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Three-Component Synthesis of Alkyl-Substituted Functionalized 4*H*-Thiopyrans, 1,2- and 1,4-Dihydropyridines, 2-Alkylsulfanylpyridines, Thieno[2,3-*b*]pyridines, and Cyclohexa-1,3-diene

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Abstract—Three-component condensation of aliphatic aldehydes with CH-acids has afforded functionalized alkyl-substituted 4*H*-thiopyrans, 1,2- and 1,4-dihydropyridines, 2-alkylsulfanylpyridines, thieno[2,3-*b*]pyridines, and cyclohexa-1,3-diene.

Keywords: aliphatic aldehyde, CH-acid, 4*H*-thiopyran, 1,4-dihydropyridine, thieno[2,3-*b*]pyridine, cyclohexa-1,3-diene

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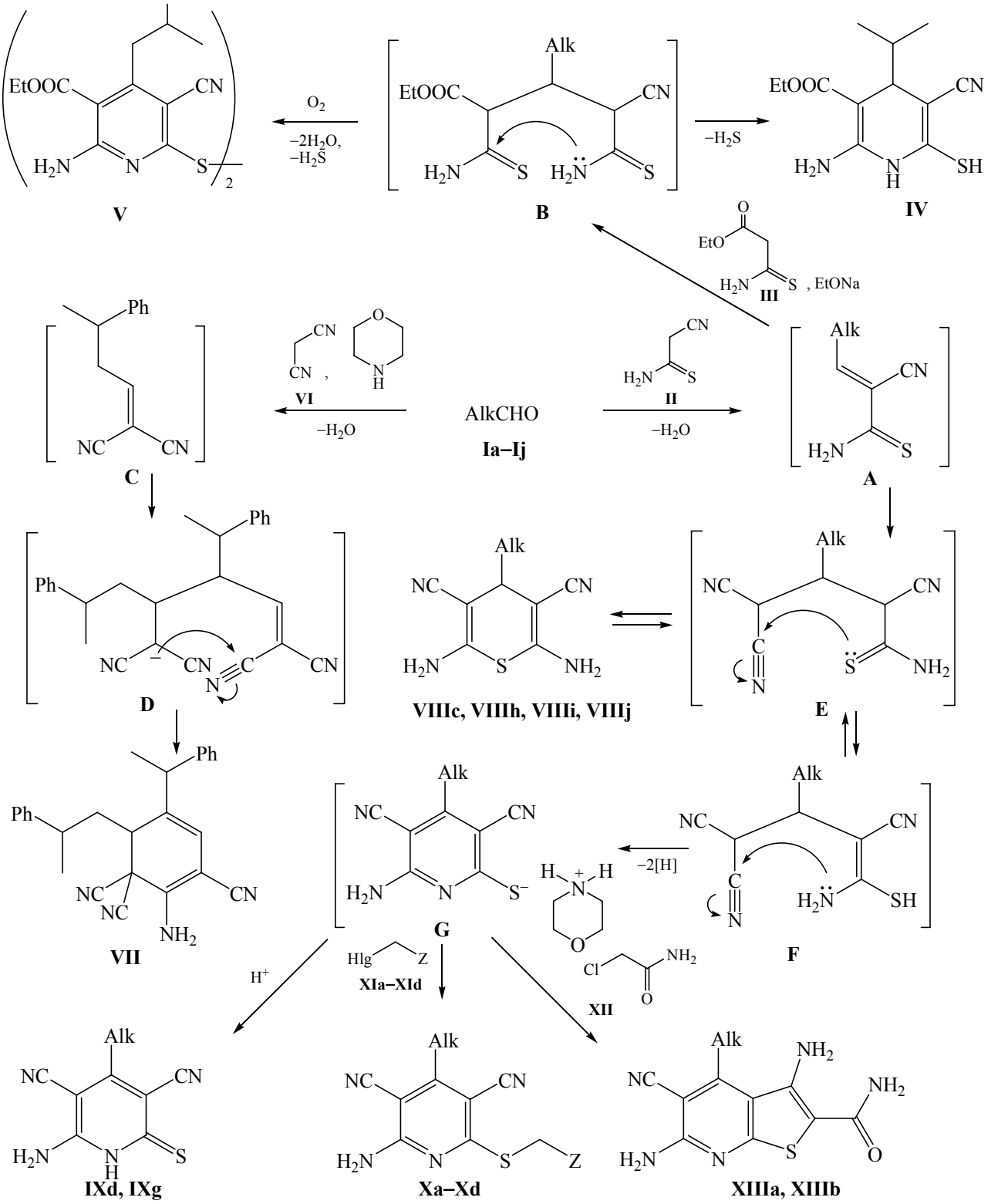
Multicomponent synthesis of heterocyclic compounds has recently become increasingly important [1–3]. This method is particularly relevant to obtain scarcely studied alkyl-substituted carbo- and heterocyclic compounds starting from aliphatic aldehydes, since the latter are known for high toxicity, flammability, and ability to readily isomerize and dimerize [4] as compared with the aromatic analogs.

Extending the earlier research on synthesis of alkyl-substituted carbo- and heterocyclic compounds via a multicomponent condensation [5–7], we investigated new possibilities of three-component interaction of aliphatic aldehydes **Ia**–**Ij** with a number of CH-acids and organic bases under conditions of the Knöevenagel reaction. It was found that condensation of aliphatic aldehydes **Ia** and **Ib** with cyanothioacetamide **II** and ethyl 3-amino-3-thioxopropanoate **III** in anhydrous ethanol at 20°C in the presence of sodium ethylate resulted in ethyl 2-amino-4-isopropyl-6-mercapto-5-cyano-3-carboxylate **IV** and diethyl 6,6'-disulfandiylbis(2-amino-4-isobutyl-5-cyanonicotinate **V**. Apparently, the reaction proceeded through formation of alkene **A** followed by addition of the CH-acid **III** to give the adduct **B**. The latter intermediate [Alk = $(Me)_2CH$] underwent chemoselective intramolecular cyclization accompanied with hydrogen sulfide elimination to form the substituted 1,4-dihydropyridine **IV**. In the case of Alk = $(Me)_2CHCH_2$, the reaction stopped at the stage of formation of the corresponding 1,4-dihydropyridine **IV** due to oxidation of the hydrosulfide group with air oxygen into organic disulfide **V**. On top of that, the reaction was accompanied with aromatization of the dihydropyridine core (Scheme 1).

In the case of the Knöevenagel condensation involving 2-phenylpropionaldehyde **Ic** and malononitrile **VI** in the presence of morpholine as a catalyst, the formed alkene **C** was capable of the Michael-type dimerization under the reaction conditions. The adduct **D** underwent intramolecular cyclization into the substituted 1,3-cyclohexadiene **VII**.

Three-component condensation of aliphatic aldehydes **I** with cyanothioacetamide **II** and malononitrile **VI** in the presence of morpholine in anhydrous ethanol at 20°C resulted in the formation of 4-alkyl-2,6-diamino-3,5-dicyano-4*H*-thiopyrans **VIIIc**, **VIIIh**, **VIIIi**, and **VIIIj**. At the same time, the same reaction in ethanol medium under reflux allowed preparation of 4-substituted 6-amino-2-thioxo-3,5-dicyano-1,2-dihydropyridines **IXd** and **IXg**, similarly to the analogous condensation involving aromatic aldehydes [8–10]. Thiopyrans **VIII**, the kinetic control products, underwent ring-opening via formation of intermediates

Scheme 1.



I, **VIII**, **IX**, **XIII**, Alk = $(Me)_2CH$ (**a**), $(Me)_2CHCH_2$ (**b**), Me(Ph)CH (**c**), Me(Ph)$CHCH_2$ (**d**), cyclohex-2-enyl (**e**), $Me(CH_2)_{10}$ (**f**), $Ph(CH_2)_2$ (**g**), $Me(CH_2)_6$ (**h**), $PhCH_2$ (**i**), $Me(CH_2)_5$ (**j**); **X**, **XI**, Hlg = Cl, Z = Ph, Alk = cyclohex-2-enyl (**a**); Hlg = Br, Z = 4-ClC_6H_4CO, Alk = $Me(CH_2)_{10}$ (**b**); Hlg = Br, Z = 4-$NO_2C_6H_4CO$, Alk = $PhCH_2$ (**c**); Hlg = I, Z = H, Alk = CH_2Ph (**d**).

Table 1. Yields, melting points and elemental analysis data for compounds **IV**–**X** and **XIII**

Comp. no.	Yield, %	mp, °C	Found, %			Formula	Calculated, %		
			C	H	N		C	H	N
IV	65	197–199 (EtOH)	53.84	6.29	15.65	$C_{12}H_{17}N_3O_2S$	53.91	6.41	15.72
V	69	263–265 (AcOH)	55.98	5.63	14.92	$C_{26}H_{32}N_6O_4S_2$	56.10	5.79	15.10
VII	72	218–220 (PrOH)	79.44	6.02	14.15	$C_{26}H_{24}N_4$	79.48	6.22	14.30
VIIIc	80	206–208 (EtOH)	63.72	4.89	19.76	$C_{15}H_{14}N_4S$	63.81	5.00	19.84
VIIIh	75	165–167 (EtOH)	60.70	7.15	20.12	$C_{14}H_{20}N_4S$	60.84	7.29	20.27
VIIIi	77	183–185 (EtOH)	62.58	4.43	20.76	$C_{14}H_{12}N_4S$	62.66	4.51	20.88
VIIIj	70	159–161 (PrOH)	57.84	6.60	20.71	$C_{13}H_{18}N_4S$	57.97	6.74	20.80
IXd	66	233–235 (EtOH)	65.19	4.68	18.95	$C_{16}H_{14}N_4S$	65.28	4.79	19.03
IXg	68	118–120 (MeOH)	64.18	4.21	19.86	$C_{15}H_{12}N_4S$	64.26	4.32	19.98
Xa[a]	71	162–163 (AcOH)	69.28	5.18	16.02	$C_{20}H_{18}N_4S$	69.34	5.24	16.17
Xb	89	188–190 (AcOH)	64.58	6.32	11.49	$C_{26}H_{31}ClN_4OS$	64.65	6.47	11.60
Xc	73	203–205 (BuOH)	61.48	3.46	16.22	$C_{22}H_{15}N_5O_3S$	61.53	3.52	16.31
Xd	82	241–243 (AcOH)	64.11	4.22	19.86	$C_{15}H_{12}N_4S$	64.26	4.31	19.98
XIIIa[b]	78	281–282 (AcOH)	52.26	4.68	25.30	$C_{12}H_{13}N_5OS$	52.35	4.76	25.44
XIIIb[a]	65	289–290 (BuOH)	53.86	5.15	24.03	$C_{13}H_{15}N_5OS$	53.96	5.23	24.20

[a] Fluoresced under UV irradiation. [b] Sublimated at 200°C.

E and **F** to yield the substituted morpholinium pyridine-2-thiolates **G**. They were stabilized into pyridinethiones **IX** in acidic medium. Formation of the salts **G** was confirmed by formation of thioethers **X** when alkyl halides **XIa**–**XId** were introduced in the reaction, in accordance with fundamentals of pyridinethiones chemistry [11–13]. Noteworthily, compounds **Xa–Xd** are promising building blocks to create drugs for treatment of inflammatory processes [14] and cardiovascular diseases [15].

When α-chloroacetamide **XII** was used as alkylating agent in the presence of equimolar amount of 10% aqueous KOH, the reaction led to formation of 4-alkylthieno[2,3-*b*]pyridines **VIIIa** and **VIIIb**, showing potential antiviral [16, 17] and antitumor [18, 19] activity. Apparently, the reaction intermediates were the corresponding thioesters **X**, undergoing intramolecular cyclization in alkaline medium to form compounds **XIII**. 2-Alkylthio-3-cyanopyridine are convenient starting reagents for thieno[2,3-*b*]pyridines synthesis [20].

Spectral and physico-chemical properties of the synthesized compounds are shown in Tables 1 and 2. In particular, IR spectra of the obtained compounds contained the expected characteristic absorption bands of NH_2 (3099–3450 cm^{-1}), C≡N (1706–1724 cm^{-1}), and C=O (2172–2252 cm^{-1}) groups stretching. GC–MS spectra revealed the presence of the $[M + 1]^+$ molecular ion peak. Mass spectrum of compound **IXg** contained the molecular ion peak and peaks of other fragments including the $[M + 2]^+$ peak confirming the presence of one sulfur atom in the molecule [21]. The ^{1}H NMR spectra contained the signals of all the expected structural fragments.

EXPERIMENTAL

IR spectra were recorded with a Perkin Elmer Spectrum One spectrophotometer (KBr pellets). ^{1}H NMR spectra were obtained using a Bruker Avanse II (400.13 MHz) spectrometer (solutions in DMSO-d_6) relative to TMS as internal reference. Mass spectra were registered with a Chrommass GC/MC (Hewlett Packard) 5890/5972 mass spectrometer [column HP-5 MS (70 eV)] (in the cases of CH_2Cl_2 solutions) and with a Kratos MS-890 spectrometer (70 eV) with the direct specimen injection the ion source (**VII**, **IXb**,

Table 2. IR and ^{1}H NMR spectral data for compounds **IV**–**X** and **XIII**

Comp. no.	ν, cm^{-1}	δ_H, ppm, (*J*, Hz)
IV	3411, 3320, 3312, 3099 (NH, NH_2), 2172 (C≡N), 1724 (C=O), 1642 [δ(NH_2)]	0.89 d (6H, 2Me, *J* 6.6), 1.18 t (3H, $CH_2\underline{CH_3}$, *J* 7.0), 1.51–1.66 m (1H, $\underline{CH}Me_2$), 3.93 d (1H, C^4H, *J* 4.3), 4.14 q (2H, OCH_2, *J* 7.0), 6.17 br. s (2H, NH_2), 11.71 br. s (1H, NH); the signal of SH proton was not observed presumably due to the rapid deuterium exchange
V	3435, 3351, 3221 (NH_2), 2215 (C≡N), 1706 (C=O), 1632 [δ(NH_2)]	0.89 d (12H, 4Me, *J* 6.2), 1.35 t (6H, $2\underline{Me}CH_2$, *J* 6.6), 1.76–1.92 m (2H, $2\underline{CH}Me_2$), 2.79 d (2H, $2\underline{CH_2}CH$, *J* 6.8), 4.36 q (4H, $2OCH_2$, *J* 6.6), 7.20 br. s (4H, $2NH_2$)
VII	3450, 3340, 3215 (NH_2), 2252, 2200 (C≡N), 1644 [δ(NH_2)]	1.19 d (3H, Me, *J* 6.6), 1.33 d (3H, Me, *J* 6.5), 1.71–1.83 m (1H, $\underline{CH}Me$), 2.18 q (1H, $\underline{CH}Me$, *J* 6.5), 2.87 d (2H, $CH_2\underline{CH}$, *J* 6.7), 3.38 t (1H, C^6H, *J* 6.8), 6.05 s (1H, C^4H), 6.82–6.99 m (2H, Ph), 7.06–7.19 m (3H, Ph), 7.23–7.38 m (3H, Ph), 7.42 t (2H, Ph, *J* 8.1), 7.55 br. s (2H, NH_2)
VIIIc	3444, 3314, 3210 (NH_2), 2202 (C≡N), 1647 [δ(NH_2)]	1.28 d (3H, Me, *J* 6.9), 2.81–3.04 m (1H, $\underline{CH}Me$), 3.05 d (1H, C^4H, *J* 5.8), 6.70 br. s (2H, NH_2), 6.85 br. s (2H, NH_2), 7.11–7.43 m (5H, Ph)
VIIIh	3440, 3295, 3202 (NH_2), 2204 (C≡N), 1643 [δ(NH_2)]	0.86 t (3H, Me, *J* 7.1), 1.08–1.55 m (10H, $5CH_2$), 2.99 t (1H, C^4H, *J* 6.9), 6.75 br. s (4H, $2NH_2$)
VIIIi	3435, 3302, 3215 (NH_2), 2200 (C≡N), 1642 [δ(NH_2)]	2.73 d (2H, CH_2, *J* 6.4), 3.38 t (1H, C^4H, *J* 6.4), 6.75 br. s (4H, $2NH_2$), 7.02–7.46 m (5H, Ph)
VIIIj	3401, 3333, 3219 (NH_2), 2199 (C≡N), 1649 [δ(NH_2)]	1.92 t (3H, Me, *J* 6.8), 1.18–1.42 m (8H, $4CH_2$), 1.48–1.64 m (2H, CH_2), 2.93 t (1H, C^4H, *J* 7.2), 6.53 br. s (4H, $2NH_2$)
IXd	3418, 3311, 3209 (NH, NH_2), 2216 (C≡N), 1640 [δ(NH_2)]	1.31 d (3H, Me, *J* 7.2), 3.92–3.51 m (1H, $\underline{CH}Me$), 3.61–4.01 m (2H, CH_2), 7.02–7.43 m (5H, Ph), 10.02 br. s (2H, NH_2), 11.82 br. s (1H, NH)
IXg	3402, 3300, 3196 (NH, NH_2), 2217 (C≡N), 1647 [δ(NH_2)]	2.71–3.11 m (4H, $2CH_2$), 7.04–7.48 m (5H, Ph), 7.81 br. s (2H, NH_2), 12.71 br. s (1H, NH)
Xa	3446, 3334, 3216 (NH_2), 2214 (C≡N), 1624 [δ(NH_2)]	1.65–1.82 m (1H, C^6H, cyclohexene), 2.04–2.33 m (5H, cyclohexene), 3.01–3.14 m (1H, C^1H, cyclohexene), 4.45 s (2H, SCH_2), 5.66–5.79 m (2H, CH=CH), 7.23 d (1H, Ph, *J* 6.9), 7.29 t (2H, Ph, *J* 6.9), 7.47 d (2H, Ph, *J* 7.1), 7.94 br. s (2H, NH_2)
Xb	3435, 3312, 3198 (NH_2), 2219 (C≡N), 1714 (C=O), 1648 [δ(NH_2)]	0.87 t (3H, Me, *J* 7.1), 1.06–1.52 m (16H, $8CH_2$), 1.55–1.78 m (2H, CH_2), 2.72 t (2H, CH_2, *J* 7.7), 4.83 s (2H, SCH_2), 7.53 d (2H, Ar, *J* 8.6), 7.64 br. s (2H, NH_2), 8.05 d (2H, Ar, *J* 8.6)
Xc	3430, 3318, 3206 (NH_2), 2220 (C≡N), 1706 (C=O), 1641 [δ(NH_2)]	4.11 s (2H, CH_2), 4.99 s (2H, SCH_2), 7.16–7.43 m (5H, Ph), 7.81 br. s (2H, NH_2), 8.22 d (2H, C_6H_4, *J* 8.4), 8.38 d (2H, C_6H_4, *J* 8.4)
Xd	3438, 3302, 3190 (NH_2), 2222 (C≡N), 1643 [δ(NH_2)]	2.54 s (3H, Me), 4.07 s (2H, CH_2), 7.14–7.46 m (5H, Ph), 7.96 br. s (2H, NH_2)
XIIIa	3398, 3326, 3174 (NH_2), 2216 (C≡N), 1662 (CONH), 1634 [δ(NH_2)]	1.02 d (6H, 2Me, *J* 5.3), 2.08–2.19 m (1H, $\underline{CH}Me_2$), 6.58 s (2H, NH_2), 6.66 s (2H, NH_2), 6.75 s (2H, NH_2)
XIIIb	3390, 3338, 3206 (NH_2), 2219 (C≡N), 1670 (CONH), 1641 [δ(NH_2)]	1.12 d (6H, 2Me, *J* 5.8), 2.06–2.24 m (1H, $\underline{CH}Me_2$), 2.93 d (2H, CH_2, *J* 6.3), 6.58 s (2H, NH_2), 6.63 s (2H, NH_2), 6.76 s (2H, NH_2)

IXg, and **Xb**). Melting points were determined with a Kofler device. The reaction progress was monitored with TLC on Silufol UV-254 plates, eluting with an acetone–hexane mixture (3 : 5) and developing with iodine vapor or UV irradiation.

Ethyl 2-amino-4-isopropyl-6-thio-5-cyano-1,4-dihydropyridine-3-carboxylate (IV). 1.0 g (10 mmol) of cyanothioacetamide **II** and a solution of sodium ethylate prepared from 0.23 g (10 mmol) of sodium and 15 mL of anhydrous ethanol were added to a

solution of 0.91 mL (10 mmol) of isobutyral **Ia** in 15 mL of anhydrous ethanol at 20°C. The reaction mixture was stirred during 5 min, then 1.5 g (10 mmol) of CH-acid **III** was added, and the mixture was stirred during 30 min and incubated during 48 h. Next, the mixture was diluted with 10% hydrochloric acid to pH 5 upon stirring and incubated at room temperature during 48 h. The formed precipitate was filtered off and washed sequentially with water, ethanol, and hexane (Tables 1 and 2). Mass spectrum, *m*/*z* (I_{rel}, %): 266 (100) $[M - 1]^+$.

Diethyl 6,6'-disulfanediylbis(2-amino-4-isobutyl-5-cyanonicotinate) (V) was prepared similarly from 1.1 mL (10 mmol) of isovaleric aldehyde **Ib**. Mass spectrum, *m*/*z* (I_{rel}, %): 557 (100) $[M + 1]^+$.

2-Amino-6-(2-phenylpropyl)-5-(1-phenylethyl)-cyclohexa-2,4-diene-1,1,3-tricarbonitrile (VII). 3 drops of morpholine were added to a solution of 1.5 mL (10 mmol) of 3-phenylbutyral **Id** and 0.66 g (10 mmol) of malononitrile **VI** in 20 mL of anhydrous ethanol at 20°C. The reaction mixture was stirred during 1 h and incubated during 48 h. The formed precipitate was filtered off and washed with ethanol and hexane. Mass spectrum, *m*/*z* (I_{rel}, %): 394 (5) $[M + 2]^+$, 393 (18) $[M + 1]^+$, 392 (39) $[M]^+$, 287 (13) $[M - PhCHMe]^+$, 246 (12), 232 (11), 143 (18), 131 (10), 118 (32), 106 (49) $[PhCH_2Me]^+$, 105 (100) $[PhCHMe]^+$, 91 (54) $[PhCH_2]^+$, 79 (47) $[C_6H_6+1]^+$, 58 (42).

4-Alkyl-2,6-diamino-3,5-dicyano-4*H*-thiopyrans (VIIIc, VIIIh, VIIIi, VIIIj) (*general procedure*). 3 drops of morpholine were added to a mixture of 10 mmol of the appropriate aldehyde **I** and 1.0 g (10 mmol) of cyanothioacetamide **II** in 20 mL of anhydrous ethanol at 20°C. The mixture was stirred during 1 h, and then 0.66 g (10 mmol) of malononitrile **VI** was added. The resulting mixture was stirred during 30 min and incubated during 24 h. The formed precipitate was filtered off and washed with ethanol and hexane (Tables 1 and 2).

2,6-Diamino-4-(1-phenylethyl)-4*H*-thiopyran-3,5-dicarbonitrile (VIIIc). Mass spectrum, *m*/*z* (I_{rel}, %): 283 (100) $[M + 1]^+$.

2,6-Diamino-4-heptyl-4*H*-thiopyran-3,5-dicarbonitrile (VIIIh). Mass spectrum, *m*/*z* (I_{rel}, %): 277 (100) $[M + 1]^+$.

2,6-Diamino-4-benzyl-4*H*-thiopyran-3,5-dicarbonitrile (VIIIi). Mass spectrum, *m*/*z* (I_{rel}, %): 269 (100) $[M + 1]^+$.

2,6-Diamino-4-hexyl-4*H*-thiopyran-3,5-dicarbonitrile (VIIIj). Mass spectrum, *m*/*z* (I_{rel}, %): 270 (100) $[M + 1]^+$.

4-Alkyl-6-amino-2-thioxo-3,5-dicyano-1,2-dihydropyridines (IXd, IXg) (*general procedure*). 0.9 mL (10 mmol) of morpholine was added to a mixture of 10 mmol of the appropriate aldehyde **I** and 1.0 g (10 mmol) of cyanothioacetamide **II** in 20 mL of anhydrous ethanol at 20°C. The mixture was stirred during 30 min, and then 0.66 g (10 mmol) of malononitrile **VI** was added. The mixture was refluxed during 1 h, cooled, diluted with 10% hydrochloric acid to pH 5, and incubated during 48 h. The formed precipitate was filtered off and washed with ethanol and hexane (Tables 1 and 2).

6-Amino-2-thioxo-4-(2-phenylpropyl)-1,2-dihydropyridine-3,5-dicarbonitrile (IXd). Mass spectrum, *m*/*z* (I_{rel}, %): 294 (8) $[M]^+$, 234 (11), 178 (9), 105 (100) $[M - PhCHMe]^+$, 91 (14) $[PhCH_2]^+$, 77 (22) $[Ph]^+$, 51 (12), 43 (24).

6-Amino-2-thioxo-4-(2-phenylethyl)-1,2-dihydropyridine-3,5-dicarbonitrile (IXg). Mass spectrum, *m*/*z* (I_{rel}, %): 282 (4) $[M + 2]^+$, 281 (6) $[M + 1]^+$, 280 (29) $[M]^+$, 279 (9) $[M - 1]^+$, 203 (3), 162 (4), 91 (100) $[PhCH_2]^+$, 77 (4) $[Ph]^+$, 65 (11), 51 (3), 39 (3).

4-Alkyl-6-amino-2-alkylsulfanyl-3,5-dicyanopyridines (Xa–Xd) were prepared similarly from the appropriate alkyl halides **Xa**–**Xd** instead of hydrochloric acid.

2-Amino-6-benzylsulfanyl-4-(cyclohex-3-en-1-yl)-pyridine-3,5-dicarbonitrile (Xa). Mass spectrum, *m*/*z* (I_{rel}, %): 345 (100) $[M - 1]^+$.

6-Amino-4-undecyl-2-(4-chlorobenzoylmethylsulfanyl)pyridine-3,5-dicarbonitrile (Xb). Mass spectrum, *m*/*z* (I_{rel}, %): 484 (3) $[M + 1]^+$, 483 (4) $[M]^+$, 482 (5) $[M - 1]^+$, 343 (6), 139 (100), $[4\text{-}ClC_6H_4CO]^+$, 125 (6), 111 (18), 43 (14).

6-Amino-4-benzyl-2-(4-nitrobenzoylmethylsulfanyl)pyridine-3,5-dicarbonitrile (Xc). Mass spectrum, *m*/*z* (I_{rel}, %): 430 (100) $[M + 1]^+$.

6-Amino-4-benzyl-2-methylsulfanylpyridine-3,5-dicarbonitrile (Xd). Mass spectrum, *m*/*z* (I_{rel}, %): 281 (100) $[M + 1]^+$.

Substituted thieno[2,3-*b*]pyridines (XIIIa, XIIIb) were prepared similarly using 5.6 mL (10 mmol) of 10% aqueous solution of KOH and 0.94 g (10 mmol) of α-chloroacetamide **XII** instead of hydrochloric acid.

3,6-Diamino-4-isopropyl-5-cyanothieno[2,3-*b*]-pyridine-2-carboxamide (XIIIa). Mass spectrum, *m*/*z* (I_{rel}, %): 276 (100) $[M + 1]^+$.

3,6-Diamino-4-isobutyl-5-cyanothieno[2,3-*b*]-pyridine-2-carboxamide (XIIIb). Mass spectrum, *m*/*z* (I_{rel}, %): 290 (100) $[M + 1]^+$.

REFERENCES

1. Tietze, L.F., Brasche, G., and Guericke, K., *Domino Reactions in Organic Synthesis*, Weinheim: Wiley-VCH, 2006.
2. Orru, R.V.A., Book of Abstracts, *Chemystry of Nitrogen Containing Heterocycles CNCH–2012*, Kharkiv, 2012, p. L-1.
3. Shestopalov, A.M., Shestopalov, A.A., and Rodinovskaya, L.A., *Synthesis*, 2008, no. 1, p. 1.
4. *Comprehensive Organic Chemistry*, Barton, D. and Ollis, W.D., Eds., Oxford: Pergamon, 1979.
5. Dyachenko, V.D. and Chernega, A.N., *Russ. J. Org. Chem*., 2007, vol. 43, no. 4, p. 567. DOI: 10.1134/S1070428006040142.
6. Dyachenko, V.D., *Russ. J. Gen. Chem*., 2006, vol. 76, no. 2, p. 282. DOI: 10.1134/S1070363206020216.
7. Dyachenko, V.D., Karpov, E.N., and Fes'kov, I.A., *Russ. J. Gen. Chem*., 2013, vol. 83, no. 9, p. 1716. DOI: 10.1134/S1070363213090156.
8. Abdel-Latif, F.F., *Bull. Chem. Soc. Japan*, 1989, vol. 62, no. 11, p. 3768.
9. Sharanin, Yu.A., Shestopalov, A.M., Nesterov, V.N., Melenchuk, S.N., Promonenkov, V.K., Shklover, V.E., Struchkov, Yu.T., and Litvinov, V.P., *Zh. Org. Khim.*, 1989, vol. 25, no. 6, p. 1323.
10. Sharanin, Yu.A., Promonenkov, V.K., Shestopalov, A.M., Nesterov, V.N., Melenchuk, S.N., Shklover, V.E., and Struchkov, Yu.T., *Zh. Org. Khim.*, 1989, vol. 25, no. 3, p. 622.
11. Litvinov, V.P., Rodinovskaya, L.A., Sharanin, Yu.A., Shestopalov, A.M., and Senning, A., *Sulfur Rep*., 1992, vol. 13, no. 1, p. 1. DOI: 10.1080/01961779208048951.
12. Litvinov, V.P., Krivokolysko, S.G., and Dyachenko, V.D., *Chem. Heterocycl. Compd*., 1999, vol. 35, no. 5, p. 509. DOI: 10.1007/BF02324634.
13. Litvinov, V.P., *Russ. Chem. Rev*., 2006, vol. 75, no. 7, p. 577. DOI: 10.1007/BC2006v075n07ABEH003619.
14. Morioka, M., Tkegami, H., Jakiyama, M., Hayashi, M., Ooike, S., Fujino, Y., Abe, D., and Tomozone, H., EP Patent 1876178, 2008.
15. Nell, P., Hubsch, W., Albrecht, B., and Keldenich, J., EP Patent 102006042143, 2008.
16. Leisther, S., Ludwig, A., Reichelt, C., and Schulze, A., EP Patent 1681292, 2006.
17. Hussein, A.M., Abu-Shanab, F.A., and Ishak, E.A., *Phosphorus, Sulfur., Silicon Relat. Elem*., 2000, vol. 159, no. 1, p. 55. DOI: 10.1080/10426500008043650.
18. Reichelt, C., Ludwig, A., and Leistner, S., EP Patent 1683799, 2006.
19. Cywin, C.L., Chen, Z., Fleck, R.W., Hao, M.-H., Hickey, E., Liu, W., Marshall, D.R., Nemoto, P., Sorcek, R.J., Sun, S., Wu, J.-P., Morwick, T., and Emeigh, J., US Patent 6964956, 2005.
20. Litvinov, V.P., Dotsenko, V.V., and Krivokolysko, S.G., *Khimiya tienopiridinov i rodstvennykh sistem* (Chemistry of Thienopyridines and Related Systems), Moscow: Nauka, 2006.
21. Pretch, E., Bühlmann, P., and Affolter, C., *Structure Determination of Organic Compounds: Tables of Spectral Data*, Springer: Berlin, 2000.