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СИНТЕЗ ЗАМЕЩЕННЫХ ПРОИЗВОДНЫХ 5-АРИЛ-5-ОКСО-1-ЦИАНО-3-((ТИОФЕН-2-ИЛ)АМИНО)ПЕНТА-1,3-ДИЕН-2-ОЛАТОВ КАЛИЯ, СОДЕРЖАЩИХ ФРАГМЕНТЫ БЕНЗО[*d*]ОКСАЗОЛА, БЕНЗО[*d*]ИМИДАЗОЛА И БЕНЗО[*d*]ТИАЗОЛА

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В работе представлены новые результаты исследований синтетических превращений замещенных 3-тиенилимино-3H-фуран-2-онов с нуклеофильными агентами различного строения. Прекурсоры для данного исследования – 3-тиенилимино-3H-фуран-2-оны – вызывают большой интерес. Ранее такие структуры успели зарекомендовать себя как удобный и практичный каркас для создания новых материалов с полезными прикладными свойствами, особенно в области медицинской химии. Они позволяют сочетать в своей структуре несколько важных фармакофорных фрагментов, а именно фрагмент 2-аминотиофена и фрагмент 2,4-диоксобутановой кислоты. Помимо этого, они обладают несколькими реакционными центрами, а также характеризуются масштабируемыми методами получения, что делает их весьма привлекательной структурой для изучения синтетических превращений. Данные преимущества позволяют не останавливаться в поиске новых перспективных материалов ввиду возможности введения дополнительных интересующих структурных фрагментов в скелет потенциальных целевых продуктов превращений. Так, нами была исследована возможность введения в каркас дополнительного фрагмента, потенциально обеспечивающего усовершенствование прикладных свойств получаемых материалов. В качестве такого фрагмента нами были выбраны бициклические гетероциклические фрагменты – бензо[d]оксазол, бензо[d]имидазол и бензо[d]тиазол. Ранее было показано, что наличие таких фрагментов в структурах различных соединений обеспечивает их высокую биологическую активность, а также возможность применения в других технологических областях. Предложенный нами метод синтеза замещенных производных 5-арил-5-оксо-1-циано-3-((3-R-4,5,6,7-тетрагидробензо[b]тиофен-2-ил)амино)пента-1,3-диен-2-олатов калия, содержащих в своей структуре фрагменты бензо[d]оксазола, бензо[d]имидазола или бензо[d]тиазола, включает в себя несколько стадий: взаимодействие 4-арил-2-гидрокси-4-оксобутановых кислот с

производными 2-амино-4,5,6,7-тетрагидробензо[b]тиофен-3-карбоновой кислоты, внутримолекулярную циклизацию полученных продуктов в среде пропионового ангидрида, а затем дециклизацию полученных замещенных 3-тиенилимино-3H-фуран-2-онов под действием замещенных метиленнитрильных производных, содержащих бициклические фрагменты с гетероатомами азота, кислорода и серы, в присутствии трет-бутоксида калия. Данный метод обеспечивает получение продуктов с заданными гетероциклическими фрагментами с высоким химическим выходом (75-84%). Подтверждение структуры выделенных итоговых соединений проводилось методами ^{1}H и ^{13}C ЯМР спектроскопии, а также элементного анализа. Полученные соединения, вследствие наличия в своей структуре множества фрагментов, представляющих интерес как для фармацевтики, так и других технологий, обладают огромной перспективностью и открывают новые возможности для создания материалов с полезными прикладными свойствами.

Ключевые слова: 2-аминотиофены, 2,4-диоксобутановые кислоты, 3-(тиофен-2-илимино)фуран-2(3*H*)-оны

SYNTHESIS OF SUBSTITUTED DERIVATIVES OF POTASSIUM 5-ARYL-1-CYANO-5-OXO-3-((THIOPHEN-2-YL)AMINO)PENTA-1,3-DIEN-2-OLATES CONTAINING BENZO[*d*]OXAZOLE, BENZO[*d*]IMIDAZOLE AND BENZO[*d*]THIAZOLE FRAGMENTS

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This work reflects the results of new research on the study of synthetic transformations of substituted 3-thienylimino-3H-furan-2-ones with nucleophilic agents of various structures. The precursors for this study – 3-thienylimino-3H-furan-2-ones – are of great interest for study. They have previously established themselves as a convenient and practical framework for the creation and search for new materials with useful applied properties, especially in the field of medicinal chemistry. They allow the combination of several important pharmacophore moieties in their structure, namely a 2-aminothiophene moiety and a 2,4-dioxobutanoic acid moiety. In addition, they have several reaction centers and are characterized by scalable production methods, which makes them a very attractive structure for studying synthetic transformations. These advantages allow us to keep on searching for new promising materials due to the possibility of introducing additional structural fragments of interest into the skeleton of potential target products of transformations. Thus, we have investigated the possibility of introducing an additional fragment into the framework, potentially providing improvement of applied properties of the obtained materials. As such a fragment we have chosen bicyclic heterocyclic fragments – benzo[d]oxazole, benzo[d]imidazole and benzo[d]thiazole. It was previously shown that the presence of such fragments in the structures of various compounds provides their high biological activity, as well as the possibility of application in other technological fields. Our proposed method of substituted potassium 5-aryl-5-oxo-1-cyano-3-((3-R-4,5,6,7-tetrahydrobenzo[b]thiophen-2-yl)amino)penta-1,3-dien-2-olates derivatives containing benz[d]oxazole, benz[d]imidazole, or benz[d]thiazole fragments in their structure consists of several stages: interaction of 4-aryl-2-hydroxy-4-oxobutanoic acids with derivatives of 2-amino-

4,5,6,7-tetrahydrobenzo[b]thiophen-3-carboxylic acids, intramolecular cyclisation of the obtained products in propionic anhydride, and then decyclization of the obtained substituted 3-thienylimino-3H-furan-2-ones under the action of substituted heteroaromatic methylenenitrile derivatives containing bicyclic fragments with nitrogen, oxygen and sulfur heteroatoms in the presence of potassium tert-butoxide. This method provides products with the given heterocyclic fragments in high chemical yields (75-84%). The structures of the isolated final compounds were confirmed by ^{1}H and ^{13}C NMR spectroscopy and elemental analysis. The obtained compounds, due to the presence of many fragments in their structure, which are of interest both for pharmaceuticals and other technologies, are extremely promising and open new opportunities for the creation of materials with useful applied properties.

Keywords: 2-aminothiophenes, 2,4-dioxobutanoic acids, 3-(thiophene-2-ylimino)furan-2(3*H*)-ones

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INTRODUCTION

The study of compounds containing fragments such as benzo[*d*]oxazole, benzo[*d*]imidazole and benzo[*d*]thiazole is an important aspect of modern medicinal chemistry and pharmaceutical research [1-3]. These bicyclic heterocyclic fragments are characterized by fused benzene rings and five-membered heterocycles containing nitrogen, oxygen and sulphur atoms. They have emerged as attractive scaffolds in drug discovery due to their ability to interact with diverse biological targets and exhibit remarkable pharmacological properties. It has previously been demonstrated that these compounds have a wide range of therapeutic applications, including anticancer [4-6], anti-inflammatory [7], antimicrobial [8], anti-Alzheimer [9] and antidepressant [10] activities. Furthermore, their utility extends beyond medicine to industrial applications such as dyes [11, 12], polymers [13, 14], food packaging [15] and advanced materials [16, 17], highlighting their multifaceted importance in modern science and technology.

It is worth noting that the structure of 3-iminofuran-2(3*H*)-ones allows different functional groups to be combined to produce a wide range of properties [18]. Also, these structures are characterized by the presence of several reaction centers and rather simple methods of preparation [19], which allowed earlier to obtain on their basis a wide range of compounds with various useful properties. Products obtained from 3-iminofuran-2(3*H*)-ones exhibit antinociceptive [20-22], anti-inflammatory [23,24], anticancer [25-27], antimicrobial [28,29] and hemostatic [30] activities and can be used in materials for optical applications [31].

This work is a continuation of our study of synthetic transformations of substituted 3-thienylimino-3*H*-furan-2-ones with nucleophilic agents of various structures and reflects the results of the synthesis of new derivatives of 3-iminofuran-2(3*H*)-ones, whose target products include bicyclic heterocyclic fragments in their structure, allowing the creation of new materials with promising potential applications.

EXPERIMENTAL PART

All commercially available used reagents were used as purchased. The starting 4-aryl-2-hydroxy-4-oxobut-2-enoic acids **1** [32], 2-aminothiophene-3-carboxylic acid derivatives **2** [33] and heteroaromatic methylenitrile derivatives **5** [34,35] have been synthesized according to known procedures. Physicochemical properties of these compounds are consistent with those previously published.

The reaction progress and purity of the obtained compounds were controlled by TLC using Silufol 254 UV precoated plates using a diethyl ether – benzene – acetone mixture (10:9:1) as an eluent. Recording of ^{1}H and ^{13}C NMR spectra was carried out on a Bruker Avance III spectrometer (working frequencies of 400 and 100 MHz) in DMSO-d_6. Melting points were measured on a Stuart SMP40 apparatus. Elemental analysis was carried out on a Leco CHNS-932 elemental analyzer.

General procedure for the synthesis of substituted potassium 5-aryl-1-cyano-3-((3-*R*-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxopenta-1,3-dien-2-olates 6a-h. To 1 mmol of compounds **4a-f** in 5 ml of anhydrous dioxane, 1 mmol of the corresponding acetonitrile derivatives **5a-c** and 1 mmol of *t*-BuOK were added. The resulting mixture was stirred at room temperature for 24 h. The resulting precipitate was filtered out and recrystallized from ethanol.

Potassium 1-(1*H*-benzo[*d*]imidazol-2-yl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxo-5-phenylpenta-1,3-dien-2-olate (6a). Yield 0.44 g (83%), orange solid, mp 193.4-194.6 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.75 m (4H, 2CH_2), 2.48 m (2H, CH_2), 2.62 m (2H, CH_2), 6.35 s (1H, C=CH), 7.02 m (2H_{Ar}), 7.50 m (5H_{Ar}), 7.71 m (2H_{Ar}), 12.03 s (1H, NH), 13.75 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 190.1, 172.6, 165.5, 150.6, 147.5, 143.8, 139.8, 133.9, 132.6, 132.1, 132.0, 129.2, 128.8, 128.1, 127.8, 120.8, 120.2, 116.8, 110.9, 108.6, 95.1, 86.7, 24.6, 24.3, 23.1, 22.1. Found, %: C, 63.60; H, 3.76; N, 13.20; S, 6.09. $C_{28}H_{20}KN_5O_2S$. Calculated, %: C, 63.50; H, 3.81; N, 13.22; S, 6.05.

Potassium 1-(1*H*-benzo[*d*]imidazol-2-yl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxo-5-(*p*-tolyl)penta-1,3-dien-2-olate (6b). Yield 0.46 g (82%), orange solid, mp 202.7-203.3 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.78 m (4H, 2CH_2), 2.37 s (3H, CH_3), 2.52 m (2H, CH_2), 2.61 m (2H, CH_2), 6.38 s (1H, C=CH), 7.01 m (2H_{Ar}), 7.26 m (2H_{Ar}), 7.44 m (1H_{Ar}),7.51 m (1H_{Ar}),7.61 m (2H_{Ar}), 8.71 s (1H, NH), 11.64 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 189.9, 172.6, 165.5, 151.4, 150.3, 147.6, 144.1, 142.3, 137.3, 132.9, 132.7, 129.4, 128.2, 120.9, 120.8, 120.3, 120.2, 116.8, 110.9, 108.6, 95.3, 86.7, 24.6, 24.3, 23.1, 22.1, 21.5. Found, %: C, 64.12; H, 4.04; N, 12.85; S, 5.98. $C_{29}H_{22}KN_5O_2S$. Calculated, %: C, 64.07; H, 4.08; N, 12.88; S, 5.90.

Potassium 1-(1*H*-benzo[*d*]imidazol-2-yl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-(4-methoxyphenyl)-5-oxopenta-1,3-dien-2-olate (6c). Yield 0.47 g (84%), orange solid, mp 207.4-209.1 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.75 m (4H, 2CH_2), 2.52 m (2H, CH_2), 2.57 m (2H, CH_2), 3.86 s (3H, CH_3), 6.32 s (1H, C=CH), 7.05 m (3H_{Ar}), 7.20 m (1H_{Ar}), 7.68 m (1H_{Ar}), 7.88 m (1H_{Ar}), 8.01 m (2H_{Ar}), 12.04 s (1H, NH), 13.74 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 189.6, 175.9, 165.4, 163.1, 157.9, 153.7, 150.8, 131.9, 131.4, 131.1, 130.4, 130.1, 129.0, 122.8, 120.7, 116.8, 114.5, 114.1, 111.0, 108.2, 95.4, 86.7, 56.0, 24.6, 24.3, 23.1, 22.0. Found, %: C, 62.29; H, 3.90; N, 12.54; S, 5.70. $C_{29}H_{22}KN_5O_3S$. Calculated, %: C, 62.23; H, 3.96; N, 12.51; S, 5.73.

Potassium 1-(1*H*-benzo[*d*]imidazol-2-yl)-5-(4-chlorophenyl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxopenta-1,3-dien-2-olate (6d). Yield 0.45 g (80%), orange solid, mp 181.6-183.2 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.74 m (4H, 2CH_2), 2.43 m (2H, CH_2), 2.61 m (2H, CH_2), 6.32 s (1H, C=CH), 7.43 m (2H_{Ar}), 7.49 m (2H_{Ar}), 7.67 m (2H_{Ar}), 7.81 m (2H_{Ar}), 8.77 s (1H, NH), 11.63 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 189.4, 172.4, 165.3, 151.2, 150.8, 148.2, 147.3, 138.5, 137.0, 133.3, 132.8, 131.0, 129.9, 129.4, 129.0, 128.9, 128.5, 120.4, 114.5, 108.8, 94.9, 86.7, 24.6, 24.3, 23.0, 22.1. Found, %: C, 59.59; H, 3.47; N, 12.47; S, 5.64. $C_{28}H_{19}ClKN_5O_2S$. Calculated, %: C, 59.62; H, 3.40; N, 12.42; S, 5.68.

Potassium 1-(1*H*-benzo[*d*]imidazol-2-yl)-5-(4-bromophenyl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxopenta-1,3-dien-2-olate (6e). Yield 0.46 g (75%), orange solid, mp 147.5-148.4 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.76 m (4H, 2CH_2), 2.43 m (2H, CH_2), 2.63 m (2H, CH_2), 6.75 s (1H, C=CH), 7.12 m (2H_{Ar}), 7.34 m (2H_{Ar}), 7.60 m (2H_{Ar}), 7.77 m (2H_{Ar}), 11.98 s (1H, NH), 13.24 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 193.6, 173.5, 164.8, 161.7, 160.2, 149.0, 142.2, 141.1, 139.2, 137.7, 135.4, 133.6, 132.0, 129.0, 128.9, 127.4, 124.8, 123.8, 118.2, 110.4, 96.0, 92.7, 24.4, 24.2, 23.1, 22.1. Found, %: C, 61.39; H, 3.27; N, 10.25; S, 5.81. $C_{28}H_{18}BrKN_4O_3S$. Calculated, %: C, 61.30; H, 3.31; N, 10.21; S, 5.84.

Potassium 1-(benzo[*d*]thiazol-2-yl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxo-5-(*p*-tolyl)penta-1,3-dien-2-olate (6f). Yield 0.44 g (79%), orange solid, mp 201.4-203.5 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.72 m (4H, 2CH_2), 2.38 s (3H, CH_3), 2.47 m (2H, CH_2), 2.51 m (2H, CH_2), 6.31 s (1H, C=CH), 7.16 m (1H_{Ar}), 7.32 m (3H_{Ar}), 7.67 m (1H_{Ar}), 7.86 m (1H_{Ar}),7.92 m (2H_{Ar}), 13.77 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 190.2, 175.8, 165.5, 158.0, 152.4, 150.6, 143.1, 136.0, 133.7, 132.0, 129.8, 129.3, 128.0, 125.5, 122.3, 122.1, 121.4, 119.9, 114.5, 95.5, 80.1, 24.1, 24.0, 23.1, 22.0, 21.6. Found, %: C, 62.18; H, 3.70; N, 9.95; S, 11.49. $C_{29}H_{21}KN_4O_2S_2$. Calculated, %: C, 62.12; H, 3.78; N, 9.99; S, 11.44.

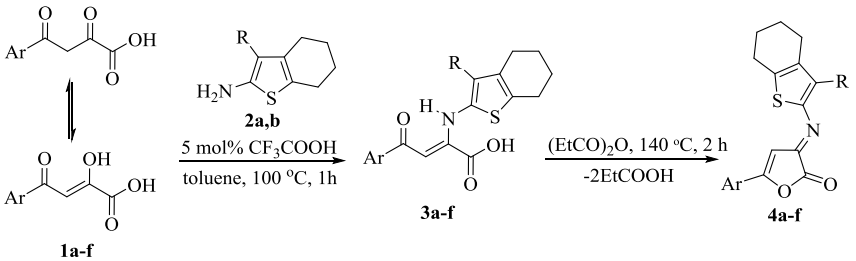
Potassium 1-(benzo[*d*]oxazol-2-yl)-1-cyano-3-((3-cyano-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-oxo-5-phenylpenta-1,3-dien-2-olate (6g). Yield 0.41 g (78%), orange solid, mp 130.7-133.4 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.81

m (4H, $2CH_2$), 2.52 m (4H, $2CH_2$), 6.04 s (1H, C=CH), 7.26 m ($2H_{Ar}$), 7.50 m ($5H_{Ar}$), 7.91 m ($2H_{Ar}$), 13.76 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 193.6, 173.5, 164.8, 161.7, 160.2, 149.0, 142.2, 141.1, 139.2, 137.7, 135.4, 133.6, 132.0, 129.0, 128.9, 127.4, 124.8, 123.8, 118.2, 110.4, 96.0, 92.7, 24.4, 24.2, 23.1, 22.1. Found, %: C, 63.46; H, 3.57; N, 10.62; S, 6.00. $C_{28}H_{19}KN_4O_3S$. Calculated, %: C, 63.38; H, 3.61; N, 10.56; S, 6.04.

Potassium 1-(benzo[*d*]oxazol-2-yl)-1-cyano-3-((3-(ethoxycarbonyl)-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-(4-hydroxyphenyl)-5-oxopenta-1,3-dien-2-olate (6h). Yield 0.50 g (84%), orange solid, mp 232.4-233.6 °C (ethanol). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.35 t (3H, J = 7.0 Hz, CH_3), 1.73 m (4H, $2CH_2$), 2.56 m (2H, CH_2), 2.70 m (2H, CH_2), 4.35 q (2H, J = 7.0 Hz, OCH_2), 5.90 s (1H, C=CH), 6.99 m ($3H_{Ar}$), 7.26 m ($1H_{Ar}$),7.57 m ($1H_{Ar}$), 7.81 m ($1H_{Ar}$),7.84 m ($2H_{Ar}$), 13.32 s (1H, NH). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 188.1, 173.9, 165.3, 161.6, 159.4, 148.9, 142.7, 141.0, 138.2, 136.1, 134.5, 132.2, 131.1, 130.7, 129.3, 124.8, 123.7, 118.1, 114.6, 113.0, 110.5, 93.1, 60.2, 26.5, 24.5, 23.1, 22.8, 14.8. Found, %: C, 60.66; H, 4.05; N, 7.10; S, 5.44. $C_{30}H_{24}KN_3O_6S$. Calculated, %: C, 60.69; H, 4.07; N, 7.08; S, 5.40.

RESULTS AND DISCUSSION

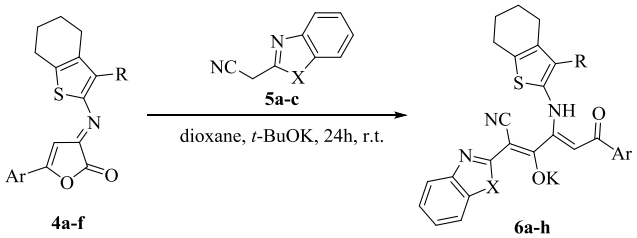
The starting 3-(thiophen-2-ylimino)furan-2(3*H*)-ones **4a-f** were prepared by intramolecular cyclisation of the corresponding 5-aryl-4-oxo-2-(thiophen-2-ylimino)but-2-enoic acids **3a-f**, obtained in turn by interaction of the corresponding 4-aryl-2-hydroxy-4-oxobut-2-enoic acids **1a-f** and 2-aminothiophene-3-carboxylic acid derivatives **2a,b** according to the previously published procedure [19]. The compounds **4a-f** obtained serve as key intermediates for the subsequent synthesis of target structures (Scheme 1).



1: Ar = C_6H_5 (**a**), 4-MeC_6H_4 (**b**), 4-$MeOC_6H_4$ (**c**), 4-ClC_6H_4 (**d**), 4-BrC_6H_4 (**e**), 4-OHC_6H_4 (**f**);
2: R = CN (**a**), COOEt (**b**);
3,4: R = CN, Ar = C_6H_5 (**a**), 4-MeC_6H_4 (**b**), 4-$MeOC_6H_4$ (**c**), 4-ClC_6H_4 (**d**), 4-BrC_6H_4 (**e**), R = COOEt, Ar = 4-OHC_6H_4 (**f**).

Scheme 1
Схема 1

We found that the interaction between the 3-(thiophene-2-ylimino)furan-2(3H)-ones **4a-f** and acetonitrile derivatives containing heterocyclic substituents **5a-c** in the presence of t-BuOK in anhydrous dioxane led to the formation of potassium salts **6a-h** with a yield of 75-84% (Scheme 2). As it is supposed, in the course of this reaction there is an attack of C-nucleophilic carboanion formed after the interaction of potassium tert-butylate and compounds **5a-c** on carbon atom of carbonyl group of lactone in compounds **4a-f**. As a result, the decyclisation of furan ring takes place, and then formation of final target products – substituted 1-cyano-3-((3-R-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-aryl-5-oxopenta-1,3-dien-2-olates **6a-h**. The potassium salts obtained are stable and do not undergo further intramolecular cyclization.



4: R = CN, Ar = C_6H_5 (**a**), 4-MeC_6H_4 (**b**), 4-$MeOC_6H_4$ (**c**), 4-ClC_6H_4 (**d**), 4-BrC_6H_4 (**e**), R = COOEt, Ar = 4-OHC_6H_4 (**f**);
5: X = NH (**a**), S (**b**), O (**c**);
6: R = CN, X = NH, Ar = C_6H_5 (**a**), 4-MeC_6H_4 (**b**), 4-$MeOC_6H_4$ (**c**), 4-ClC_6H_4 (**d**), 4-BrC_6H_4 (**e**), X = S, Ar = 4-MeC_6H_4 (**f**), X = O, Ar = C_6H_4 (**g**), R = COOEt, X = O, Ar = 4-OHC_6H_4 (**h**).

Scheme 2
Схема 2

Compounds **6a-h** are orange solid substances well soluble in DMSO, chloroform, soluble in toluene, methanol, ethanol at heating, and insoluble in water and alkanes. According to the ^{1}H NMR data for DMSO-d_6 solution compounds **6a-h**, spectra are characterized by existence of a singlet of the *CH*-groups at 5.90-6.75 ppm and a singlet of the proton of the *NH*-group at 11.63-13.77 ppm. The ^{13}C NMR spectra of compounds **6a-h** shows the characteristic signals of the carbonyl carbons of the aroyl moiety in the δ_C 189.4-193.6 ppm and the signals of the methine group carbons in the δ_C 94.9-96.0 ppm.

CONCLUSIONS

Thus, the target substituted 1-cyano-3-((3-R-4,5,6,7-tetrahydrobenzo[*b*]thiophen-2-yl)amino)-5-aryl-5-oxopenta-1,3-diene-2-olates of potassium **6a-h** were obtained by decyclisation of

3-(thiophen-2-ylimino)furan-2(3*H*)-ones under the action of various substituted heterocyclic methylene nitriles. Due to the interesting structural feature of the newly synthesised compounds, the prospect of continuing the research to find the unique applied properties of these materials remains relevant for further study.

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The authors declare the absence a conflict of interest warranting disclosure in this article.

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ЛИТЕРАТУРА

1. **Xiang P., Zhou T., Wang L., Sun C.-Y., Hu J., Zhao Y.-L., Yang L.** Novel Benzothiazole, Benzimidazole And Benzoxazole Derivatives As Potential Antitumor Agents: Synthesis And Preliminary In Vitro Biological Evaluation. *Molecules*. 2012. V. 17. N 1. P. 873-883. DOI: 10.3390/molecules17010873.
2. **Al Awadh A.A.** Biomedical applications of selective metal complexes of indole, benzimidazole, benzothiazole and benzoxazole: A review (From 2015 to 2022). *Saudi Pharm. J.* 2023. V. 31. N 9. P. 101698. DOI: 10.1016/j.jsps.2023.101698.
3. **Faydalı N., Arpacı Ö.T.** Benzimidazole and Benzoxazole Derivatives Against Alzheimer's Disease. *Chem. Biodivers.* 2024. V. 21. N 6. P. e202400123. DOI: 10.1002/cbdv.202400123.
4. **Park S.J., Song I., Yeom G.S., Nimse S.B.** The microtubule cytoskeleton: A validated target for the development of 2-Aryl-1H-benzo[d]imidazole derivatives as potential anticancer agents. *Biomed. Pharmacother.* 2024. V. 171. P. 116106. DOI: 10.1016/j.biopha.2023.116106.
5. **Gour P.B., Ahmed S., Gajendhiran R., Rahiman A.K., Ahmed M., Fahelelbom K.M., Hadda T.B., Bhat A.R., Dadmal T.L.** Design, synthesis, and biological evaluation of benzo[d]oxazole-2-thio and oxazolo[4,5-b]pyridine-2-thio derivatives: molecular docking, POM analysis, in silico pharmacokinetics, and pharmacophore insights for antitumor, GPCR, and kinase targets. *J. Mol. Struct.* 2025. V. 1333. P. 141705. DOI: 10.1016/j.molstruc.2025.141705.
6. **Osmaniye D., Çelikateş B.K., Sağlık B.N., Levent S., Çevik U.A., Çavuşoğlu B.K., Ilgın S., Özkay Y., Kaplancıklı Z.A.** Synthesis of some new benzoxazole derivatives and investigation of their anticancer activities. *Eur. J. Med. Chem.* 2021. V. 210. P. 112979. DOI: 10.1016/j.ejmech.2020.112979.
7. **Kumar G., Singh N.P.** Synthesis, anti-inflammatory and analgesic evaluation of thiazole/oxazole substituted benzothiazole derivatives. *Bioorg. Chem.* 2021. V. 107. P. 104608. DOI: 10.1016/j.bioorg.2020.104608.
8. **Gangurde K.B., More R.A., Adole V.A., Ghotekar D.S.** Design, synthesis and biological evaluation of new series of benzotriazole-pyrazole clubbed thiazole hybrids as bioactive heterocycles: Antibacterial, antifungal, antioxidant, cytotoxicity study. *J. Mol. Struct.* 2024. V. 1299. P. 136760. DOI: 10.1016/j.molstruc.2023.136760.
9. **Hussain R., Rahim F., Rehman W., Khan S., Rasheed L., Maalik A., Taha M., Alanazi M.M., Alanazi A.S., Khan I., Shah S.A.** Synthesis, in vitro analysis and molecular docking study of novel benzoxazole-based oxazole derivatives for the treatment of Alzheimer's disease. *Arab. J. Chem.* 2023. V. 16. N 11. P. 105244. DOI: 10.1016/j.arabjc.2023.105244.
10. **Sahariah M., Chowdhury R., Pegu P., Ali F., Dutta R.S., Sahu S.** Design, synthesis and in-vitro anti-depressant activity

REFERENCES

1. **Xiang P., Zhou T., Wang L., Sun C.-Y., Hu J., Zhao Y.-L., Yang L.** Novel Benzothiazole, Benzimidazole And Benzoxazole Derivatives As Potential Antitumor Agents: Synthesis And Preliminary In Vitro Biological Evaluation. *Molecules*. 2012. V. 17. N 1. P. 873-883. DOI: 10.3390/molecules17010873.
2. **Al Awadh A.A.** Biomedical applications of selective metal complexes of indole, benzimidazole, benzothiazole and benzoxazole: A review (From 2015 to 2022). *Saudi Pharm. J.* 2023. V. 31. N 9. P. 101698. DOI: 10.1016/j.jsps.2023.101698.
3. **Faydalı N., Arpacı Ö.T.** Benzimidazole and Benzoxazole Derivatives Against Alzheimer's Disease. *Chem. Biodivers.* 2024. V. 21. N 6. P. e202400123. DOI: 10.1002/cbdv.202400123.
4. **Park S.J., Song I., Yeom G.S., Nimse S.B.** The microtubule cytoskeleton: A validated target for the development of 2-Aryl-1H-benzo[d]imidazole derivatives as potential anticancer agents. *Biomed. Pharmacother.* 2024. V. 171. P. 116106. DOI: 10.1016/j.biopha.2023.116106.
5. **Gour P.B., Ahmed S., Gajendhiran R., Rahiman A.K., Ahmed M., Fahelelbom K.M., Hadda T.B., Bhat A.R., Dadmal T.L.** Design, synthesis, and biological evaluation of benzo[d]oxazole-2-thio and oxazolo[4,5-b]pyridine-2-thio derivatives: molecular docking, POM analysis, in silico pharmacokinetics, and pharmacophore insights for antitumor, GPCR, and kinase targets. *J. Mol. Struct.* 2025. V. 1333. P. 141705. DOI: 10.1016/j.molstruc.2025.141705.
6. **Osmaniye D., Çelikateş B.K., Sağlık B.N., Levent S., Çevik U.A., Çavuşoğlu B.K., Ilgın S., Özkay Y., Kaplancıklı Z.A.** Synthesis of some new benzoxazole derivatives and investigation of their anticancer activities. *Eur. J. Med. Chem.* 2021. V. 210. P. 112979. DOI: 10.1016/j.ejmech.2020.112979.
7. **Kumar G., Singh N.P.** Synthesis, anti-inflammatory and analgesic evaluation of thiazole/oxazole substituted benzothiazole derivatives. *Bioorg. Chem.* 2021. V. 107. P. 104608. DOI: 10.1016/j.bioorg.2020.104608.
8. **Gangurde K.B., More R.A., Adole V.A., Ghotekar D.S.** Design, synthesis and biological evaluation of new series of benzotriazole-pyrazole clubbed thiazole hybrids as bioactive heterocycles: Antibacterial, antifungal, antioxidant, cytotoxicity study. *J. Mol. Struct.* 2024. V. 1299. P. 136760. DOI: 10.1016/j.molstruc.2023.136760.
9. **Hussain R., Rahim F., Rehman W., Khan S., Rasheed L., Maalik A., Taha M., Alanazi M.M., Alanazi A.S., Khan I., Shah S.A.** Synthesis, in vitro analysis and molecular docking study of novel benzoxazole-based oxazole derivatives for the treatment of Alzheimer's disease. *Arab. J. Chem.* 2023. V. 16. N 11. P. 105244. DOI: 10.1016/j.arabjc.2023.105244.
10. **Sahariah M., Chowdhury R., Pegu P., Ali F., Dutta R.S., Sahu S.** Design, synthesis and in-vitro anti-depressant activity

evaluation of some 2-styrylbenzimidazole derivatives. *Futur. J. Pharm. Sci.* 2024. V. 10. P. 20. DOI: 10.1186/s43094-024-00589-2.

11. **He B., Zhu S., Li J., Mo L., Li J., Liu Y., Song X., Hu M., Yang Z., Yuan J.** Benzothiazole-based D-A-D type dichroic dyes for dimming devices. *J. Mol. Struct.* 2025. V. 1330. P. 141521. DOI: 10.1016/j.molstruc.2025.141521.
12. **Girase J.D., Nagar M.R., Jayakumar J., Jou J.H., Vaidyanathan S.** New deep blue fluorophores based on benzo[d]thiazole group as acceptor core: Theoretical, synthesis, photophysical and electroluminescent investigation. *J. Lumin.* 2022. V. 248. P. 118992. DOI: 10.1016/j.jlumin.2022.118992.
13. **Pang B., Liao C., Xu X., Yu L., Li R., Peng Q.** Benzo[d]thiazole Based Wide Bandgap Donor Polymers Enable 19.54% Efficiency Organic Solar Cells Along with Desirable Batch-to-Batch Reproducibility and General Applicability. *Adv. Mater.* 2023. V. 35. N 21. P. 2300631. DOI: 10.1002/adma.202300631.
14. **Luo J., Peng S., Zhang J., Jin Y., Chen D., Mu Y., Xiao L., Hu D., Yang Q.D., Ji S., Min Y.** New wide bandgap conjugated D-A copolymers based on Benzo[d]thiazole for efficient photovoltaics. *Org. Electron.* 2023. V. 120. P. 106860. DOI: 10.1016/j.orgel.2023.106860.
15. **Li N.N., Wei T.T., Jin Z.B., Liu C.Q., Wang Z., Li F., Muddassir M., Prakash O., Kumar A., Liu J.Q.** A novel dimer induced AIE smart material for fluorescence colorimetric detection of food freshness and Zn^{2+}. *J. Mol. Struct.* 2024. V. 1315. P. 138985. DOI: 10.1016/j.molstruc.2024.138985.
16. **Hoan D.Q., Cuong N.T., Vy N.T., Chi M.P., Thinh N.H., Hieu N.T., Thao L.P., Vinh N.T., Hai L.T.** A Novel Benzo[d]Thiazole Derivative as Selective Fluorescent Chemosensors for Al^{3+} and Its AIE Properties. *J. Fluoresc.* 2025. DOI: 10.1007/s10895-025-04361-4.
17. **Tardío C., Álvarez Conde J., Rodríguez A.M., Prieto P., Hoz A.D., Cabanillas-González J., Torres-Moya I.** Donor–Acceptor–Donor 1H-Benzo[d]imidazole Derivatives as Optical Waveguides. *Molecules*. 2023. V. 28. N 12. P. 4631. DOI: 10.3390/molecules28124631.
18. **Пархома К.Ю., Давыденкова Е.Д., Махмудов Р.Р., Горбунова И.А., Шипиловских Д.А.** Синтез, внутримолекулярная циклизация и антиноцицептивная активность 4-(гет)арил-4-оксо-2-[(3-этоксикарбонил-5,6,7,8-тетрагидро-4Н-циклогепта[b]-тиофен-2-ил)амино]бут-2-еновых кислот. *Изв. АН. Сер. Хим.* 2024. Т. 73. Вып. 11. С. 3359-3366. DOI: 10.1007/s11172-024-4452-y.
19. **Никонов И.П., Шаравьева Ю.О., Махмудов Р.Р., Шипиловских Д.А., Горбунова И.А.** Синтез, внутримолекулярная циклизация и антиноцицептивная активность 4-(гет)арил-4-оксо-2-{[4-(4-R-фенил)-3-(этоксикарбонил)тиофен-2-ил]амино}бут-2-еновых кислот. *Изв. вузов. Химия и хим. технология.* 2024. Т. 67. Вып. 11. С. 22-32. DOI: 10.6060/ivkkt.20246711.7055.
20. **Шаравьева Ю.О., Махмудов Р.Р., Шипиловских Д.А., Силайчев П.С., Горбунова И.А.** Синтез и исследование антиноцицептивной активности замещенных эфиров 4-оксо-2-(3-циано-4,5,6,7-тетрагидробензо[b]тиофен-2-иламино)бут-2-еновых кислот. *Изв. вузов. Химия и хим. технология.* 2024. Т. 67. Вып. 7. С. 19-27. DOI: 10.6060/ivkkt.20246707.7029.
21. **Kozlov D.A., Lipin D.V., Gorbunova I.A., Shipilovskikh D.A., Timin A.S., Silaichev P.S., Makhmudov R.R., Shadrin V.M., Shipilovskikh S.A.** Synthesis and Antinociceptive Activity of Substituted Derivatives of Potassium 1-Cyano-3-{(3-cyano-4,5,6,7-tetrahydrobenzo-[b]thiophen-2-yl)amino}-5-oxopenta-1,3-dien-2-olates. *Russ. J. Gen. Chem.* 2024. V. 94. N 5. P. 1024-1030. DOI: 10.1134/S1070363224050025.

evaluation of some 2-styrylbenzimidazole derivatives. *Futur. J. Pharm. Sci.* 2024. V. 10. P. 20. DOI: 10.1186/s43094-024-00589-2.

11. **He B., Zhu S., Li J., Mo L., Li J., Liu Y., Song X., Hu M., Yang Z., Yuan J.** Benzothiazole-based D-A-D type dichroic dyes for dimming devices. *J. Mol. Struct.* 2025. V. 1330. P. 141521. DOI: 10.1016/j.molstruc.2025.141521.
12. **Girase J.D., Nagar M.R., Jayakumar J., Jou J.H., Vaidyanathan S.** New deep blue fluorophores based on benzo[d]thiazole group as acceptor core: Theoretical, synthesis, photophysical and electroluminescent investigation. *J. Lumin.* 2022. V. 248. P. 118992. DOI: 10.1016/j.jlumin.2022.118992.
13. **Pang B., Liao C., Xu X., Yu L., Li R., Peng Q.** Benzo[d]thiazole Based Wide Bandgap Donor Polymers Enable 19.54% Efficiency Organic Solar Cells Along with Desirable Batch-to-Batch Reproducibility and General Applicability. *Adv. Mater.* 2023. V. 35. N 21. P. 2300631. DOI: 10.1002/adma.202300631.
14. **Luo J., Peng S., Zhang J., Jin Y., Chen D., Mu Y., Xiao L., Hu D., Yang Q.D., Ji S., Min Y.** New wide bandgap conjugated D-A copolymers based on Benzo[d]thiazole for efficient photovoltaics. *Org. Electron.* 2023. V. 120. P. 106860. DOI: 10.1016/j.orgel.2023.106860.
15. **Li N.N., Wei T.T., Jin Z.B., Liu C.Q., Wang Z., Li F., Muddassir M., Prakash O., Kumar A., Liu J.Q.** A novel dimer induced AIE smart material for fluorescence colorimetric detection of food freshness and Zn^{2+}. *J. Mol. Struct.* 2024. V. 1315. P. 138985. DOI: 10.1016/j.molstruc.2024.138985.
16. **Hoan D.Q., Cuong N.T., Vy N.T., Chi M.P., Thinh N.H., Hieu N.T., Thao L.P., Vinh N.T., Hai L.T.** A Novel Benzo[d]Thiazole Derivative as Selective Fluorescent Chemosensors for Al^{3+} and Its AIE Properties. *J. Fluoresc.* 2025. DOI: 10.1007/s10895-025-04361-4.
17. **Tardío C., Álvarez Conde J., Rodríguez A.M., Prieto P., Hoz A.D., Cabanillas-González J., Torres-Moya I.** Donor–Acceptor–Donor 1H-Benzo[d]imidazole Derivatives as Optical Waveguides. *Molecules*. 2023. V. 28. N 12. P. 4631. DOI: 10.3390/molecules28124631.
18. **Parkhoma K.Yu., Davydenkova E.D., Makhmudov R.R., Gorbunova I.A., Shipilovskikh D.A.** Synthesis, intramolecular cyclization, and antinociceptive activity of 4-(het)aryl-4-oxo-2-[(3-ethoxycarbonyl-5,6,7,8-tetrahydro-4H-cyclohepta[b]-thiophen-2-yl)amino]but-2-enoic acids. *Izv. AN. Ser. Khim.* 2024. V. 73. N 11. P. 3359-3366 (in Russian). DOI: 10.1007/s11172-024-4452-y.
19. **Nikonov I.P., Sharavyeva Yu.O., Makhmudov R.R., Shipilovskikh D.A., Gorbunova I.A.** Synthesis, Intramolecular Cyclization and Antinociceptive Activity of 4-(Het)Aryl-2-{[3-(Ethoxycarbonyl)-4-(4-R-Phenyl)Thiophen-2-Yl]Amino}-4-Oxobut-2-Enoic Acids. *ChemChemTech [Izv. Vyssh. Uchebn. Zaved. Khim. Khim. Tekhnol.]*. 2024. V. 67. N 11. P. 22-32. DOI: 10.6060/ivkkt.20246711.7055.
20. **Sharavyeva Yu.O., Makhmudov R.R., Silaichev P.S., Shipilovskikh D.A., Gorbunova I.A.** Synthesis and Study of Antinociceptive Activity of Substituted 2-(3-Cyano-4,5,6,7-tetrahydrobenzo[b]thiophen-2-ylamino)-4-oxobut-2-enoates. *ChemChemTech [Izv. Vyssh. Uchebn. Zaved. Khim. Khim. Tekhnol.]*. 2024. V. 67. N 7. P. 19-27. DOI: 10.6060/ivkkt.20246707.7029.
21. **Kozlov D.A., Lipin D.V., Gorbunova I.A., Shipilovskikh D.A., Timin A.S., Silaichev P.S., Makhmudov R.R., Shadrin V.M., Shipilovskikh S.A.** Synthesis and Antinociceptive Activity of Substituted Derivatives of Potassium 1-Cyano-3-{(3-cyano-4,5,6,7-tetrahydrobenzo-[b]thiophen-2-yl)amino}-5-oxopenta-1,3-dien-2-olates. *Russ. J. Gen. Chem.* 2024. V. 94. N 5. P. 1024-1030. DOI: 10.1134/S1070363224050025.

22. **Gorbunova I.A., Parkhoma K.Yu., Makhmudov R.R., Shipilovskikh D.A., Denislamova E.S., Timin A.S., Shipilovskikh S.A.** Synthesis of Substituted 5-Amino-3-(R-carbonyl)-1-(2-oxoethylidene)-6,7,8,9-tetrahydrobenzo[4,5]thieno[3,2-e]pyrrolo[1,2-a]pyrimidin-2(1H)-ones with Antinociceptive Activity. *Russ. J. Gen. Chem.* 2024. V. 94. N 4. P. 779-787. DOI: 10.1134/S1070363224040066.
23. **Горбунова И.А., Оконешникова Е.А., Махмудов Р.Р., Шадрин В.М., Силайчев П.С., Шипиловских С.А., Шипиловских Д.А.** Синтез и противовоспалительная активность N-замещенных 4-арил-2-[(3-циано-4,5,6,7-тетрагидробензо[b]тиофен-2-ил)амино]-4-оксобут-2-енамидов. *Изв. АН. Сер. Хим.* 2024. Т. 73. Вып. 9. С. 2758-2764. DOI: 10.1007/s11172-024-4389-1.
24. **Шаравьева Ю.О., Горбунова И.А., Махмудов Р.Р., Шипиловских Д.А., Силайчев П.С., Шипиловских С.А.** Синтез и противовоспалительная активность 4-арил-2-[(3-цианотиофен-2-ил)амино]-4-оксобут-2-еноатов. *Изв. АН. Сер. Хим.* 2023. Т. 72. Вып. 12. С. 3005-3012. DOI: 10.1007/s11172-023-4112-7.
25. **Gorbunova I.A., Rogova A., Akhmetova D.R., Sidorov R.Yu., Priakhin E.E., Makhmudov R.R., Shipilovskikh D.A., Epifanovskaya O.S., Timin A.S., Shipilovskikh S.A.** Design and one-pot synthesis of new substituted pyrrolo[1,2-a]thieno[3,2-e]pyrimidine as potential antitumor agents: in vitro and in vivo studies. *Bioorg. Chem.* 2024. V. 148. P. 107468. DOI: 10.1016/j.bioorg.2024.107468.
26. **Горбунова И.А., Рогова А., Пархома К.Ю., Шипиловских Д.А., Карпов Т.Е., Махмудов Р.Р., Тимин А.С., Шипиловских С.А.** Синтез производных 2-амино-1-(3-циано-4,5,6,7-тетрагидробензо[b]тиофен-2-ил)-4-оксо-4,5-дигидро-1Н-пиррол-3-карбоновой кислоты и изучение их противоопухолевой активности в отношении клеточной линии меланомы B16-F10. *Изв. АН. Сер. Хим.* 2024. Т. 73. Вып. 11. С. 3367-3371. DOI: 10.1007/s11172-024-4453-x.
27. **Karpov T.E., Rogova A., Akhmetova D.R., Tishchenko Yu.A., Chinakova A.V., Lipin D.V., Gavrilova N.V., Gorbunova I.A., Shipilovskikh S.A., Timin A.S.** Encapsulation of a small-molecule drug based on substituted 2-aminothiophenes in calcium carbonate carriers for therapy of melanoma. *Biomater. Sci.* 2024. V. 12. N 13. P. 3431-3445. DOI: 10.1039/D4BM00390J.
28. **Сюткина А.И., Чащина С.В., Махмудов Р.Р., Новикова В.В., Чернов И.Н., Игидов Н.М.** Синтез, анальгетическая и противомикробная активность N-гетариламидов 2-(2-(диарилметилен)гидразоно)-5,5-диметил-4-оксогексановой кислоты. *Изв. вузов. Химия и хим. технология.* 2022. Т. 65. Вып. 3. С. 74-82.
29. **Горбунова И.А., Шадрин В.М., Пулина Н.А., Новикова В.В., Дубровина С.С., Шипиловских Д.А., Шипиловских С.А.** Синтез и антибактериальная активность 4-оксо-2-тиениламинобут-2-еновых кислот. *Журн. общ. химии.* 2023. Т. 93. Вып. 1. С. 22-30. DOI: 10.31857/S0044460X23010031.
30. **Липин Д.В., Козлов Д.А., Шадрин В.М., Пархома К.Ю., Старков А.В., Шипиловских Д.А., Пулина Н.А., Шипиловских С.А.** Синтез и гемостатическая активность замещенных 1-циано-3-{(3-циано-4,5,6,7-тетрагидробензо-[b]тиофен-2-ил)амино}-5-оксопента-1,3-диен-2-олатов калия. *Журн. Орг. химии.* 2023. Т. 59. Вып. 8. Р. 1041-1049. DOI: 10.1134/S1070428023080055.
31. **Zhestkij N.A., Efimova A.S., Timofeeva M., Novikov A.S., Gorbunova I.A., Shipilovskikh D.A., Dmitriev M.V., Shipilovskikh S.A., Milichko V.A.** Chemical Tuning of Second Harmonic Generation Efficiency in Aminothiophene-Based

22. **Gorbunova I.A., Parkhoma K.Yu., Makhmudov R.R., Shipilovskikh D.A., Denislamova E.S., Timin A.S., Shipilovskikh S.A.** Synthesis of Substituted 5-Amino-3-(R-carbonyl)-1-(2-oxoethylidene)-6,7,8,9-tetrahydrobenzo [4,5]thieno[3,2-e]pyrrolo[1,2-a]pyrimidin-2(1H)-ones with Antinociceptive Activity. *Russ. J. Gen. Chem.* 2024. V. 94. N 4. P. 779-787. DOI: 10.1134/S1070363224040066.
23. **Gorbunova I.A., Okoneshnikova E.A., Makhmudov R.R., Shadrin V.M., Silaichev P.S., Shipilovskikh S.A., Shipilovskikh D.A.** Synthesis and anti-inflammatory activity of N-substituted 4-aryl-2-[(3-cyano-4,5,6,7-tetrahydrobenzo[b]thiophen-2-yl)amino]-4-oxobut-2-enamides. *Izv. AN. Ser. Khim.* 2024. V. 73. N 9. P. 2758-2764 (in Russian). DOI: 10.1007/s11172-024-4389-1.
24. **Sharavyeva Yu.O., Gorbunova I.A., Makhmudov R.R., Shipilovskikh D.A., Silaichev P.S., Shipilovskikh S.A.** Synthesis and anti-inflammatory activity of 4-aryl-2-[(3-cyanothiophen-2-yl)amino]-4-oxobut-2-enoates. *Izv. AN. Ser. Khim.* 2023. V. 72. N. 12. P. 3005-3012 (in Russian). DOI: 10.1007/s11172-023-4112-7.
25. **Gorbunova I.A., Rogova A., Akhmetova D.R., Sidorov R.Yu., Priakhin E.E., Makhmudov R.R., Shipilovskikh D.A., Epifanovskaya O.S., Timin A.S., Shipilovskikh S.A.** Design and one-pot synthesis of new substituted pyrrolo[1,2-a]thieno[3,2-e]pyrimidine as potential antitumor agents: in vitro and in vivo studies. *Bioorg. Chem.* 2024. V. 148. P. 107468. DOI: 10.1016/j.bioorg.2024.107468.
26. **Gorbunova I.A., Rogova A., Parkhoma K.Yu., Shipilovskikh D.A., Karpov T.E., Makhmudov R.R., Timin A.S., Shipilovskikh S.A.** Synthesis of 2-amino-1-(3-cyano-4,5,6,7-tetrahydrobenzo[b]thiophen-2-yl)-4-oxo-4,5-dihydro-1H-pyrrole-3-carboxylic acid derivatives and studies of their antitumor activity against melanoma cell line B16-F10. *Izv. AN. Ser. Khim.* 2024. V. 73. N 11. P. 3367-3371 (in Russian). DOI: 10.1007/s11172-024-4453-x.
27. **Karpov T.E., Rogova A., Akhmetova D.R., Tishchenko Yu.A., Chinakova A.V., Lipin D.V., Gavrilova N.V., Gorbunova I.A., Shipilovskikh S.A., Timin A.S.** Encapsulation of a small-molecule drug based on substituted 2-aminothiophenes in calcium carbonate carriers for therapy of melanoma. *Biomater. Sci.* 2024. V. 12. N 13. P. 3431-3445. DOI: 10.1039/D4BM00390J.
28. **Siutkina A.I., Chashchina S.V., Makhmudov R.R., Novikova V.V., Chernov I.N., Igidov N.M.** Synthesis, Analgesic and Antimicrobial Activity of N-Hetarylamides of 2-(2-(Diarylmethylene)Hydrazono)-5,5-Dimethyl-4-Oxohexanoic Acid. *ChemChemTech [Izv. Vyssh. Uchebn. Zaved. Khim. Khim. Tekhnol.]*. 2022. V. 65. N 3. P. 74-84. DOI: 10.6060/ivkkt.20226503.6522.
29. **Gorbunova I.A., Shadrin V.M., Pulina N.A., Novikova V.V., Dubrovina S.S., Shipilovskikh D.A., Shipilovskikh S.A.** Synthesis and Antibacterial Activity of 4-Oxo-2-thienylaminobut-2-enoic Acids. *Russ. J. Gen. Chem.* 2023. V. 93. N 1. P. 8-15. DOI: 10.1134/S1070363223010024.
30. **Lipin D.V., Kozlov D.A., Shadrin V.M., Parkoma K.Yu., Starkov A.V., Shipilovskikh D.A., Pulina N.A., Shipilovskikh S.A.** Synthesis and Hemostatic Activity of Substituted Potassium 1-Cyano-3-{(3-cyano-4,5,6,7-tetrahydrobenzo[b]thiophen-2-yl)amino}-5-oxopenta-1,3-dien-2-olates. *Russ. J. Org. Chem.* 2023. V. 59. N 8. P. 1322-1328. DOI: 10.1134/S1070428023080055.
31. **Zhestkij N.A., Efimova A.S., Timofeeva M., Novikov A.S., Gorbunova I.A., Shipilovskikh D.A., Dmitriev M.V., Shipilovskikh S.A., Milichko V.A.** Chemical Tuning of Second Harmonic Generation Efficiency in Aminothiophene-Based

ing of Second Harmonic Generation Efficiency in Aminothiophene-Based Molecular Microcrystals. *J. Phys. Chem. C*. 2024. V. 128. N 43. P. 18534-18539. DOI: 10.1021/acs.jpcc.4c04885.

32. **Verbić T.Ž., Drakulić B.J., Zloh M.F., Pecelj J.R., Popović G.V., Juranić I.O.** An LFER study of the protolytic equilibria of 4-aryl-2,4-dioxobutanoic acids in aqueous solutions. *J. Serbian Chem. Soc.* 2007. V. 72. N 12. P. 1201-1216. DOI: 10.2298/JSC0712201V.
33. **Gewald K., Schinke E., Böttcher H.** Heterocyclen aus CH-aciden Nitrilen, VIII. 2-Amino-thiophene aus methylenaktiven Nitrilen, Carbonylverbindungen und Schwefel. *Chem. Ber.* 1966. V. 99. N 1. P. 94-100. DOI: 10.1002/cber.19660990116.
34. **AlNeyadi S.S., Salem A.A., Ghattas M.A., Atatreh N., Abdou I.M.** Antibacterial activity and mechanism of action of the benzazole acrylonitrile-based compounds: In vitro, spectroscopic, and docking studies. *Eur. J. Med. Chem.* 2017. V. 136. P. 270-282. DOI: 10.1016/j.ejmech.2017.05.010.
35. **Lu H.Y., Barve I.J., Selvaraju M., Sun C.M.** One-Pot Synthesis of Unsymmetrical Bis-Heterocycles: Benzimidazole-, Benzoxazole-, and Benzothiazole-Linked Thiazolidines. *ACS Comb. Sci*. 2020. V. 22. N 1. P. 42-48. DOI: 10.1021/acscombsci.9b00161.

Molecular Microcrystals. *J. Phys. Chem. C*. 2024. V. 128. N 43. P. 18534-18539. DOI: 10.1021/acs.jpcc.4c04885.

32. **Verbić T.Ž., Drakulić B.J., Zloh M.F., Pecelj J.R., Popović G.V., Juranić I.O.** An LFER study of the protolytic equilibria of 4-aryl-2,4-dioxobutanoic acids in aqueous solutions. *J. Serbian Chem. Soc.* 2007. V. 72. N 12. P. 1201-1216. DOI: 10.2298/JSC0712201V.
33. **Gewald K., Schinke E., Böttcher H.** Heterocyclen aus CH-aciden Nitrilen, VIII. 2-Amino-thiophene aus methylenaktiven Nitrilen, Carbonylverbindungen und Schwefel. *Chem. Ber.* 1966. V. 99. N 1. P. 94-100. DOI: 10.1002/cber.19660990116.
34. **AlNeyadi S.S., Salem A.A., Ghattas M.A., Atatreh N., Abdou I.M.** Antibacterial activity and mechanism of action of the benzazole acrylonitrile-based compounds: In vitro, spectroscopic, and docking studies. *Eur. J. Med. Chem.* 2017. V. 136. P. 270-282. DOI: 10.1016/j.ejmech.2017.05.010.
35. **Lu H.Y., Barve I.J., Selvaraju M., Sun C.M.** One-Pot Synthesis of Unsymmetrical Bis-Heterocycles: Benzimidazole-, Benzoxazole-, and Benzothiazole-Linked Thiazolidines. *ACS Comb. Sci.* 2020. V. 22. N 1. P. 42-48. DOI: 10.1021/acscombsci.9b00161.

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