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SYNTHETIC STRATEGIES DUE TO NEW 1,2,4-TRIAZOLES GETTING (LITERATURE REVIEW)

[1]*Prytula R. L., [2]Shmatenko O. P., [3]Bushuyeva I. V. and [3]Parchenko V. V.

[1]National Military Medical Clinical Center "Main Military Clinical Hospital", Ukraine.
[2]Ukrainian Military Medical Academy, Ukraine.
[3]Zaporizhzhia State Medical and Pharmaceutical University, Ukraine.

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***Corresponding Author**
Prytula R. L.
National Military Medical Clinical Center "Main Military Clinical Hospital", Ukraine.

ABSTRACT

1,2,4-Triazole is one of the most common "frameworks" in the synthesis of new biologically active molecules. Derivatives of the 1,2,4-triazole exhibit various types of biological activity and can fully satisfy the needs of the pharmaceutical industry for the creation of new drugs. This heterocyclic structure is the main component of various drugs available in clinical therapy: ribavirin (direct-acting antivirals), letrozole (aromatase inhibitors), itraconazole, fluconazole (fungicides), alprazolam (sedative agent). A wide range of biological and therapeutic properties of the 1,2,4 triazoles will encourage the scientific community to develop new accessible synthetic methods for their preparation for decades. Amidines, imidates, amidrazones, aryldiazoniums, and hydrazones are among the most relevant triazole precursors. The simplicity of construction and the strength of this heterocycle, as well as the possibility of highly selective introduction of "valuable" substituents into the composition of 1,2,4-triazole at the last stages, create a number of advantages over other organic substances. Thus, the generalization of literary sources in recent years regarding the synthesis methods of a number of new 1,2,4-triazole derivatives indicates the prospect of finding new biologically active molecules that can be the basis for the creation of original medicines.

KEYWORDS: 1,2,4-triazoles, synthesis, transformation, chemical modification, biological activity.

INTRODUCTION

Azageterocyclic systems are the most widespread among organic compounds. A special place among them is occupied by the 1,2,4-triazoles, which are the object of research by scientists in various directions.[1] 1,2,4-Triazoles are fairly stable compounds and play an important role as typical pharmacophores. The 1,2,4-triazole system in combination with fragments of other chemical compounds is a part of substances that are active pharmaceutical ingredients (APhI) of well-known drugs: antifungal (fluconazole, itraconazole, posaconazole, voriconazole, ravuconazole), anxiolytic, anticonvulsant and hypnotic (estazolam, alprazolam), anxiolytics and muscle relaxants (relaxant (antimigramin). rizatriptan), antiplatelet agents (trapidyl), antidepressants (trazodone), anticancer agents (anastrozole), aromatase inhibitors (letrozole), antiviral (ribavirin) and anticonvulsants (loreclezole).[2–4] The group of fungicides includes prothioconazole, triadimefon, metconazole, propiconazole, tebuconazole, epoxyconazole, triadimenol and cyproconazole.[5] It is also known that the 1,2,4-triazole and its derivatives have a wide spectrum of bioactivity, they exhibit neuroprotective[6], antioxidant[7], antimalarial[8], antileucine[9], antidiuretic[10], antiviral[11], anticonvulsant[12] activity, are also antagonists of CB1 cannabinoid receptors[13], inhibitors of γ aminobutyric acid-A (GABA-A).[14] Another group of the 1,2,4-triazole derivatives, which contains an arylideneamino group in the fourth position of the 1,2,4-triazole ring, exhibits antitumor activity.[15] In parallel with this, it should be noted that there is no generalization of information regarding the state of modern synthesis methods of new 1,2,4-triazole derivatives. Thus, **the aim** of our work was to analyze literary sources regarding new modern methods of the 1,2,4-triazole derivatives obtaining, which are promising for the manifestation of various types of biological activity.

RESEARCH MATERIALS AND METHODS

The analysis of literary sources convincingly proves the prospect of finding new biologically active compounds in a number of substituted 1,2,4-triazoles. Today, there are many scientific schools that are engaged in the study of synthetic and biological properties of new molecules based on the heterocyclic system of the 1,2,4-triazole. It should be noted that the introduction of various functional substituents to the 1,2,4-triazole core has a positive effect not only on increasing pharmacological activity and the emergence of a new action, but also on the availability of various transformations based on the 1,2,4-triazole system. It is important to note that 1,2,4-triazole derivatives, in addition to high biological activity, are low-toxic or practically non-toxic compounds. When conducting a comparative analysis of available

literary sources in recent years, attention should be paid to the lack of data on the information's generalization about the synthetic potential of new 1,2,4-triazole derivatives.

RESULTS AND THEIR DISCUSSION

The original method of cyclocondensation of S-methylisothiourea **1.1**, obtained by alkylation of substituted thioureas with hydrazides **1.2** to obtain 3,4,5-trisubstituted 1,2,4-triazoles **1.3** (Fig. 1) is given in the work.[16] At the same time, *in situ* synthesis was used, which included S-alkylation of thiourea with 1,3-propane-sultone and subsequent ring closure.[17]

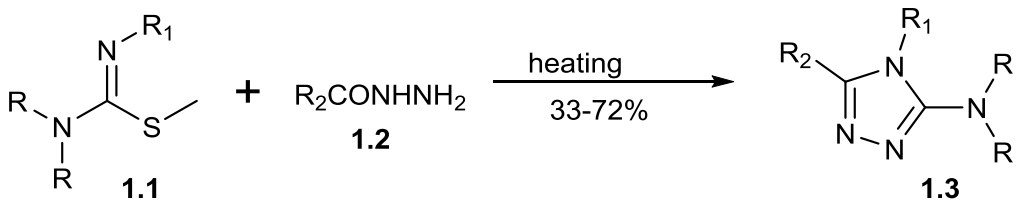


Fig. 1. Synthesis scheme of the 1,2,4-triazole derivatives by the condensation method of S-methylisothiourea.

According to the results of oxidative desulfurization of N,N′-disubstituted thioureas **1.4** with molecular iodine (I_2), intermediate carbodiimides **1.5** were obtained, which were condensed *in situ* at room temperature with formohydrazide to get 3,4-disubstituted aminotriazoles **1.6** (Fig. 2). It is also possible to use a more nucleophilic substituent, according to the process given in the work.[18] In addition, 2-iodoxybenzoic acid (IBX) can be used as an oxidizing agent.[19]

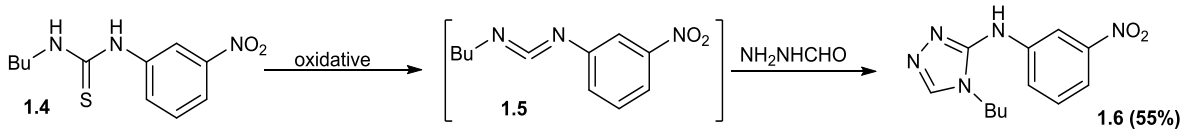


Fig. 2: Scheme of oxidative desulfurization of N,N′-disubstituted.

A well-known method of 1,2,4-triazolthiones obtaining **1.8** is the condensation of hydrazides with isothiocyanates (Fig. 3). At the same time, the solvent can be used several times without affecting the yield of final products.[20] Other examples of the conditions for this classical reaction are given in the works.[21]

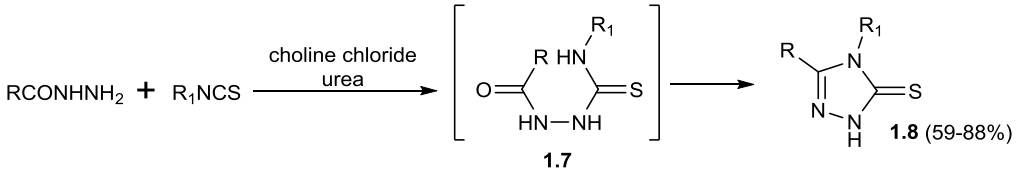


Fig. 3. The method of triazolthiones' obtaining by condensation of hydrazides with isothiocyanates.

The original synthesis method of 3,4,5-trisubstituted triazoles is proposed to use by microwave irradiation (Fig. 4). The reaction gives high yields, for example, compounds **1.9** (80%), when the reagents are heated at 140°C in the presence of 2-fluoropyridine as a base with weakened nucleophilicity.[22] A less environmentally pure way to obtain such triazoles is amide's thionation using the Lavesson reagent with subsequent condensation with hydrazide in the presence of one equivalent of $Hg(OAc)_2$.[23]

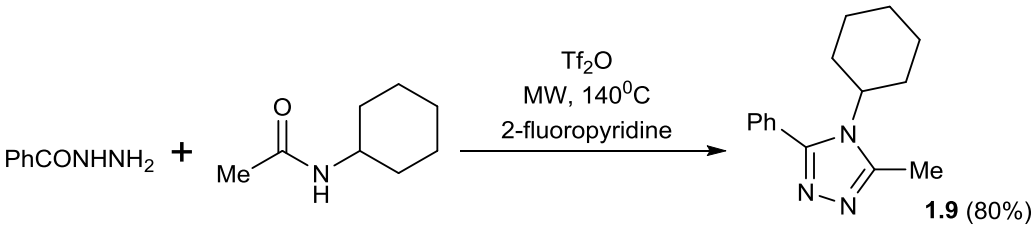


Fig. 4: Synthesis scheme of 3,4,5-trisubstituted triazoles by activation of amides with trifluoromethanesulfonic anhydride.

Aromatic nitriles can be condensed with hydrazides in EtOH under microwave irradiation (700 W) in the presence of 30 mol. % of 4-dimethylaminopyridine (DMAP). Thus, 3,5-disubstituted 1,2,4-triazoles were obtained.[24] The reaction between dialkylcyanamides **1.10** and aryl hydrazides was carried out under the catalysis of $ZnCl_2$ at 80°C in EtOH (Fig. 5).[25] Nickel (II) bisacetylacetonate $[Ni(acac)_2]$[26] was used as a catalyst in dioxane for the condensation of hydrazides with benzoylcyanamide.

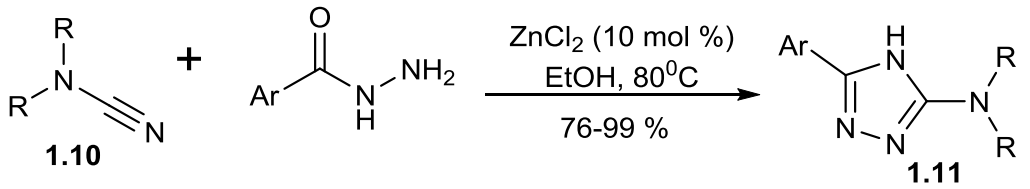


Fig. 5. Scheme of obtaining derivatives by reaction between dialkylcyanamides and aryl hydrazides.

Dimerization of N-arylbenzohydrazides **1.12** under the influence of trifluoromethanesulfonic anhydride and pyridine as a base took place at a low temperature (-30 °C) with the formation of 4-amino-1,2,4-triazolium triflate **1.13** (Fig. 1.6). However, when the base was 2-fluoropyridine, the product was 1,3,4-oxadiazoline.[27]

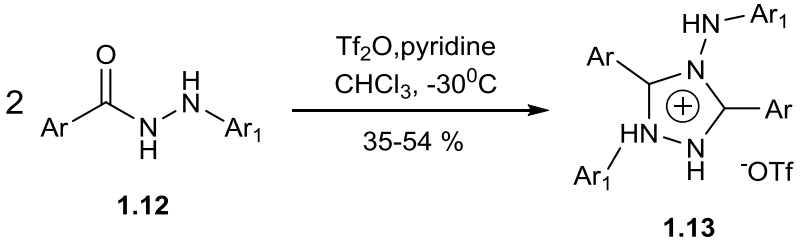


Fig. 6: Scheme of obtaining derivatives by reaction between dialkylcyanamides and aryl hydrazides.

The reaction of two molecules of N-substituted 2-phenylhydrazinecarbothioamides **1.14** with tetrachloro-1,4-benzoquinone (chloranil) in the presence of Ph_3P gives phenylazo-1,2,4-triazole **1.15** (Fig. 7).[28]

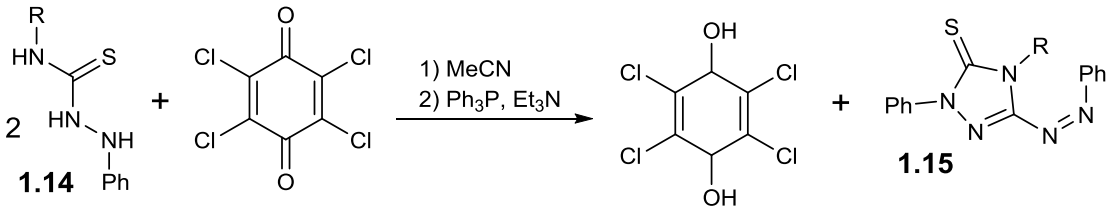


Fig. 7: Reaction of two molecules of *N*-substituted 2 phenylhydrazinecarbothioamides with tetrachlor-1,4-benzoquinone.

Thiosemicarbazones **1.16, 1.17** (Ar = 4-$O_2NC_6H_4$) are precursors of iminoisothiocyanate **1.18**, which is formed after the release of HY, which undergoes cycloaddition to imine to form the internal salt of triazolinium thione **1.19**; in some cases, isomer **1.20** was obtained (Fig. 8).[29] *N* -(Phenoxycarbonyl)hydrazones **1.17** obtained from aldehydes also underwent a similar transformation in the preparation of **1.19** compounds, which can be reduced to triazolidinones **1.20**.

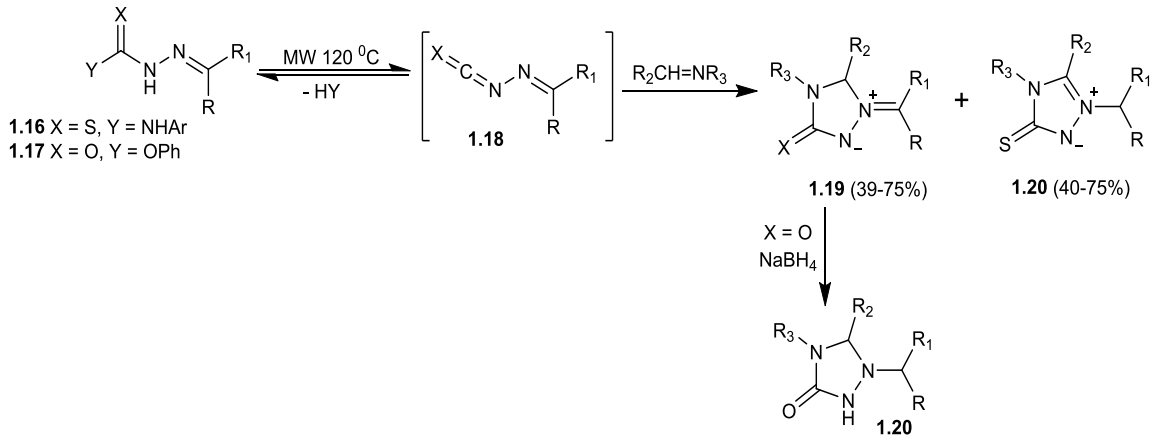


Fig. 8: Scheme of the cycloaddition of thiosemicarbazones to an imine with the formation of an internal salt of a triazolinium thion.

Efficient synthesis of urazoles **1.2**4, avoiding the use of isocyanates, was carried out by solvent-free condensation of ethylcarbamate **1.21** and phenylcarbamate **1.22** obtained *in situ* from diphenylcarbonate and amine (Fig. 9). This method allowed to obtain urazoles **1.24** in very good yields. In an alternative way, ethylphenylhydrazine-1,2-dicarboxylate **1.23**, also obtained *in situ*, reacted with an amine to obtain urazoles **1.24.**[30]

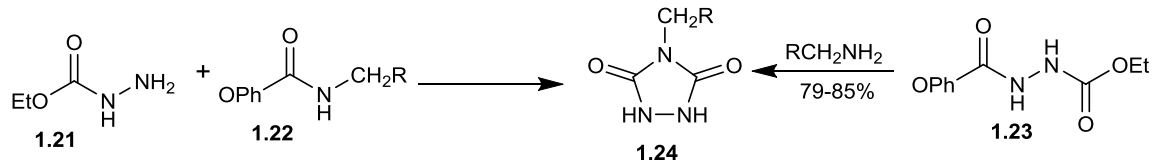


Fig. 1.9: Scheme of the cycloaddition of thiosemicarbazones to an imine with the formation of an internal salt of a triazolinium thion.

The iodine-catalyzed coupling of hydrazones **1.25** with primary amines **1.26** in the presence of three equivalents of tert-butyl hydroperoxide allowed to obtain a wide range of 1,3,5-threesubstituted triazoles **1.27** with a yield of 34-92% (Fig. 10). The proposed reaction mechanism occurs through the formation of an azoimine intermediate product.[31]

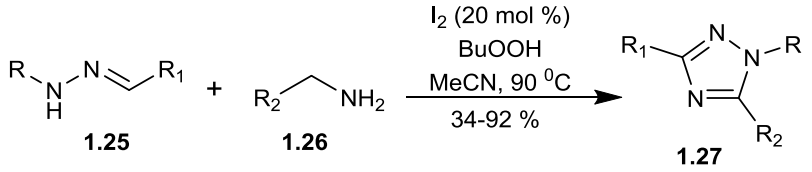


Fig. 10: Scheme of hydrazones' combination with primary amines in the presence of three equivalents of tert-butyl hydroperoxide.

Bromination of N,N-disubstituted hydrazones **1.28** and replacement of the hydrazonoyl bromide formed *in situ* with sodium thiocyanate leads to the formation of the inner salt of 5-thioxo-1,2,4-triazolium thion **1.29** (Fig. 11).[32] The same synthesis can also be carried out using ammonium thiocyanate in the presence of ammonium persulfate.[33]

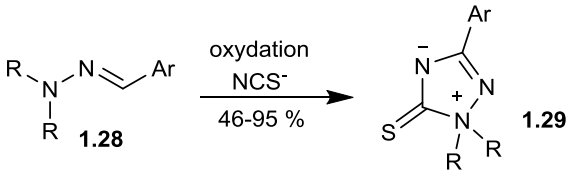


Fig. 11: Interaction scheme of the hydrazonoyl bromide with sodium thiocyanate and the formation of 1,2,4-triazole derivatives.

Diarylhydrazones **1.30** can react in the presence of $Cu(OAc)_2$ and DABCO at room temperature to form 1,3,5-triaryltriazoles **1.31** (Fig. 12). The reaction is considered to occur via dimerization, followed by oxidative cyclization catalyzed by Cu (II). In the absence of DABCO, isomeric 2,4,5-triaryl-1,2,3-triazoles are formed.[34]

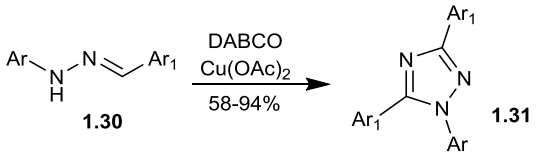


Fig. 12: Scheme's formation of 1,3,5-triaryltriazoles using the condensation of diarylhydrazones.

There is also known the synthesis method of 1,3,5-trisubstituted 1,2,4-triazoles **1.33** in one stage using nitriles and N-arylhydrazonoyl chlorides **1.32** (Fig. 13). The imidate formed *in situ* from the corresponding nitrile and hydrochloric acid in EtOH undergoes 1,3-dipolar cycloaddition with nitrilimines formed from hydrazonoyl chlorides **1.32**, which are converted into triazoles **1.33.**[35]

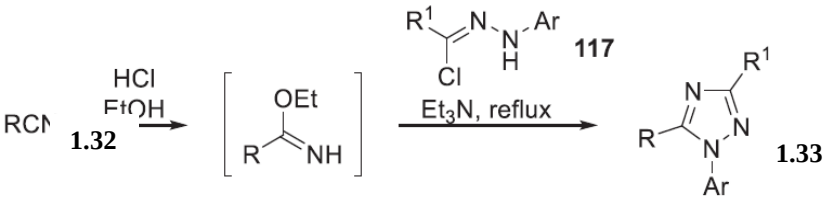


Fig. 13: Scheme's formation of 1,3,5-triaryltriazoles using the condensation of diarylhydrazones in the presence of $Cu(OAc)_2$ and DABCO.

Selective 1,3-dipolar cycloaddition of organocyanamide anions formed *in situ* from the tosylated derivative **1.34** with nitrilimines gives 1,2,4-triazole-3-imines **1.35** (Fig. 13). Treatment of the 1,2,4-triazole-3-imines with nitrite and sodium acetate in 50% acetic acid leads to the formation of the corresponding 1,2,4-triazole-5-ones **1.36.**[36,37]

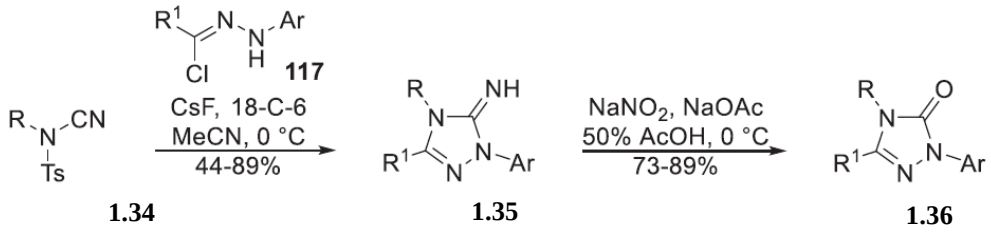


Fig. 13. Selective scheme of 1,3-dipolar cycloaddition of a tosylated derivative with nitrilimines.

Azomethinimine 1,3-dipole **1.38** was formed from tosylhydrazones **1.37** with PhIO and reacted regioselectively with imines. This leads to the formation of substituted 1,2,4-triazolines **1.39**, and after NBS-mediated aromatization to 1,2,4-triazoles **1.40** (Fig. 14).[38]

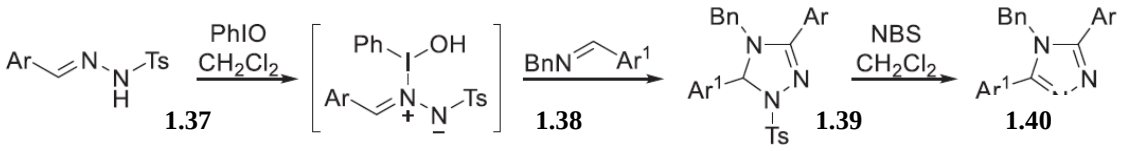


Fig. 14: Selective scheme of 1,3-dipolar cycloaddition of a tosylated derivative with nitrilimines.

Imidoyl chlorides **1.44**, formed *in situ* from amides and thionyl chloride, react with 5-glucopyranosyl-substituted tetrazoles **1.45** to form trisubstituted 1,2,4-triazoles **1.46** (Fig. 15). The latter ones can be debenzylated after catalytic hydrogenation **1.47.**[39]

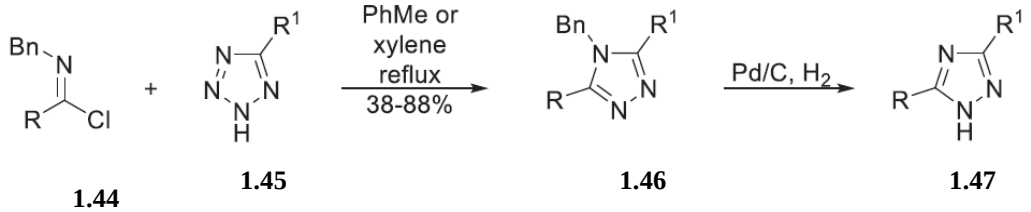


Fig. 15. Scheme of 1,3-dipolar cycloaddition to obtain 1,2,4-triazole derivatives.

Aryldiazonium salts react with alkylidenedihydropyridines **1.49** obtained from N-acylated 4-(aminomethyl)pyridines **1.48** in a [3 + 2] cyclocondensation reaction with the formation of

substituted 1,2,4-triazolium salts **1.50** or neutral 1,2,4-triazoles **1.51** (R = H) (Fig. 16). The presented reaction offers a general route for the synthesis of 3-(pyrid-4-yl)-substituted 1,2,4-triazoles.[40]

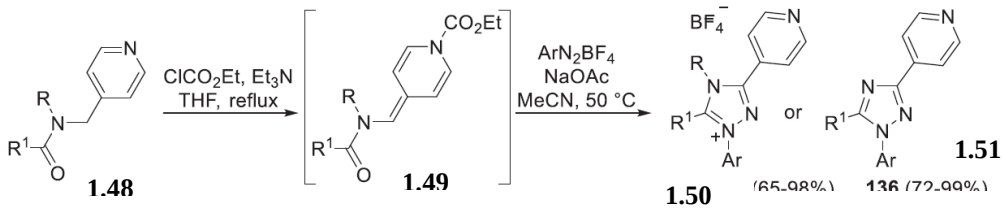


Fig. 16: Scheme of cyclocondensation with the formation of substituted 1,2,4-triazolium salts or neutral 1,2,4-triazoles

The regioselectivity of the [3+2] cycloaddition of isocyanides with aryl diazonium salts depends on the metal catalyst. Ag_2CO_3 catalysis leads to the formation of 1,3-disubstituted 1,2,4-triazoles **1.52**, while $Cu(OAc)_2$ catalysis in the presence of LiOAc additive (2 equiv.) leads to the formation of 1,5-disubstituted 1,2,4- triazole **1.53** as the main products (Fig. 17).[41]

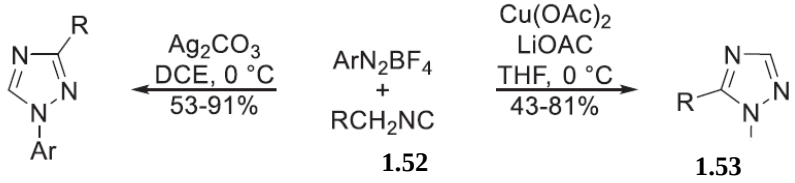


Fig. 17. Scheme of cycloaddition of [3+2] isocyanides with aryldiazonium salts to obtain 1,2,4-triazole derivatives.

Imides can be condensed with arylhydrazines **1.55** in the presence of aluminum oxide to form 1,3,5-trisubstituted triazoles. Asymmetric imides **1.54** with one alkyl and one aryl group are cyclized regioselectively, forming 3-alkyl-1,5-diaryltriazole **1.56** (Fig. 18). Similarly, N,N-di(trifluoroacetyl)anilines react with hydrazine to form 4-aryl-3,5-di(trifluoromethyl)-1,2,4-triazoles.[42,43]

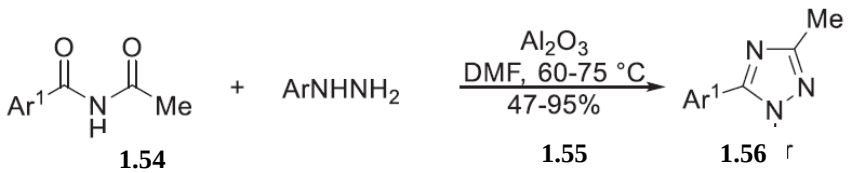
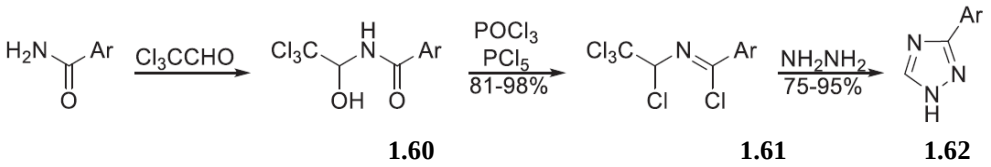


Fig. 18: Condensation scheme of imides with arylhydrazines in the presence of aluminum oxide.

Benzamides react with trichloroacetaldehyde to form adducts **1.60**, which can be chlorinated to reactive N-polychloroalkyl imidoyl chlorides **1.61**. The latter ones condense with hydrazine to form monosubstituted 1,2,4-triazoles **1.62** (Fig. 19).[44]



1.60 **1.61** **1.62**

Fig. 19. Reaction scheme of the reactive N-polychloroalkyl imidoyl chlorides with hydrazine with the formation of monosubstituted 1,2,4-triazoles.

CONCLUSIONS

Literature sources for recent years have been summarized on synthesis methods of a number of new 1,2,4-triazole derivatives, which may be promising for the development of new highly effective bioactive compounds.

LITERATURE

1. Fan, Y. L., Ke, X., Liu, M. Coumarin–triazole Hybrids and Their Biological Activities / HeteroCorporation, 2018; 791–802.
2. Emami, S., Ghobadi, E., Saednia, S., and others Current advances of triazole alcohols derived from fluconazole: Design, in vitro and in silico studies. European Journal of Medicinal Chemistry, 2019; 170C: 173–194. doi. 10.1016/j.ejmech.2019.03.020.
3. Peyton, L. R., Gallagher, S., Hashemzadeh, M. Triazole antifungals: A review / Prous Science, 2015; 705–718.
4. H. Zhou, C., Wang, Y. Recent Researches in Triazole Compounds as Medicinal Drugs. Current Medicinal Chemistry, 2012; 19(2C): 239–280. doi. 10.2174/092986712803414213.
5. Aggarwal, R., Sumran, G. An insight on medicinal attributes of 1,2,4-triazoles / Elsevier Masson SAS, 2020; 112652.
6. Liao, L., Jiang, C., Chen, J., та ін. Synthesis and biological evaluation of 1,2,4-triazole derivatives as potential neuroprotectant against ischemic brain injury. European Journal of Medicinal Chemistry, 2020; 190C: 112114. doi. 10.1016/j.ejmech.2020.112114.
7. Peng, Z., Wang, G., Zeng, Q. H., та ін. Synthesis, antioxidant and anti-tyrosinase activity of 1,2,4-triazole hydrazones as antibrowning agents. Food Chemistry, 2021; 341C: 128265. doi. 10.1016/j.foodchem.2020.128265.

8. Chu, X. M., Wang, C., Wang, W. L., та ін. Triazole derivatives and their antiplasmodial and antimalarial activities / Elsevier Masson SAS, 2019; 206–223.
9. El-Saghier, A. M., Mohamed, M. A., Abd-Allah, O. A., та ін. Green synthesis, antileishmanial activity evaluation, and in silico studies of new amino acid-coupled 1,2,4-triazoles. Medicinal Chemistry Research, 2019; 28(2C): 169–181. doi. 10.1007/s00044-018-2274-x.
10. Kaya, M., MENTEŞE, E., SÖKMEN, B. B., and others The determination of molecular dynamic properties of Novel 5-oxo-1,2,4-triazole phthalocyanines and investigation of their urease inhibition properties. Journal of Molecular Structure, 2020; 1222C: 128870. doi. 10.1016/j.molstruc.2020.128870.
11. Cao, X., Wang, W., Wang, S., and others Asymmetric synthesis of novel triazole derivatives and their in vitro antiviral activity and mechanism of action. European Journal of Medicinal Chemistry, 2017; 139C: 718–725. doi. 10.1016/j.ejmech.2017.08.057.
12. Kaproń, B., Czarnomysy, R., Wysokiński, M., та ін. 1,2,4-Triazole-based anticonvulsant agents with additional ROS scavenging activity are effective in a model of pharmacoresistant epilepsy. Journal of Enzyme Inhibition and Medicinal Chemistry, 2020; 35(1C): 993–1002. doi. 10.1080/14756366.2020.1748026.
13. Han, S., Zhang, F. F., Xie, X., та ін. Design, synthesis, biological evaluation, and comparative docking study of 1,2,4-triazolones as CB1 receptor selective antagonists. European Journal of Medicinal Chemistry, 2014; 74C: 73–84. doi. 10.1016/j.ejmech.2013.12.018.
14. Huang, L., Ding, J., Li, M., та ін. Discovery of [1,2,4]-triazolo [1,5-a]pyrimidine-7(4H)-one derivatives as positive modulators of GABAA1 receptor with potent anticonvulsant activity and low toxicity. European Journal of Medicinal Chemistry, 2020; 185C: 111824. doi. 10.1016/j.ejmech.2019.111824.
15. Çavuşoğlu, B. K., Yurttaş, L., Cantürk, Z. The synthesis, antifungal and apoptotic effects of triazole-oxadiazoles against Candida species. European Journal of Medicinal Chemistry, 2018; 144C: 255–261. doi. 10.1016/j.ejmech.2017.12.020.
16. Batchelor, D. V., Beal, D. M., Brown, T. B., та ін. A convenient synthesis of highly substituted 3-N,N-dialkylamino-1,2,4- triazoles. Synlett, 2008; 16C: 2421–2424. doi. 10.1055/S-2008-1078208.
17. Bogolyubsky, A. V., Savych, O., Zhemera, A. V., та ін. Facile One-Pot Parallel Synthesis of 3-Amino-1,2,4-triazoles. ACS Combinatorial Science, 2018; 20(7C): 461–466. doi. 10.1021/ACSCOMBSCI.8B00060/SUPPL_FILE/CO8B00060_SI_001.PDF.

18. Guin, S., Rout, S. K., Khatun, N., та ін. Tandem synthesis of [1,2,4]-triazoles mediated by iodine—a regioselective approach. Tetrahedron, 2012; 68(25C): 5066–5074. doi. 10.1016/J.TET.2012.04.042.
19. Chaudhari, P. S., Pathare, S. P., Akamanchi, K. G. O -iodoxybenzoic acid mediated oxidative desulfurization initiated domino reactions for synthesis of azoles. Journal of Organic Chemistry. 2012; 77(8C): 3716–3723. doi. 10.1021/JO2025509/SUPPL_FILE/JO2025509_SI_001.PDF.
20. Komar, M., Kraljević, T. G., Jerković, I., та ін. Application of Deep Eutectic Solvents in the Synthesis of Substituted 2-Mercaptoquinazolin-4(3H)-Ones: A Comparison of Selected Green Chemistry Methods. Molecules, 2022; 27(2C): 558. doi. 10.3390/MOLECULES27020558.
21. Hassan, G. S., El-Messery, S. M., Al-Omary, F. A. M., та ін. Nonclassical antifolates, part 4. 5-(2-Aminothiazol-4-yl)-4-phenyl-4H-1,2, 4-triazole-3-thiols as a new class of DHFR inhibitors: Synthesis, biological evaluation and molecular modeling study. European Journal of Medicinal Chemistry, 2013; 66C: 135–145. doi. 10.1016/j.ejmech.2013.05.039.
22. Bechara, W. S., Khazhieva, I. S., Rodriguez, E., та ін. One-pot synthesis of 3,4,5-trisubstituted 1,2,4-triazoles via the addition of hydrazides to activated secondary amides. Organic Letters, 2015; 17(5C): 1184–1187. doi. 10.1021/ACS.ORGLETT.5B00128/SUPPL_FILE/OL5B00128_SI_003.CIF.
23. Demange, L., Boeglin, D., Moulin, A., та ін. Synthesis and pharmacological in vitro and in vivo evaluations of novel triazole derivatives as ligands of the ghrelin receptor. 1. Journal of Medicinal Chemistry, 2007; 50(8C): 1939–1957. doi. 10.1021/JM070024H/SUPPL_FILE/JM070024HSI20070219_023555.PDF.
24. Sangshetti, J. N., Kalam Khan, F. A., Chouthe, R. S., та ін. Synthesis, docking and ADMET prediction of novel 5-((5-substituted-1-H-1,2,4-triazol-3-yl) methyl)-4,5,6,7-tetrahydrothieno[3,2-c]pyridine as antifungal agents. Chinese Chemical Letters, 2014; 25(7C): 1033–1038. doi. 10.1016/J.CCLET.2014.04.003.
25. Yunusova, S. N., Bolotin, D. S., Suslonov, V. V., та ін. 3-dialkylamino-1,2,4-triazoles via ZnII-catalyzed acyl hydrazide-dialkylcyanamide coupling. ACS Omega, 2018; 3(7C): 7224–7234. doi. 10.1021/ACSOMEGA.8B01047/SUPPL_FILE/AO8B01047_SI_002.CIF.
26. Prezent, M. A., Daeva, E. D., Baranin, S. V., та ін. A new synthesis of 2-(aminoalkyl)-1,2,4-triazolo[1,5-a]pyrimidines. Mendeleev Communications, 2017; 27(2C): 169–171.

doi. 10.1016/J.MENCOM.2017.03.021.

27. Kotipalli, T., Kavala, V., Konala, A., та ін. Reagent/Substituent Switching Approach for the Synthesis of Substituted 1,3,4-Oxadiazole/1,3,4-Oxadiazoline and 1,2,4-Triazole Derivatives from N-Substituted Hydrazides. Advanced Synthesis & Catalysis, 2016; 358(16C): 2652–2660. doi. 10.1002/ADSC.201600274.
28. Hassan, A. A., Mohamed, N. K., Aly, A. A., та ін. Eschenmoser-Coupling Reaction Furnishes Diazenyl-1,2,4-triazole-5(4H)-thione Derivatives. ChemistrySelect, 2019; 4(2C): 465–468. doi. 10.1002/SLCT.201802870.
29. Bongers, A., Ranasinghe, I., Lemire, P., та ін. Synthesis of Cyclic Azomethine Imines by Cycloaddition Reactions of N-Isocyanates and N-Isothiocyanates. Organic Letters, 2016; 18(15C): 3778–3781. doi. 10.1021/ACS.ORGLETT.6B01788/SUPPL_FILE/OL6B01788_SI_002.CIF.
30. Vlaminck, L., Voorde, B. Van De, Prez, F. E. Du. Sustainable synthesis routes towards urazole compounds. Green Chemistry, 2017; 19(23C): 5659–5664. doi. 10.1039/C7GC02027A.
31. Chen, Z., Li, H., Dong, W., та ін. I2-Catalyzed Oxidative Coupling Reactions of Hydrazones and Amines and the Application in the Synthesis of 1,3,5-Trisubstituted 1,2,4-Triazoles. Organic Letters, 2016; 18(6C): 1334–1337. doi. 10.1021/acs.orglett.6b00277.
32. Prieto, A., Uzel, A., Bouyssi, D., and others Thiocyanation of N,N-Dialkylhydrazonoyl Bromides: An Entry to Sulfur-Containing 1,2,4-Triazole Derivatives. European Journal of Organic Chemistry, 2017; 2017(28C): 4201–4204. doi. 10.1002/EJOC.201700819.
33. Mondal, S., Samanta, S., Hajra, A. Synthesis of Triazolium Inner Salts by Thiocyanation of Aldehyde-Derived Hydrazones. European Journal of Organic Chemistry, 2018; 2018(8C): 1060–1066. doi. 10.1002/EJOC.201701722.
34. Guru, M. M., Punniyamurthy, T. Copper(II)-catalyzed aerobic oxidative synthesis of substituted 1,2,3- and 1,2,4-triazoles from bisarylhydrazones via C-H functionalization/C-C/N-N/C-N bonds formation. Journal of Organic Chemistry, 2012; 77(11C): 5063–5073. doi. 10.1021/JO300592T/SUPPL_FILE/JO300592T_SI_007.PDF.
35. Wang, L. Y., Tsai, H. J., Lin, H. Y., and others One-flask synthesis of 1,3,5-trisubstituted 1,2,4-triazoles from nitriles and hydrazonoyl chlorides via 1,3-dipolar cycloaddition. RSC Advances, 2014; 4(27C): 14215–14220. doi. 10.1039/C4RA00113C.
36. Sharma, P., Bhat, S. V., Prabhath, M. R. R., and others Synthesis of 1,2,4-Triazol-3-imines via Selective Stepwise Cycloaddition of Nitrile Imines with Organo-cyanamides.

Organic Letters, 2018; 20(14C): 4263–4266. doi. 10.1021/ACS.ORGLETT.8B01673.

37. Bayrak, H., Demirbas, A., Karaoglu, S. A., and others Synthesis of some new 1,2,4-triazoles, their Mannich and Schiff bases and evaluation of their antimicrobial activities. European Journal of Medicinal Chemistry, 2009; 44(3)C: 1057–1066. doi. 10.1016/J.EJMECH.2008.06.019.
38. Maiti, D. K., Chatterjee, N., Pandit, P., and others Generation of azomethine imine and metal-free formal 1,3-dipolar cycloaddition of imine with PhIO: reaction, scope, and synthesis. Chemical Communications, 2010; 46(12): C. 2022–2024. doi. 10.1039/B924761K.
39. Kun, S., Bokor, É., Varga, G., та ін. New synthesis of 3-(β-D-glucopyranosyl)-5-substituted-1,2,4-triazoles, nanomolar inhibitors of glycogen phosphorylase. European Journal of Medicinal Chemistry, 2014; 76C: 567–579. doi. 10.1016/J.EJMECH.2014.02.041.
40. Joshi, M. S., Pigge, F. C. Construction of 1,2,4-Triazole Derivatives via Cyclocondensation of Alkylidene Dihydropyridines and Aryldiazonium Salts. Organic Letters, 2016; 18(22): C. 5916–5919. doi. 10.1021/ACS.ORGLETT.6B03019.
41. Liu, J. Q., Shen, X., Wang, Y., та ін. Cycloaddition of Isocyanides with Aryl Diazonium Salts: Catalyst-Dependent Regioselective Synthesis of 1,3- and 1,5-Disubstituted 1,2,4-Triazoles. Organic Letters, 2018; 20(21): C. 6930–6933. doi. 10.1021/acs.orglett.8b03069.
42. Neuhaus, W. C., Moura-Letts, G. Alumina-promoted synthesis of N-aryl-1,2,4-triazoles from substituted hydrazines and imides. Tetrahedron Letters, 2016; 57(45): C. 4974–4977. doi. 10.1016/J.TETLET.2016.09.086.
43. Li, Y., He, Y., Shao, T., та ін. Modification and Biological Evaluation of a Series of 1,5-Diaryl-1,2,4-triazole Compounds as Novel Agents against Pancreatic Cancer Metastasis through Targeting Myoferlin. Journal of Medicinal Chemistry, 2019(62): 10. C. 4949–4966. doi. 10.1021/ACS.JMEDCHEM.9B00059/SUPPL_FILE/JM9B00059_SI_002.CSV.
44. Guirado, A., López-Caracena, L., López-Sánchez, J. I., and others A new, high-yield synthesis of 3-aryl-1,2,4-triazoles. Tetrahedron, 2016; 72(49): 8055–8060. doi. 10.1016/j.tet.2016.10.045.