ISSN 1070-4280, Russian Journal of Organic Chemistry, 2020, Vol. 56, No. 10, pp. 1733–1737. © Pleiades Publishing, Ltd., 2020.
Russian Text © The Author(s), 2020, published in Zhurnal Organicheskoi Khimii, 2020, Vol. 56, No. 10, pp. 1557–1563.

Synthesis of Hexahydropyrimidines and 1,2,3,4-Tetrahydropyridines by Reaction of Ethyl Benzoylacetate with Formaldehyde and Primary Amines

D. R. Kireeva[a],* and A. I. Kamalova[a]

[a] *Ufa Institute of Chemistry, Ufa Federal Research Center, Russian Academy of Sciences, Ufa, 450054 Russia*

**e-mail: hetcom@anrb.ru*

Received June 15, 2020; revised June 28, 2020; accepted July 4, 2020

Abstract—The reaction of ethyl benzoylacetate with formaldehyde and primary amines in boiling pyridine or methanol afforded new 1,2,3,4-tetrahydropyridine derivatives and substituted hexahydropyrimidines.

Keywords: ethyl benzoylacetate, hexahydropyrimidine, tetrahydropyridine, diethyl 2,4-dibenzoylpentanedioate, debenzoylation, one-pot synthesis, multicomponent reactions

DOI: 10.1134/S1070428020100103

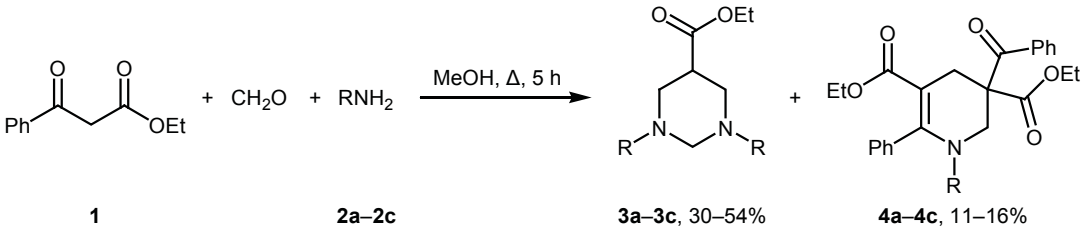
Six-membered nitrogen heterocycles of the hexahydropyrimidine and 1,2,3,4-tetrahydropyridine series exhibit a broad spectrum of biological activity. Hexahydropyrimidines were found to show antitumor [1], cytotoxic [2–4], antibacterial [5, 6], antiviral [7], and nootropic activities [8]. Tetrahydropyridine derivatives possessing antimalarial [9], antibacterial [10], insecticidal [11], and analgesic activities [12] have been reported. Tetrahydropyridines are also promising as potential anti-Alzheimer and anti-Parkinson drugs [13, 14]. In recent time, one-pot multi-component methods for the synthesis of 1,2,3,4-tetrahydropyridine [15, 16] and hexahydropyrimidine derivatives [17–20] have attracted much interest.

The present work was aimed at synthesizing a series of substituted 1,2,3,4-tetrahydropyridines and some hexahydropyrimidine derivatives using ethyl benzoylacetate (**1**) as starting material. We previously proposed a procedure for the synthesis of analogous compounds on the basis of ethyl acetoacetate [21, 22] and showed that hexahydropyrimidine derivatives containing an amino acid fragment exhibit pronounced cytotoxicity [3]. With the goal of extending the range of biologically active compounds we examined the reaction of ester **1** with formaldehyde and primary amines.

The amine components were methylamine (**2a**), propylamine (**2b**), butylamine (**2c**), and benzylamine (**2d**). The reactions were carried out by heating the reactants at a **1**–formaldehyde–amine ratio of 1:15:2 in boiling methanol for 5 h (Scheme 1). Ethyl benzoylacetate (**1**) reacted with 33% aqueous formaldehyde and 25.2% aqueous methylamine in boiling methanol gave 30% of ethyl 1,3-dimethylhexahydropyrimidine-5-carboxylate (**3a**). Apart from compound **3a**, diethyl 3-benzoyl-1-methyl-6-phenyl-1,2,3,4-tetrahydropyridine-3,5-dicarboxylate (**4a**) was formed as minor product (16%). It should be noted that products like **4** were not detected previously in analogous reactions [22].

Keto ester **1** reacted with formaldehyde and propylamine (**2b**) or butylamine (**2c**) in a similar way. In the

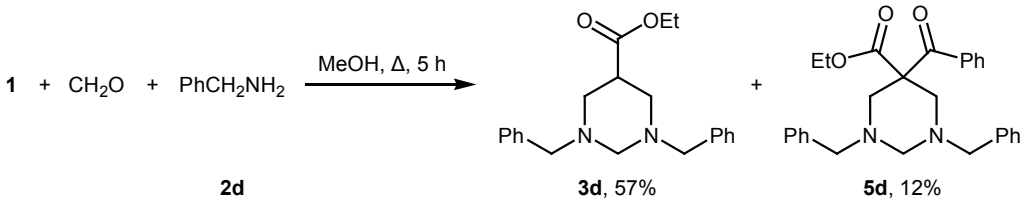
Scheme 1.



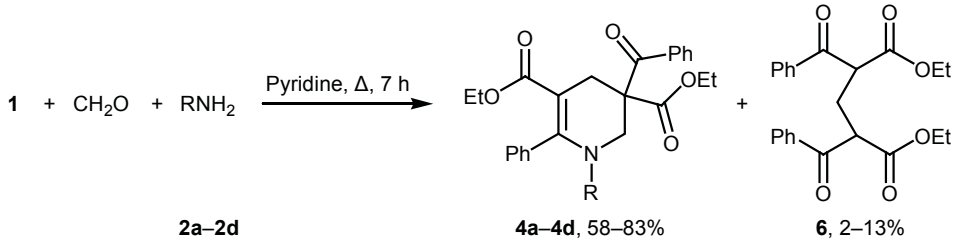
1 **2a–2c** **3a–3c**, 30–54% **4a–4c**, 11–16%

R = Me (**a**), Pr (**b**), Bu (**c**).

Scheme 2.



Scheme 3.



R = Me (**a**), Pr (**b**), Bu (**c**), $PhCH_2$ (**d**).

reaction with propylamine (**2b**), heterocyclic compounds **3b** and **4b** were formed in 36 and 5% yields, respectively, and 54% of 1,3-dibutylhexahydropyrimidine **3c** and 11% of 1,2,3,4-tetrahydropyridine **4c** were obtained from butylamine (**2c**). An interesting result was obtained in the reaction of **1** with 33% aqueous formaldehyde and benzylamine (**2d**) (Scheme 2). In this case, we isolated 57% of hexahydropyrimidine **3d** and 12% of 5-benzoyl derivative **5d**, whereas no 1,2,3,4-tetrahydropyridine derivative was formed.

Raising the amine proportion to a **1**–CH_2O–**2b** ratio of 1:15:4 increased the yield of hexahydropyrimidine **3b** to 50%, while tetrahydropyridine **4b** was formed only in trace amount. On the other hand, sharp decrease of the formaldehyde fraction and hence decrease of the amount water in the system (**1**–CH_2O–**2b** ratio 2:2:1) favored formation of tetrahydropyridine **4b** (18%), whereas the yield of **3b** was as low as 5%. Furthermore, in the latter case, the overall yield significantly decreased. The reaction in DMFA [21] at a **1**–CH_2O–**2b** ratio of 2:2:1 was accompanied by considerable tar formation, compound **4b** was isolated in 10% yield, and no corresponding hexahydropyrimidine derivative was detected.

The observed debenzoylation (Schemes 1, 2) with the formation of hexahydropyrimidines **3** is likely to occur [22] according to the retro-aldol mechanism, and the benzoyl group under the given conditions appears to be a better leaving group than the acetyl group in ethyl acetoacetate; the reactions with the latter gave mixtures of **3** and 5-acetylhexahydropyrimidines **5** [22]. Saleh et al. [23] reported an example of debenzoylation of 1,3-dicarbonyl compounds in the reactions with aqueous formaldehyde and aromatic amines in the presence of a catalytic amount of $FeCl_3$ in methylene chloride. Elimination of the benzoyl group was rationalized by $FeCl_3$-catalyzed nucleophilic addition of water (from formaldehyde solution) to the carbonyl group [23].

The condensation of ethyl benzoylacetate (**1**) with aqueous formaldehyde and amines **2a**–**2d** at a ratio of 2:2:1 in boiling pyridine for 7 h afforded 1,2,3,4-tetrahydropyridines **4a**–**4d** as the major products (61, 77, 58, and 83%, respectively). Apart from compounds **4a**–**4d**, diethyl 2,4-dibenzoylpentanedioate (**6**) was formed in 10, 2, 13, and 2% yield, respectively (Scheme 3).

Our results led us to presume that aprotic solvents such as pyridine and dimethylformamide favor initial formation of diethyl 2,4-dibenzoylpentanedioate (**6**) by aldol condensation of two molecules of **1** with formaldehyde. The subsequent reaction of **6** with the corresponding iminium cation yields 1,2,3,4-tetrahydropyridine [21]. When the reaction is carried out in methanol, the initial formation of iminium cation is followed by Mannich type aminomethylation of ketone **1** to produce hexahydropyrimidines **3** and **5**. Increased concentration of formaldehyde in the reaction mixture makes the Mannich reaction preferred.

Thus, we have proposed a one-pot synthesis of new 1,2,3,4-tetrahydropyridine derivatives in 40–83% yield by condensation of ethyl benzoylacetate with formaldehyde and primary amines in boiling pyridine. When the

reaction is carried out in boiling methanol, the corresponding hexahydropyrimidines are formed as the major products (yield 30–57%).

EXPERIMENTAL

The ^{1}H, ^{13}C, and ^{15}N NMR spectra were recorded on a Bruker Avance III spectrometer (USA) at 500, 125, and 50 MHz, respectively, using $CDCl_3$ as solvent and tetramethylsilane as internal standard (^{1}H, ^{13}C). The mass spectra (electrospray ionization) were obtained with a Shimadzu LC-MS-2010EV instrument (Japan). Elemental analysis was performed with a Euro EA-3000 CHNS analyzer (HEKAtech, Germany). Analytical TLC was carried out using Sorbfil PTSKh-AF-A plates manufactured by *Imid* Ltd. (Russia); eluent hexane–ethyl acetate (7:3). Macherey–Nagel Kieselgel 60 (70–230 mesh) was used for column chromatography. Commercially available amines (Acros Organics) and ethyl benzoyl acetate (Aldrich) were used without further purification.

Reaction of ethyl benzoylacetate (1) with formaldehyde and primary amines 2a–2d (*general procedure***).** Ethyl benzoylacetate (**1**), 1 mmol, was dissolved in 20 mL of methanol, 2 mmol of primary amine **2a**–**2d** and 15 mmol of 33% aqueous formaldehyde were added with stirring, and the mixture was refluxed for 5 h. The solvent was distilled off under reduced pressure, and the residue was extracted with 20 mL of methylene chloride. The extract was washed with water (3×10 mL), dried over anhydrous sodium sulfate, and evaporated under reduced pressure, and the residue was subjected to silica gel column chromatography using hexane–ethyl acetate (0 to 30% of the latter) as eluent.

Ethyl 1,3-dimethylhexahydropyrimidine-5-carboxylate (3a). Yield 0.14 g (30%), light yellow oily material. Its physicochemical properties and spectral characteristics coincided with those reported in [22].

Ethyl 1,3-dipropylhexahydropyrimidine-5-carboxylate (3b). Yield 0.23 g (36%), light yellow oily material. Its physicochemical properties and spectral characteristics coincided with those reported in [22].

Ethyl 1,3-dibutylhexahydropyrimidine-5-carboxylate (3c). Yield 0.38 g (54%), light yellow oily material. Its physicochemical properties and spectral characteristics coincided with those reported in [22].

Ethyl 1,3-dibenzylhexahydropyrimidine-5-carboxylate (3d). Yield 0.50 g (57%), yellow oil. ^{1}H NMR spectrum, δ, ppm: 1.27 t (3H, CH_3, J = 7.1 Hz), 2.59 m (2H, 4-H$_{ax}$, 6-H$_{ax}$), 3.06 m (1H, 5-H), 3.32 d (1H, 2-H$_{ax}$, J = 8.9 Hz), 3.62 s (4H, C**H**$_2$Ph), 3.64–3.80 m (3H, 2-H$_{eq}$, 4-H$_{eq}$, 6-H$_{eq}$), 4.19 q (2H, OCH_2, J = 7.1 Hz), 7.25–7.40 m (10H, Ph). ^{13}C NMR spectrum, δ_C, ppm: 13.81 (CH_3), 37.71 (C^5), 56.67 (CH_2N), 58.61 (**C**H$_2$Ph), 61.66 (OCH_2), 74.87 (NCH_2N), 128.19, 128.30, 128.49, 128.58, 128.79 (CH_{arom}), 137.55(C^i), 170.67 (C=O). Mass spectrum: *m/z* 339 [M + H]$^+$. Found, %: C 74.31; H 7.65; N 8.33. $C_{21}H_{26}N_2O_2$. Calculated, %: C 74.52; H 7.74; N 8.28.

Ethyl 5-benzoyl-1,3-dibenzylhexahydropyrimidine-5-carboxylate (5d). Yield 0.14 g (12%), yellow oil. ^{1}H NMR spectrum, δ, ppm: 1.13 t (3H, CH_3, J = 7.1 Hz), 3.15 d (2H, 4-H$_{ax}$, 6-H$_{ax}$, J = 12.2 Hz), 3.26 d (1H, 2-H$_{ax}$, J = 9.0 Hz), 3.58–3.82 m (3H, 2-H$_{eq}$, 4-H$_{eq}$, 6-H$_{eq}$), 3.61 s (2H, C**H**$_2$Ph), 3.62 s (2H, C**H**$_2$Ph), 4.16 q (2H, OCH_2, J = 7.1 Hz), 7.22–7.41 m (13H, Ph), 7.80 br.s (1H, *o*-H), 7.82 br.s (1H, *o*-H). ^{13}C NMR spectrum, δ_C, ppm: 14.18 (CH_3), 56.94, 58.16 (**C**H$_2$Ph), 59.49 (CH_2N), 60.54 (OCH_2), 74.87 (NCH_2N), 126.98, 127.08, 127.18, 128.01, 128.12, 128.26, 128.42, 128.75, 128.95, 132.24 (CH_{arom}), 136.71, 137.55, 138.24 (C^i), 170.67 (CO_2), 196.31 (C=O). Mass spectrum: *m/z* 443 [M + H]$^+$. Found, %: C 76.01; H 6.79; N 6.33. $C_{28}H_{30}N_2O_3$. Calculated, %: C 75.99; H 6.83; N 6.33.

Compounds 4a–4d (*general procedure***).** Ethyl benzoylacetate (**1**, 2 mmol) and 33% aqueous formaldehyde (2 mmol) were added in succession with stirring to a solution of primary amine **2a**–**2d** (1 mmol) in 6 mL of pyridine, and the mixture was refluxed for 7 h (TLC). The solvent was distilled off under reduced pressure, the residue was dissolved in 20 mL of methylene chloride, and the solution was washed with water (3×10 mL), dried over anhydrous sodium sulfate, and evaporated under reduced pressure. The residue was subjected to column chromatography using hexane–ethyl acetate (0 to 30% of the latter) as eluent.

Diethyl 3-benzoyl-1-methyl-6-phenyl-1,2,3,4-tetrahydropyridine-3,5-dicarboxylate (4a). Yield 0.33 g (61%), light yellow crystals. The physicochemical properties and spectral characteristics of the product coincided with those reported in [24]. ^{13}C NMR spectrum, δ_C, ppm: 13.81 and 13.95 (CH_2**C**H$_3$), 31.01 (C^4), 40.40 (NCH_3), 55.19 (C^2), 55.96 (C^3), 58.69, 61.84 (OCH_2), 94.53 (C^5), 127.94, 128.05, 128.24, 128.48, 128.53 (CH_{arom}), 132.90 (C^p), 135.67, 137.57 (C^i), 156.40 (C^6), 167.81 (3-C=O), 171.18 (5-C=O), 195.52 (Ph**C**=O).

Diethyl 3-benzoyl-6-phenyl-1-propyl-1,2,3,4-tetrahydropyridine-3,5-dicarboxylate (4b). Yield 0.45 g (77%), yellow oil. ^{1}H NMR spectrum, δ, ppm: 0.60 t (3H, $CH_2CH_2C\mathbf{H}_3$, J = 7.3 Hz), 0.74 t (3H, $OCH_2C\mathbf{H}_3$, J = 7.0 Hz), 1.13 t (3H, $OCH_2C\mathbf{H}_3$, J = 7.0 Hz), 1.32–1.45 m (2H, $NCH_2C\mathbf{H}_2$), 2.74 t (2H, NCH_2, J = 7.4 Hz), 3.04 d and 3.33 d (1H each, 4-H, J = 16.4 Hz), 3.65–3.74 m (2H, OCH_2), 3.78 d and 3.83 d (1H each, 2-H, J = 12.7 Hz), 4.12–4.27 m (2H, 5-CO_2CH_2), 7.06–7.18 m (2H, *o*-H), 7.28–7.44 m (5H, H_{arom}), 7.48–7.53 m (1H, *p*-H), 7.89–7.95 m (2H, *o*-H). ^{13}C NMR spectrum, δ_C, ppm: 10.94 ($CH_2CH_2\mathbf{C}H_3$), 13.83, 13.88 ($CH_2\mathbf{C}H_3$), 22.07 ($NCH_2\mathbf{C}H_2$), 31.24 (C^4), 52.51 (C^2), 53.37 (NCH_2), 55.73 (C^3), 58.50, 61.72 (OCH_2), 94.02 (C^5), 127.81 (C^p), 128.20, 128.43, 128.51 (CH_{arom}), 133.75 (C^p), 135.76, 137.57 (C^i), 156.04 (C^6), 167.67 (3-C=O), 171.12 (5-C=O), 195.42 (Ph**C**=O). ^{15}N NMR spectrum: δ_N 89.78 ppm. Mass spectrum: *m*/*z* 450.3 $[M + H]^+$. Found, %: C 73.03; H 6.98; N 3.16. $C_{27}H_{31}NO_5$. Calculated, %: C 72.14; H 6.95; N 3.12.

Diethyl 3-benzoyl-1-butyl-6-phenyl-1,2,3,4-tetrahydropyridine-3,5-dicarboxylate (4c). Yield 0.39 g (65%), yellow–orange oil. ^{1}H NMR spectrum, δ, ppm: 0.67 t (3H, $CH_2CH_2C\mathbf{H}_3$, J = 7.3 Hz), 0.73 t (3H, $CH_2C\mathbf{H}_3$, J = 7.1 Hz), 0.93–1.10 m (2H, $CH_2C\mathbf{H}_2CH_3$), 1.13 t (3H, $CH_2C\mathbf{H}_3$, J = 7.1 Hz), 1.28–1.36 m (2H, $NCH_2C\mathbf{H}_2$), 2.73 t (2H, NCH_2, J = 7.8 Hz), 3.00 d and 3.27 d (1H each, 4-H, J = 16.4 Hz), 3.64–3.71 m (2H, OCH_2), 3.74 d and 3.79 d (1H each, 2-H, J = 12.7 Hz), 4.12–4.24 m (2H, 5-CO_2CH_2), 7.06–7.14 m (2H, *o*-H), 7.28–7.60 m (6H, H_{arom}), 7.86–7.91 m (2H, *o*-H). ^{13}C NMR spectrum, δ_C, ppm: 13.58, 13.83, 13.90 (CH_3), 19.66 ($CH_2\mathbf{C}H_2CH_3$), 30.98 ($CH_2\mathbf{C}H_2CH_3$), 31.22 (C^4), 51.54 (C^2), 52.50 (NCH_2), 55.78 (C^3), 58.64, 61.79 (OCH_2), 93.98 (C^5), 127.83, 128.17, 128.41, 128.49, 128.52 (CH_{arom}), 132.87 (C^p), 135.91, 137.54 (C^i), 156.13 (C^6), 167.86 (3-C=O), 171.25 (5-C=O), 195.65 (Ph**C**=O). Mass spectrum: *m*/*z* 464 $[M + H]^+$. Found, %: C 73.01; H 7.17; N 3.04. $C_{28}H_{33}NO_5$. Calculated, %: C 72.55; H 7.18; N 3.02.

Diethyl 3-benzoyl-1-benzyl-6-phenyl-1,2,3,4-tetrahydropyridine-3,5-dicarboxylate (4d). Yield 0.54 g (83%), yellow oil. ^{1}H NMR spectrum, δ, ppm: 0.74 t (3H, $CH_2C\mathbf{H}_3$, J = 7.1 Hz), 1.01 t (3H, $CH_2C\mathbf{H}_3$, J = 7.1 Hz), 3.12 d and 3.30 d (1H each, 4-H, J = 16.6 Hz), 3.64 d (1H, 2-H, J = 12.9 Hz), 3.69–3.76 m (2H, OCH_2), 3.76 d (1H, 2-H, J = 12.9 Hz), 3.95 d (1H, $C\mathbf{H}_2Ph$, J = 15.8 Hz), 4.12–4.21 m (2H, OCH_2), 4.05 d (1H, $C\mathbf{H}_2Ph$, J = 15.8 Hz), 7.14–7.57 m (13H, H_{arom}), 7.87 d (2H, *o*-H, J = 7.3 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.79, 13.85 ($CH_2\mathbf{C}H_3$), 31.32 (C^4), 52.33 (C^2), 55.29 ($\mathbf{C}H_2Ph$), 55.56 (C^3), 58.81, 61.78 (OCH_2), 95.47 (C^5), 127.26, 127.37, 128.12, 128.46, 128.56, 128.79, 128.83 (CH_{arom}), 132.97 (C^p), 135.59, 137.41, 137.58 (C^i), 155.83 (C^6), 167.78, 171.20 (C=O), 195.29 (Ph**C**=O). Mass spectrum: *m*/*z* 498 $[M + H]^+$. Found, %: C 75.05; H 6.25; N 2.82. $C_{31}H_{31}NO_5$. Calculated, %: C 74.83; H 6.28; N 2.81.

Diethyl 2,4-dibenzoylpentanedioate (6) was isolated as a minor product in the reactions of **1** with formaldehyde and amines **2a**–**2d** in pyridine. Yield 0.05 g (10%), 0.05 g (2%), 0.06 g (13%), and 0.05 g (2%), respectively; white amorphous crystals. Its physicochemical and spectral characteristics coincided with those reported in [25].

ACKNOWLEDGMENTS

The spectral studies were carried out using the facilities of the Chemistry joint center (Ufa Institute of Chemistry, Ufa Federal Research Center, Russian Academy of Sciences).

FUNDING

This study was performed in the framework of state assignment for Ufa Institute of Chemistry, Ufa Federal Research Center, Russian Academy of Sciences (project no. AAAA-A20-120012090031-3).

CONFLICT OF INTEREST

The authors declare the absence of conflict of interest.

REFERENCES

1. Siddiqui, A.Q., Merson-Davies, L., and Cullis, P.M., *J. Chem. Soc., Perkin Trans. 1*, 1999, p. 3243. https://doi.org/10.1039/A903293B
2. Liu, S.-W., Jin, J., Chen, C., Liu, J.-M., Li, J.-Y., Wang, F.-F., Jiang, Z.-K., Hu, J.-H., Gao, Z.-X., Yao, F., You, X.-F., Si, S.-Y., and Sun, C.-H., *J. Antibiot*., 2013, vol. 66, p. 281. https://doi.org/10.1038/ja.2012.118
3. Latypova, D.R., Badamshin, A.G., Gibadullina, N.N., Khusnutdinova, N.S., Zainullina, L.F., Vakhitova, Y.V., Tomilov, Y.V., and Dokichev, V.A., *Med. Chem. Res*., 2017, vol. 26, p. 900. https://doi.org/10.1007/s00044-017-1802-4
4. Gibadullina, N.N., Latypova, D.R., Vakhitov, V.A., Khasanova, D.V., Zainullina, L.F., Vakhitova, Yu.V., Lobov, A.N., Ugrak, B.I., Tomilov, Yu.V., and Dokichev, V.A., *J. Fluorine Chem*., 2018, vol. 211, p. 94. https://doi.org/10.1016/j.jfluchem.2018.04.011

5. Janati, F., Heravi, M.M., and Mirshokraie, A., *J. Chem*., 2013, vol. 2013, article ID 214617. https://doi.org/10.1155/2013/214617
6. Zohdi, H.F., Rateb, N.M., and Elnagdy, S.M., *Eur. J. Med. Chem*., 2011, vol. 46, p. 5636. https://doi.org/10.1016/j.ejmech.2011.09.036
7. Hwang, J.Y., Kim, H.-Y., Jo, S., Park, E., Choi, J., Kong, S., Park, D.-S., Heo, J.M., Lee, J.S., Ko, Y., Choi, I., Cechetto, J., Kim, J., Lee, J., No, Z., and Windisch, M.P., *Eur. J. Med. Chem*., 2013, vol. 70, p. 315. https://doi.org/10.1016/j.ejmech.2013.09.055
8. Sapozhnikova, T.A., Borisevich, S.S., Kireeva, D.R., Gabdrakhmanova, S.F., Khisamutdinova, R.Yu., Makara, N.S., Gibadullina, N.N., Zarudii, F.S., and Khursan, S.L., *Behav. Brain Res*., 2019, vol. 373, article ID 112109. https://doi.org/10.1016/j.bbr.2019.112109
9. Misra, M., Pandey, S.K., Pandey, V.P., Pandey, J., Tripathi, R., and Tripathi, R.P., *Bioorg. Med. Chem*., 2009, vol. 17, p. 625. https://doi.org/10.1016/j.bmc.2008.11.062
10. Aridoss, C., Amirthaganesan, S., and Jeong, Y.T., *Bioorg. Med. Chem. Lett*., 2010, vol. 20, p. 2242. https://doi.org/10.1016/j.bmcl.2010.02.015
11. Sun, Ch.-W., Wang, J., Wu, Y., Nan, S.-B., and Zhang, W.-G., *Heterocycles*, 2013, vol. 87, p. 1865. https://doi.org/10.3987/COM-13-12766
12. Brown, B.S., Keddy, R., Zheng, G.Z., Schmidt, R.G., Koenig, J.R., McDonald, H.A., Bianchi, B.R., Honore, P., Jarvis, M.F., Surowy, C.S., Polakowski, J.S., Marsh, K.C., Faltynek, C.R., and Lee, C.-H., *Bioorg. Med. Chem*., 2008, vol. 16, p. 8516. https://doi.org/10.1016/j.bmc.2008.08.005
13. Suleman, N.K., Flores, J., Tanko, J.M., Isin, E.M., and Castaglonoli, N., *Bioorg. Med. Chem*., 2008, vol. 16, p. 8557. https://doi.org/10.1016/j.bmc.2008.08.013
14. Morale, M.C., Serra, P.A., L'episcopo, F., Tirolo, C., Caniglia, S., Testa, N., Gennuso, F., Giaquinta, G., Rocchitta, G., Desole, M.S., Miele, E., and Marchetti, B., *Neuroscience*, 2006, vol. 138, p. 869. https://doi.org/10.1016/j.neuroscience.2005.07.060
15. Dudognon, Y., Rodriguez, J., Constantieux, T., and Bugaut, X., *Eur. J. Org. Chem*., 2018, vol. 2018, p. 2432. https://doi.org/10.1002/ejoc.201800236
16. Shokoohian, M., Hazeri, N., Maghsoodlou, M.T., and Lashkari, M., *Chem. J. Mold*., 2019, vol. 14, p. 97. https://doi.org/10.19261/cjm.2019.639
17. Gein, V.L., Zamaraeva, T.M., Gorgopina, E.V., and Dmitriev, M.V., *Chem. Heterocycl. Compd*., 2020, vol. 56, p. 339. https://doi.org/10.1007/s10593-020-02665-w
18. Gibadullina, N.N., Latypova, D.R., Novikov, R.A., Tomilov, Y.V., and Dokichev, V.A., *Arkivoc*, 2017, vol. 2017, part (iv), p. 222. https://doi.org/10.3998/ark.5550190.p010.003
19. Palermo, V., Sathicq, A., Constantieux, T., Rodriguez, J., Vazquez, P., and Romanelli, G., *Catal. Lett*., 2015, vol. 145, p. 1022. https://doi.org/10.1007/s10562-015-1498-3
20. Hussain, A., Verma, S., Bhandari, S., and Virendra, K., *Chem. Sci. Rev. Lett*., 2018, vol. 7, no. 28, p. 926.
21. Gibadullina, N.N., Latypova, D.R., Nugumanov, T.R., Spirikhin, L.V., and Dokichev, V.A., *Chem. Heterocycl. Compd*., 2017, vol. 53, p. 1098. https://doi.org/10.1007/s10593-017-2176-8
22. Latypova, D.R., Badamshin, A.G., Lobov, A.N., and Dokichev, V.A., *Russ. J. Org. Chem*., 2013, vol. 49, p. 843. https://doi.org/10.1134/S1070428013060079
23. Saleh, A., Morton, M., and D'Angelo, J., *Synth. Commun*., 2014, vol. 44, p. 2715. https://doi.org/10.1080/00397911.2014.916302
24. Darnbrough, G., Knowles, P., O'Connor, S.P., and Tierney, F.J., *Tetrahedron*, 1986, vol. 42, p. 2339. https://doi.org/10.1016/S0040-4020(01)90615-5
25. Liu, W., Liu, J., Ogawa, D., Nishihara, Y., Guo, X., and Li, Z., *Org. Lett*., 2011, vol. 13, p. 6272. https://doi.org/10.1021/ol202749x