.56 (m, 3H, Ar), 6.95 and 7.68 and 7.00 and 7.73 (AA′XX′ and AA′XX′, 4H, J=9.0 Hz, Ar); ^{13}C NMR δ_C 14.6, 26.6, 26.7, 26.8, 26.9, 40.4, 40.7, 46.5, 49.2, 56.8, 59.9, 63.2, 63.3, 69.6, 70.1, 102.7, 103.7, 114.5, 114.8, 114.9, 115.3, 122.8, 123.1, 127.3, 127.5, 128.6, 128.7, 128.8, 128.9, 132.2, 132.5, 146.6, 146.9, 153.6, 153.7, 158.5, 158.8, 171.2, 172.0, 173.9, 174.0 (mixture of *Z*- and *E*-isomers in ratio 36:64). MS *m*/*z* (%) 441 (M^+, 1.9). Anal. Calcd for $C_{25}H_{23}N_5O_3$: C, 68.01; H, 5.25; N, 15.86. Found: C, 67.98; H, 5.21; N, 15.81%.

4.2.22. (1,3-Dioxo-2-phenyl-octahydropyrrolo[3,4-a]pyrrolizin-4-ylidene)-(4-methoxyphenylazo)acetonitrile (**5k**)

Yellow powder; yield 167 mg (78%) from **1k** and 151 mg (71%) from **2k**; mp 237–239 °C; IR (KBr) ν_{max} 2950 (CH_2), 2200 (CN), 1720 (CO) $см^{-1}$; ^1H NMR δ_H 1.52–1.55 (m, 1H, CH), 1.95–2.06 (m, 1H, CH), 2.12–2.30 (m, 2H, CH_2), 3.78 and 3.80 (s and s, 3H, OMe), 3.74–3.87 (m, 2H, CH and CH_2), 3.89 and 3.73 (dd and dd, J=8.7, 10.1 Hz, 1H, CH), 4.65–4.55 (m, 1H, CH), 5.28 and 4.91 (d and d, J=8.7 Hz, 1H, CH), 7.30–7.35 (m, 2H, Ar), 7.42–7.53 (m, 3H, Ar), 7.55 and 7.02 (AA′XX′, J=7.7 Hz, 2H, Ar), 7.69 and 7.97 (AA′XX′, J=8.8 Hz, 2H, Ar) (mixture of *Z*- and *E*-isomers in ratio 30:70); MS *m*/*z* (%) 427 (M^+, 27). Anal. Calcd for $C_{24}H_{21}N_5O_3$: C, 67.44; H, 4.95; N, 16.38. Found: C, 67.29; H, 4.81; N, 16.15%.

4.3. Reaction of 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles 1 and 2 with dimethyl maleate

General procedure: A solution of 0.5 mmol **1** or **2** and 2.5 mmol dimethyl maleate in 5 mL benzene was heated at 60 °C (TLC). The reaction mixture was evaporated and purified by column chromatography.

*4.3.1. 3-[Cyano-(4-nitrophenylazo)-methylene]-hexahydropyrrolizine-1,2-dicarboxylic acid dimethyl ester (**12a**)*

Yellow powder; yield 182 mg (88%) from **1a**; mp 90–92 °C; IR (KBr) ν_{max} 2200 (CN), 1740 (CO), 1680 (CO) cm^{-1}; ^1H NMR δ_H 1.58–1.82 (m, 1H, CH), 2.42–2.46 (m, 1H, CH_2), 2.25–2.43 (m, 2H, CH_2), 3.61, 3.69, 3.68, 3.72 (s, s, s, s, 3H, OMe), 3.64, 3.71, 3.72, 3.75 (s, s, s, s, 3H, OMe), 3.78–3.94 (m, 2H, CH), 4.50–4.58 and 4.7–4.81 (m and m, 1H, CH), 4.72, 4.96, 5.20 (d, d, d, 1H, *J*=8.5, 10.2, 8.9 Hz, CH), 7.60–7.78 (m, 1H, Ar), 7.60 and 7.75 (d and d, 1H, *J*=9.0 Hz, Ar), 8.34–8.26 (m, 2H, Ar) (mixture of isomers). MS *m*/*z* (%) 413 (M^+, 27.64). Anal. Calcd for $C_{19}H_{21}N_5O_4$: C, 55.20; H, 4.63; N, 18.27. Found: C, 55.12; H, 4.56; N, 18.24%.

*4.3.2. 3-[Cyano-(4-trifluorophenylazo)methylene]hexahydropyrrolizine-1,2-dicarboxylic acid dimethyl ester (**12b**)*

Yellow powder; yield 111 mg (51%) from **1b**; mp 108–110 °C; IR (KBr) ν_{max} 2220 (CN), 1750 (CO), 1660 (CO); ^1H NMR δ_H 7.83–7.77 (m, 2H, Ar), 1.58–1.78 (m, 1H, CH), 2.24–2.13 (m, 1H, CH_2), 2.42–2.25 (m, 2H, CH_2), 3.63, 3.68, 3.69, 3.72 (s, s, s, s 3H, OMe), 3.59, 3.69, 3.71, 3.75 (s, s, s, s, 3H, OMe), 3.79–3.89 (m, 2H, CH), 4.44–4.54 and 4.67–4.77 (m and m, 1H, CH), 4.69, 4.92 and 5.18 (d, d, d, 1H, *J*=8.3, 10.4, 9.1 Hz, CH), 7.59 (d, 1H, *J*=8.5, Ar), 7.65 and 7.76 (d and d, 1H, *J*=9.0 Hz, Ar) (mixture of isomers). MS *m*/*z* (%) 436 (M^+, 31.90). Anal. Calcd for $C_{20}H_{19}F_3N_4O_2$: C, 55.05; H, 4.39; N, 13.85. Found: C, 55.00; H, 4.37; N, 13.83%.

*4.3.3. 3-[Cyano-(4-ethoxyphenylazo)methylene]hexahydropyrrolizine-1,2-dicarboxylic acid dimethyl ester (**12c**)*

Yellow powder; yield 150 mg (68%) from **1c**; mp 132–134 °C; IR (KBr) ν_{max} 2220 (CN), 1740 (CO), 1640 (CO); ^1H NMR δ_H 1.30–1.37 (m, 1H, Me), 1.58–1.79 (m, 1H, CH), 2.13–2.23 (m, 1H,CH_2), 2.26–2.40 (m, 2H, CH_2), 3.59, 3.69, 3.71 and 3.74 (s, s, s, s, 3H, OMe), 3.64, 3.68, 3.72 and 3.75 (s, s, s, s, 3H, OMe), 4.28 and 4.35 (m, 2H, CH_2), 4.54–4.45 and 4.76–4.66 (m and m, 1H, CH), 4.69, 4.92 and 5.18 (d, d, d, 1H, *J*=8.5, 9.2, 8.9 Hz, CH), 7.53–7.62 (d and d, 1H, *J*=7.9 Hz, Ar), 7.76 (d, 1H, *J*=8.9 Hz, Ar), 7.99–8.04 (m, 2H, Ar). MS *m*/*z* (%) 440 (M^+, 18.33%). Anal. Calcd for $C_{21}H_{22}N_4O_3$: C, 59.99; H, 5.49; N, 14.80. Found: C, 59.97; H, 5.46; N, 14.77%.

*4.3.4. 3-[Cyano-(2,4-dichlorophenylazo)-methylene]-hexahydropyrrolizine-1,2-dicarboxylic acid dimethyl ester (**12d**)*

Yellow powder; yield 76 mg (35%) from **1e**; mp 124–126 °C; IR (KBr) ν_{max} 2220 (CN), 1740 (CO), 1660 (CO) cm^{-1}; ^1H NMR δ_H 1.59–1.79 (m, 1H, CH), 2.13–2.40 (m, 1H, CH_2), 2.24–2.42 (m, 2H, CH_2), 3.56, 3.68, 3.70 and 3.72 (s, s, s, s, 3H, OMe), 3.63, 3.69, 3.71 and 3.74 (s, s, s, s, 3H, OMe), 3.78–3.92 (m, 2H, CH), 4.46–4.53 and 4.67–4.76 (m and m, 1H, CH), 4.68, 4.92 and 5.17 (d, d, d, 1H, *J*=8.5, 10.4, 8.8 Hz, CH), 7.41–7.44 (m, 1H, Ar), 7.49 and 7.69 (d and d, 1H, *J*=2.0 Hz, Ar), 7.71–7.73 (m, 2H, Ar). MS *m*/*z* (%) 436 (M^+, 7.2%). Anal. Calcd for $C_{19}H_{18}Cl_2N_4O_2$: C, 52.19; H, 4.15; N, 13.82. Found: C, 52.18; H, 4.11; N, 13.80%.

4.4. Reaction of the 3-alkylsulfanyl-2-arylazo-3-(pyrrolidin-1-yl)acrylonitriles with dimethyl acetylenedicarboxylate

General procedure: A solution of 0.5 mmol 1 or 2 and 2.5 mmol dimethyl acetylenedicarboxylate in 5 ml benzene was refluxed (TLC). The reaction mixture was evaporated and purified by column chromatography.

*4.4.1. [Cyano-(4-nitrophenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine-1,2-dicarboxylic acid dimethyl ester (**14a**)*

Yellow powder; yield 82 mg (40%) from **1a** and 123 mg (60%) from **2a**; mp 256–258 °C; IR (KBr) ν_{max} 3230 (NH), 2950 (CH_2), 2200 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 11.61 (s, 1H, NH), 8.15 and 7.47 (AA′BB′, *J*=9.2 Hz, 4H, Ar), 4.32 (t, *J*=6.9 Hz, 2H, CH_2), 3.80 (s, 3H, OMe), 3.73 (s, 3H, OMe), 3.08 (dt, *J*=6.9, 14.7 Hz, 2H, CH_2), 3.07 (t, *J*=7.7 Hz, 2H, CH_2); ^{13}C NMR δ_C 25.1 (C(7)H_2), 25.9 (C(6)H_2), 48.8 (C(5)H_2), 51.1 (OMe), 51.9 (OMe), 105.9 (C(1)), 108.9, 110.1 (C(2)), 114.2 (C_{orto}), 120.1 (C(3)), 120.3 (CN), 125.6 (C_{meta}), 141.9 (C_{para}), 146.8 (C(7a)), 148.6 (C_{ipso}), 162.7 (CO), 164.2 (CO). MS *m*/*z* (%) 411 (M+, 21.3). Anal. Calcd for $C_{19}H_{17}N_5O_6$: C, 55.48; H, 4.17; N, 17.02. Found: C, 55.42; H, 4.15; N, 16.93%.

*4.4.2. [Cyano-(4-trifluoromethylphenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine-1,2-dicarboxylic acid dimethyl ester (**14b**)*

Yellow powder; yield 137 mg (63%) from **2b**; mp 238–240 °C; IR (KBr) ν_{max} 3240 (NH), 2955 (CH_2), 2215 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 2.51–2.54 (m, 2H, CH_2), 3.05 (t, 2H, *J*=7.2 Hz, CH_2), 3.07 (t, *J*=7.7 Hz, 2H, CH_2), 3.08 (dt, *J*=6.9, 14.7 Hz, 2H, CH_2), 3.71 (s, 3H, OMe), 3.77 (s, 3H, OMe), 4.28 (t, 2H, *J*=7.2 Hz, CH_2), 7.49 and 7.67 (AA′XX′, 4H, *J*=8.7 Hz, Ar), 11.55 (s, 1H, NH). MS *m*/*z* (%) 434 (M+, 36.7). Anal. Calcd for $C_{20}H_{17}F_3N_4O_4$: C, 55.30; H, 3.94; N, 12.90. Found: C, 55.19; H, 3.86; N, 12.78%.

*4.4.3. 3-[Cyano-(4-ethoxycarbonylphenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine (**14c**)*

Yellow powder; yield 90 mg (41%) from **2c**; mp 235–237 °C; IR (KBr) ν_{max} 3270 (NH), 2950, 2860 (CH2), 2200 (CN), 1700 (CO) cm^{-1}; ^1H NMR δ_H 1.36 (t, *J*=7.1 Hz, 3H, Me), 25.1 (CH_2-7), 2.58 (dt, *J*=7.1, 19.5 Hz, 2H, CH_2), 3.07 (t, *J*=7.3 Hz, 2H, CH_2), 3.74 (s, 3H, OMe), 3.80 (s, 3H, OMe), 4.28 (q, *J*=7.1 Hz, 2H, CH_2), 4.29 (t, *J*=7.1 Hz, 2H, CH_2), 7.38 and 7.89 (AA′BB′, *J*=8.9 Hz, 4H, Ar), 11.35 (s, 1H, NH); ^{13}C NMR δ_C 14.1 (Me), 25.9 (C(6)H_2), 48.6 (C(5)H_2), 51.1 (OMe), 51.8 (OMe), 60.2 (CH_2O), 105.7 (C(1)), 106.9, 110.3 (C(2)), 114.0 (C_{orto}), 120.6 (C(3)), 119.5 (CN), 123.1 (C_{para}), 130.7 (C_{meta}), 146.4 (C(7a)), 146.9 (C_{ipso}), 162.8 (CO), 164.3 (CO), 165.3 (CO). MS *m*/*z* (%) 438 (M+, 8.6%). Anal. Calcd for $C_{22}H_{22}N_4O_6$: C, 60.27; H, 5.06; N, 12.78. Found: C, 60.23; H, 5.01; N, 12.56%.

*4.4.4. 3-[Cyano-(2,4-dichlorophenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine (**14d**)*

Yellow powder; yield 72 mg (36%) from **2e**; mp 187–189 °C; IR (KBr) ν_{max} 3300 (NH), 2950 (CH_2), 2210 (CN), 1740, 1700 (CO) cm^{-1}; ^1H NMR δ_H 2.55 (dt, *J*=7.4, 20.1 Hz, 2H, CH_2), 3.08 (t, *J*=7.4 Hz, 2H, CH_2), 3.73 (s, 3H, OMe), 3.79 (s, 3H, OMe), 4.31 (t, *J*=7.5 Hz, 2H, CH_2), 7.33 (dd, *J*=8.8, 2.1 Hz, 1H, Ar), 7.45 (d, *J*=5.1 Hz, 1H, Ar), 7.46 (d, *J*=6.1 Hz, 1H, Ar), 9.50 (s, 1H, NH). MS *m*/*z* (%) 434 (M+, 8.8). Anal. Calcd for $C_{19}H_{16}Cl_2N_4O_4$: C, 52.43; H, 3.71; N, 12.87. Found: C, 52.34; H, 3.65; N, 12.80%.

*4.4.5. 3-[Cyano-(4-chlorophenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine (**14e**)*

Yellow powder; yield 92 mg (46%) from **2f**; mp 273–275 °C; IR (KBr) ν_{max} 3270 (NH), 2950, 2850 (CH_2), 2210 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 2.54 (dt, *J*=6.7, 16.2 Hz, 2H, CH_2), 3.05 (t, *J*=7.3 Hz, 2H, CH_2), 3.73 (s, 3H, OMe), 3.77 (s, 3H, OMe), 4.27 (t, *J*=7.4 Hz, 2H, CH_2), 7.24 and 7.32 (AA′BB′, *J*=9.2 Hz, 4H, Ar), 11.05 (s, 1H, NH); ^{13}C NMR δ_C 25.1 (C(7)H_2), 25.9 (C(6)H_2), 48.5 (C(5)H_2), 51.0 (OMe), 51.7 (OMe), 105.6 (C(1)), 110.6 (C(2)), 116.0 (C_{orto}), 118.9 (CN), 120.8 (C-3), 129.0 (C_{meta}), 126.0 (C_{para}), 146.1 (C(7a)), 142.0 (C_{ipso}), 162.8 (CO), 164.3 (CO). MS *m*/*z* (%) 400 (M+, 33.2). Anal. Calcd for $C_{19}H_{17}ClN_4O_4$: C, 56.94; H, 4.28;N, 13.98; Found: C, 56.86; H, 4.22; N, 13.85%.

*4.4.6. 3-[Cyano-(2-chloro-4-methylphenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine (**14f**)*

Yellow powder; yield 93 mg (45%) from **2g**; mp 264–265 °C; ^1H NMR δ_H 2.31 (s, 3H, Me), 2.57 (dt, *J*=7.0, 13.9 Hz, 2H, CH_2), 3.08 (t, *J*=7.6 Hz, 2H, CH_2), 3.73 (s, 3H, OMe), 3.79 (s, 3H, OMe), 4.30 (t, *J*=7.2 Hz, 2H, CH_2), 7.12 (d, *J*=9.4 Hz, 1H, Ar), 7.22 (s, 1H, Ar), 7.34 (d, *J*=7.9 Hz, 1H, Ar), 9.37 (s, 1H, NH); ^{13}C NMR δ_C 25.1 (C(7)H_2), 25.9 (C(6)H_2), 48.8 (C(5)H_2), 51.2 (OMe), 51.9 (OMe), 80.0 (Me), 108.5 (C(1)), 103.4, 109.9 (C(2)), 116.2 (C_{orto}), 119.0 (CN), 120.1 (C(3)), 129.2

(C_{meta}), 129.8 (C_{meta}), 136.2 (C_{para}), 136.2 (C_{ipso}), 146.7 (C(7a)), 163.0 (CO), 164.3 (CO). MS *m*/*z* (%) 414 (M+, 10.0%). Anal. Calcd for $C_{20}H_{19}ClN_4O_4$: C, 57.91; H, 4.62; N, 13.51; Found: C, 57.84; H, 4.52; N, 13.22%.

4.4.7. 3-[Cyano-(phenylhydrazono)-methyl]-6,7-dihydro-5H-pyrrolizine (**14g**)

Yellow powder; yield 84 mg (46%) from **1h**; mp 264–265 °C; IR (KBr) ν_{max} 3250 (NH), 2950, 2850 (CH_2), 2210 (CN), 1710 (CO) cm^{-1}; ^1H NMR δ_H 3.06 (t, *J*=7.3 Hz, 2H, CH_2), 2.58 (dt, *J*=7.3, 13.3 Hz, 2H, CH_2), 3.72 (s, 3H, OMe), 3.76 (s, 3H, OMe), 4.28 (t, *J*=7.5 Hz, 2H, CH_2), 6.95 (dt, *J*=8.3, 1.4 Hz, 1H, Ar), 7.29–7.36 (m, 4H, Ar), 11.21 (s, 1H, NH); ^{13}C NMR δ_C 25.1 (C(7)H_2), 25.9 (C(6)H_2), 48.5 (C(5)H_2), 51.0 (OMe), 51.9 (OMe), 105.6 (C(1)), 104.3, 110.8 (C(2)), 114.4 (C_{orto}), 121.1 (C(3)), 118.6 (CN), 129.2 (C_{meta}), 122.4 (C_{para}), 143.0 (C_{ipso}), 146.0 (C(7a)), 162.9 (CO), 164.3 (CO). MS *m*/*z* (%) 366 (M+, 18.8%). Anal. Calcd for $C_{19}H_{18}N_4O_4$: C, 62.29; H, 4.95; N, 15.29; Found: C, 62.21; H, 4.92; N, 15.17%.

*4.4.7.1. X-ray Structure analysis of **14g**.* Crystal data: $C_{19}H_{18}N_4O_4$ was crystallized from ethanol. Crystal dimensions 0.32×0.26×0.1 mm, monoclinic, P21/*n*, *a*=7.6737(4) Å, *b*=9.4134(5) Å, *c*=24.0540(13) Å, α=90.00°, β=90.876°, γ=90.00°, *V*=1737.35(16) $Å^3$; *Z*=4, *Dc*=1.401 g cm^{-3}, μ=0.835 cm^{-1}, Bruker SMART 6000 detector, CuKα(λ=1.54178 Å), crossed Göbel mirrors, *T*=100 K, 9077 measured reflections, 2371 independent reflections. The data were corrected for Lorentz, absorption, and polarization effects. The structure was solved by directs methods. Full matrix least-squares refinement based on $F^2 \geq 2\sigma$, 257 parameters, hydrogen atoms placed at calculated positions with temperature factors 20% higher than parent atom and the hydrogen bond distances were free to refine, R^1=0.0581.

Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-677317. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44 (0)1223 336033 or e-mail: deposit@ccdc.cam.ac.uk).

Acknowledgements

The authors thank the Russian Foundation for Basic Research for financial support (grant RFBR # 08-03-00376_a, RFBR/NNSF # 08-03-92208_a). J.S. acknowledges Michail-Lomonosov-Forschungsstipendien (DAAD). J.S. is greatly appreciate useful discussion with Prof. R. Herges and F. Koehler (Otto-Diels-Institut für Organische Chemie, Christian Albrecht University of Kiel, Germany) and their advises about ACID application. We also thank the FWO-Vlaanderen and the University of Leuven for the financial support.

Supplementary data

Supplementary data associated with this article can be found in online version, at doi:10.1016/j.tet.2009.06.114.

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