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DOUBLE COORDINATION COMPOUNDS OF Fe(II)/Co(II)/Ni(II)/Cu(II) 1,10-PHENANTHROLINE/2,2′-BIPYRIDINE CATIONS WITH TARTRATOGERMANATE(IV) ANIONS AS NOVEL NONRESISTANT ANTIMICROBIAL AGENTS

Objective. *To study the antimicrobial activity of double coordination compounds with 1,10-phenanthroline/2,2′-bipyridine complexes of Fe(II)/ Co(II)/ Ni(II)/ Cu(II) as cations and different tartratogermanate(IV) anions, reveal the main factors of their efficiency and establish relations between their composition, structure features, and biological properties.* ***Methods***. *The developed synthesis method allowed us to obtain three different tartratogermanate anions, which exist together in the solution and can be selectively recognized by the certain type of 1,10-phenanthroline/2,2′-bipyridine cation. The antimicrobial activity of the compound was investigated by a rapid twofold dilution method in a standard liquid nutrient medium (Hottinger digestion) to determine the minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC).* ***Results***. *The complex nature of studied compounds, synergism of their biologically active structural units, and the presence of different types of intermolecular bonds result in the high antimicrobial activity against a wide range of microorganisms such as gram-positive Planococcus citreus, Micrococcus luteus, Bacillus cereus, Staphylococcus aureus, Streptococcus lactis, and, in a less degree, gram-negative Escherichia coli and Agrobacterium tumefaciens. Compounds (1)—(8) show a high antimicrobial activity because all of them belong to the type of double coordination compounds and contain similar structural units. Nevertheless, complexes (1) (23.44 μg/mL), (3) (46.9 μg/mL), (4) (23.44 μg/mL), and (8) (46.9 μg/mL) turned out to be the most effective, while (6) (>500 μg/mL) and (7) (>500 μg/mL) are less productive. Complexes that have anions* $[Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2]^{3-}$ *(1), (8) and* $[Ge_2(OH)$

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$(HTart)(\mu\text{-}Tart)_2]^{4-}$ (4) with free hydroxyl and carboxyl groups of the terminal tartaric acid are able to interact with metals in the enzymes of microorganisms and appear to be better antimicrobial drugs because they show lower inhibitory and bactericidal concentrations. ***Conclusions****. Structural features such as the cation-anionic type of compounds, variability of intermolecular interactions, joint of different biologically active units and free chelating groups in tartaric ligands lead to the combination of different action mechanisms and exclude the possibility of strain resistance.*

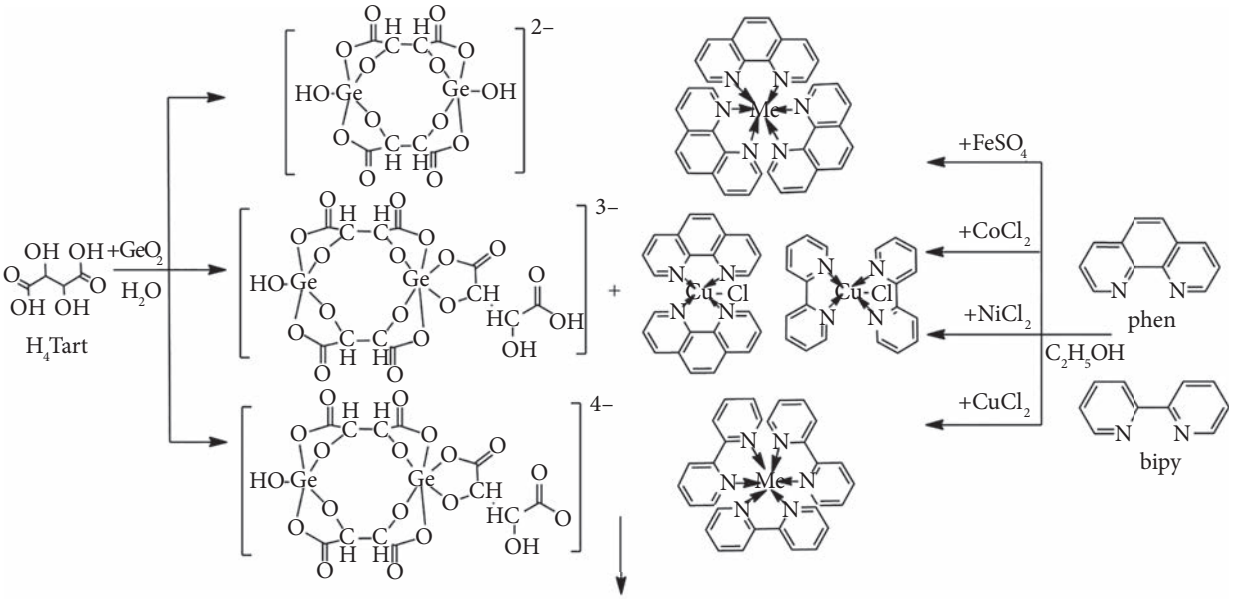
Keywords: *antimicrobials, coordination compounds, germanium(IV), 1,10-phenanthroline, 2,2′-bipyridine, d-metal.*

The ubiquitous use of antibiotics leads traditional antibacterial drugs to become less effective or even ineffective against quickly resisting microorganisms. A big challenge for scientists all over the world is to develop and implement novel strategies for fighting pathogenic bacteria [1, 2]. Interdisciplinary research in the fields of bioinorganic and medicinal chemistry allowed one to discover a wide range of coordination compounds of biometals with diverse biological activities. Big attention now is paid to the chelates and supramolecular salts that can inhibit metabolic pathways in a selective manner [3, 4]. It was established that dicationic chelates of Mn(II) Fe(II), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), and Ru(II) containing 1,10-phenanthroline show a higher activity than «metal-free» ligands against strains of *Staphylococcus aureus, Mycobacterium tuberculosis, Streptococcus pneumonia, Clostridium perfringens, Proteus vulgaris, and Escherichia coli* [5, 6]. A lot of other examples have shown as well that metal complexes turned out to be more effective than organic compounds themselves, which opens new routes in therapy against resistant bacteria [7—11].

In the framework of this study, compounds that include two different metals with unlike coordination shells and consist of separate cations and anions are considered the most perspective due to the synergism of their components and variability of action mechanisms [12, 13]. Previously the authors have developed a novel synthesis strategy that involves a combination of essential Ge(IV) with tartaric acid as an anion and Fe(II)/ Co(II)/ Ni(II)/ Cu(II) with biologically active 1,10-phenanthroline/2,2′-bipyridine as a cation, which form double coordination compounds using electrostatic, π-π stacking interactions and hydrogen bonds [14—18]. Germanium is characterized by anticarcinogenic, antimicrobial, and antioxidant activities and plays an important role in oxygen transfer, while dicarbonic dihydroxy tartaric acid (H_4Tart) is a strong chelating agent, widely used in the food industry and pharmacy [19, 20]. 1,10-phenanthroline (phen), 2,2′-bipyridine (bipy) are common heterocyclic ligands characterized by high antimicrobial activity and essential d-metals are parts of many proteins and participate in the key cellular processes such as catalysis and electron transfer [21—26]. The combination of such biologically active units results in the formation of double coordination compounds, which have lower toxicity, better solubility and biocompatibility because of their similarity to the endogenous complexes in the living organisms [12]. It has been established that compounds with tartratogermanate anions are low-toxic, belong to the IV-V toxicity class, and, unlike antibiotics, do not cause negative side effects [13].

Novel coordination compounds isolated from the described multicomponent systems have already shown high inhibiting activity on α-L-rhamnosidase — a highly productive microbial enzyme [27].

The **aim** of this paper is to extend the research by studying the antimicrobial activity of 8 cation-anionic complexes against gram-positive *Plano coccus citrus* (B-6245) 628, *Micrococcus luteus* (B-6003*)*, *Bacillus cereus* ATCC 10702 ВКПМ (VKPM) B-6644, *S. aureus* ATCC 6538P (FDA 209P), *Streptococcus sp.* (B-3872) H 46A and gram-negative *E. coli* ATCC 25922 ВКПМ (VKPM) B-6645, *Agrobacterium tumefaciens* (Smith and Townsend 1907) Conn 1942 known for their multidrug resistance and ability to «es-



[Ni(phen)$_3$]$_2$[{Ge$_2$(OH)(H$_2$Tart)(μ-Tart)$_2$}Cl] · 11H$_2$O (**1**) [Ni(phen)$_3$][Ge$_2$(OH)$_2$(μ-Tart)$_2$] · 5H$_2$O (**2**)

[CuCl(Phen)$_2$]$_4$[{Ge$_2$(OH)$_2$(μ-Tart)$_2$}Cl$_2$] · 4H$_2$O (**3**) [Cu(Phen)$_3$]$_2$[{Ge$_2$(OH)(HTart)(μ-Tart)$_2$] · 11H$_2$O (**4**)

[CuCl(bipy)$_2$]$_2$[{Ge$_2$(OH)$_2$(Tart)$_2$] · 4H$_2$O (**5**) [Ni(bipy)$_3$]$_4$[{Ge$_2$(OH)$_2$(Tart)$_2$}$_3$Cl$_2$] · 15H$_2$O (**6**)

[Fe(bipy)$_3$]$_2$[{Ge$_2$(H$_2$O)$_2$(μ-Tart)$_2$Ge(H$_2$Tart)}(S$_2$O$_7$)] · 9H$_2$O (**7**) [Co(phen)$_3$]$_2$[{Ge$_2$(OH)(H$_2$Tart)(μ-Tart)$_2$}Cl] · 11H$_2$O (**8**)

Fig. 1. Synthesis scheme and formulas of compounds (1)—(8)

cape» from common antibiotics. The main focus of this study is to confirm the hypothesis about the activity of coordination compounds isolated from the system GeO_2—Tartaric acid—d-metal-1,10-phenanthroline/2,2′-bipyridine, against a series of bacteria, establish relations among the composition, structure features, and biological properties, and reveal the main factors of their efficiency.

Materials and methods. Coordination compounds as research objects. The studied double complex compounds were obtained for the first time in the form of crystal hydrates from an aqueous-alcoholic solution according to the reaction scheme (Fig. 1) and were described in detail by X-Ray, MS, IR, TG, elemental analysis in the articles [14–18]. Structural data were specified at the Cambridge Crystallographic Data Center (CCDC) under the numbers 1964599 (1), 1964598 (2), 1878102 (3), 1878103 (4), 1883675 (5), 1883676 (6), 1576554 (7), and 1964600 (8).

The developed synthesis method allowed us to obtain three different tartratogermanate anions, which together exist in the solution and can be selectively recognized by the certain type of 1,10-phenanthroline/2,2′-bipyridine cation. The dimeric anion $[Ge_2(OH)_2(\mu\text{-Tart})_2]^{2-}$ (compounds (2), (3), (5), (6)) has two Ge(IV) atoms in its structure, bound to the two fully deprotonated bridging molecules of tartaric ligands and terminal hydroxyl groups. Coordination polyhedrons are trigonal bipyramids. Compounds (1) and (8) have the $[Ge_2(OH)(H_2Tart)(\mu\text{-Tart})_2]^{3-}$ anion in their structures, where the polyhedron of the second Ge(IV) atom is a distorted octahedron. It is bound additionally with the terminal tartaric ligand H_2Tart^{2-}, the second carboxyl and hydroxyl groups of which remain free and take part in the formation of hydrogen bonds. In the anion $[Ge_2(OH)(HTart)(\mu\text{-Tart})_2]^{4-}$ (4), the unbounded carboxyl group is deprotonated and

in $[Ge_2(H_2O)(HTart)(\mu\text{-}Tart)_2]^{3-}$ (7) terminal OH-ligand is substituted by the water molecule. Complex cations of Fe(II), Co(II), and Ni(II) have common octahedral structure, while Cu(II) forms different-ligand complexes with coordination number 5 — $[Cu(phen)_2Cl]^+$ (3) and $[CuCl(bipy)_2]^+$ (5) and 6 —$[Cu(phen)_3]^{2+}$ (4).

Strains of microorganisms. Pathogenic collection strains of gram-positive microorganisms *P. citreus* (B-6245) 628, *M. luteus* (B-6003*)*, *B. cereus* ATCC 10702 ВКПМ(VKPM) B-6644, *S. aureus* ATCC 6538P (FDA 209P), and *Streptococcus* sp. (B-3872) H 46A and gram-negative *E. coli* ATCC 25922 ВКПМ(VKPM) B-6645, *A. tumefaciens* (Smith and Townsend 1907) Conn 1942, (7 collection strains of opportunistic pathogens, including ones from the American collection of typical cultures and All-Russian collection of industrial microorganisms STATE DIGENETICS), were used as test cultures.

Cultivation of microorganisms was performed under appropriate temperature conditions using an electric dry air thermostat TSO-1/80 (Ukraine). Microscopy was performed using a light microscope MIKMED-2 Yu-33.22.926 PS (JSC «Lomo» Russia).

Antimicrobial studies. The antimicrobial activity of a compound was investigated by a rapid twofold dilution method in a standard liquid nutrient medium (Hottinger digestion) to determine the minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC), where MIC is the minimal concentration of antibiotic in the nutrient medium, at which there are no signs of reproduction of the selected strain, and MBC is the concentration that ensures the 99.99% death of cells in the microbial population.

Suspension in the meat-peptone medium containing $2 \cdot 10^9$ microbial cells in 1 mL was prepared by constant shaking in Erlenmeyer flasks at 37 °C. Ten test tubes were filled with 2 mL of this medium and 100 μL of a working solution of compound (1) in ethanol/water (1:1) was added to the first tube. After that 2 mL of the mixture from the first tube were transferred to the second one, from the second to the third one and so on. 2 mL from the last tube was poured out. This method allowed us to obtain ten solutions, each of which is twice more diluted than the previous one. The same routine was used for compounds (2)—(8).

All working solutions were inoculated with 50 μL of 50 times diluted culture medium and incubated at 37 °C for 24 hr to determine MIC, and 3 days for MBC. Then the solutions were analyzed for the presence of bacteria by the nutrient broth transparency. The solution opacity indicates that the antibiotic concentration is insufficient to suppress its viability. The microorganism sensitivity was expressed by the average concentrations in two neighboring test tubes [28]. For each of the established concentrations, the experiments were followed with appropriate controls: control of medium sterility and control of culture growth in the compound-free medium.

The lowest concentration of the test compound corresponds to the MIC index — the lowest concentration at which no growth of the culture is observed visually and when it is sown on a solid nutrient medium — meat-peptone agar (IPA).

Antimicrobial activity was determined by measuring the diameters of the inhibition growth zones of indicator microorganisms (the well diameter was taken into account). A substance is considered to have antimicrobial activity if the diameter of the growth retardation zone exceeds 11 mm [29].

To establish the toxic effect of the studied compounds, their mutagenicity was determined [30]. 18-hour cultures of *Salmonella typhimurium* TA 98 and TA 100 in nutrient broth were used as test strains. The upper agar (0.6% agar-agar with 0.5% NaCl) melted in a water bath was poured into 3 mL sterile tubes, which were then placed in a water bath at 45 °C. 0.1 mL of histidine and biotin solutions, 0.1 mL

of the studied compound at the required concentration, and 0.1 mL of the test strain culture were added to each tube.

The contents of the tubes were mixed and poured into a Petri dish with pre-filled and solidified CAC medium (selective agar mediums: A) salt solution: K_2HPO_4 — 10 g, Na_3PO_4 — 3.39 g, $(NH_4)_2SO_4$ —1.35 g, distilled water — 90 mL; B) solution of 200 mg of $MgSO_4$ in 10 mL of distilled water; C) solution of 2 g of glucose in 100 mL of distilled water; D) 20 g of agar-agar in 800 mL of distilled water).

After sterilization, all components of the solution were added to molten 2% agar. The toxic effect of chemical compounds was determined by adding to the set surface of agar medium (PA) 0.1 mL of the test preparation and 0.1 mL of the test strain culture (diluted by 10^{-5} and 10^{-6} times). The plates were incubated at 37 °C for 24 hr, then removed from the thermostat, and the number of colonies formed and cell titer were counted.

The titer of revertants was determined by counting the number of colonies on the CAC medium. The mutagenic effect of the drug was estimated by the ratio of the number of revertants to the total number of viable cells in the same experiment, compared with the spontaneous level of mutations (control).

Results. Compounds $[Ni(phen)_3]_2[\{Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2\}Cl]\cdot 11H_2O$ (1), $[Ni(phen)_3][Ge_2(OH)_2(\mu\text{-}Tart)_2]\cdot 5H_2O$ (2), $[CuCl(Phen)_2]_4[\{Ge_2(OH)_2(\mu\text{-}Tart)_2\}Cl_2]\cdot 4H_2O$ (3), $[Cu(Phen)_3]_2[Ge_2(OH)(HTart)(\mu\text{-}Tart)_2]\cdot 11H_2O$ (4), $[CuCl(bipy)_2]_2[Ge_2(OH)_2(Tart)_2]\cdot 4H_2O$ (5), $[Ni(bipy)_3]_4[\{Ge_2(OH)_2(Tart)_2\}_3Cl_2]\cdot 15H_2O$ (6), $[Fe(bipy)_3]_2[\{Ge(H_2O)(\mu\text{-}Tart)_2Ge(H_2Tart)\}(S_2O_7)]\cdot 9H_2O$ (7), and $[Co(phen)_3]_2[\{Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2\}Cl]\cdot 11H_2O$ (8) have been investigated regarding the collection reference strains of microorganisms of different taxonomic groups. All of them are more effective gram-positive organisms *P. citreus*, *Micrococcus luteus*, *B. cereus*, *S. aureus* spp., and *S. lactis* spp., than

Table 1. **Results of the antimicrobial study**

N	Conc., μg/mL	*Planococcus citreus*	*Micrococcus luteus*	*Bacillus cereus*	*Staphylococcus aureus* spp.	*Streptococcus lactis* spp.	*Escherichia coli*	*Agrobacterium fumefaciens*
1	MBC	23.44	23.44	46.9	23.44	23.44	>500	>500
	MIC	93.75	93.75	93.75	46.9	93.75	>500	>500
2	MBC	187.5	187.5	375	375	187.5	>500	>500
	MIC	375	375	375	375	375	>500	>500
3	MBC	46.9	46.9	187.5	46.9	46.9	>500	>500
	MIC	46.9	46.9	187.5	46.9	46.9	>500	>500
4	MBC	23.44	23.44	46.9	23.44	23.44	>500	>500
	MIC	23.44	23.44	46.9	46.9	23.44	>500	>500
5	MBC	187.5	187.5	375	187.5	187.5	>500	>500
	MIC	187.5	187.5	375	375	187.5	>500	>500
6	MBC	>500	>500	>500	>500	>500	>500	>500
	MIC	>500	>500	>500	>500	>500	>500	>500
7	MBC	>500	>500	>500	>500	>500	>500	>500
	MIC	>500	>500	>500	>500	>500	>500	>500
8	MBC	46.9	46.9	187.5	46.9	46.9	>500	>500
	MIC	46.9	46.9	187.5	93.75	46.9	>500	>500

gram-negative *E. coli* and *A. fumefaciens*. The antimicrobial study results are comprehensively presented in Table 1 as minimal inhibitory and minimal bactericidal concentrations (MIC and MBC, respectively).

As listed in Table 1, compounds (1)—(8) show high antimicrobial activity because they belong to the type of double coordination compounds and contain similar structural units. Nevertheless, complexes (1) (23.44 μg/mL), (3) (46.9 μg/mL), (4) (23.44 μg/mL), and (8) (46.9 μg/mL) turned out to be the most effective, while (6) (>500 μg/mL), (7) (>500 μg/mL), are less productive.

Discussion. A closer look at the antimicrobial study results allows one to reveal some common trends and relations between composition, structure, and properties. Thereby, the compounds with 1,10-phenanthroline, regardless of their d-metal, show a better antimicrobial activity than the 2,2′bipyridine-containing ones. Moreover, it is noted that not only metal-1,10-phenanthroline cation plays an important role in the suppression of microorganisms, as reported in the studies [3], but also the synergetic action of cation and anion. For example, compounds (1) and (2) contain a similar $[Ni(phen)_3]^{2+}$ cation and different anions, $[Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2]^{3-}$ and $[Ge_2(OH)_2(\mu\text{-}Tart)_2]^{2-}$, respectively, and the anion structure significantly influences their antimicrobial activity making compound (1) more effective. Moreover, all compounds that have complex anions $[Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2]^{3-}$ (1), (8) and $[Ge_2(OH)(HTart)(\mu\text{-}Tart)_2]^{4-}$ (4) show lower MIC and MBC and, therefore, appear to be better antimicrobial drugs. The hydroxyl and carboxyl groups of the terminal tartaric acid in these anions remain free and are able to interact with metals in the enzymes of microorganisms, which explains one of the mechanisms of inhibition of the test cultures and the high activity of the described complexes. Low-effective compound (7) with the $[Ge_2(H_2O)(H_2Tart)(\mu\text{-}Tart)_2]^{3-}$ anion is an exception, which can be explained by the presence of additional $S_2O_7^{2-}$ in its structure and the features of Fe(II) metal. The additional Cl^- ligand in complexes (1), (3), (6), and (8), most likely, does not influence their activity.

All the compounds are more effective to the gram-positive than to gram-negative microorganisms because of the high polar lipid content in their cell walls and complexity for antimicrobial drugs to reach their vital membrane.

Analysis of literature data and obtained results suggest that the complex nature of studied compounds leads to the diversity of their action mechanisms. Coordination compounds (1)—(8) consist of oppositely charged electrophilic (cation) and nucleophilic (anion) agents, which do not compete with each other and are bound to different parts of proteins. Moreover, summation of different inhibition effects takes place such as the oxidative protein damage, dysfunction due to the exchange of structural or catalytic metals, and loss of membrane potential, characteristic for Ge(IV) compounds transportation of reactive oxygen species and antioxidant depletion by free chelate groups in tartaric ligand molecules [4].

The closest analog of the described compounds in terms of the effect on the presented test cultures is derivatives of amine-free crown ethers, in particular, di(perfluoro-n-hexyl) dibenzo-18-crown-6, the structure and activity of which are described in the literature [31]. It was established that compounds (1)-(8) have 10 times smaller MIC than the compared drug.

It was established that double coordination compounds $[Ni(phen)_3]_2[\{Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2\}Cl]\cdot 11H_2O$ (1), $[Ni(phen)_3][Ge_2(OH)_2(\mu\text{-}Tart)_2]\cdot 5H_2O$ (2), $[CuCl(Phen)_2]_4[\{Ge_2(OH)_2(\mu\text{-}Tart)_2\}Cl_2]\cdot 4H_2O$ (3), $[Cu(Phen)_3]_2[Ge_2(OH)(HTart)(\mu\text{-}Tart)_2]\cdot 11H_2O$ (4), $[CuCl(bipy)_2]_2[Ge_2(OH)_2(Tart)_2]\cdot 4H_2O$ (5), $[Ni(bipy)_3]_4[\{Ge_2(OH)_2(Tart)_2\}_3Cl_2]\cdot 15H_2O$ (6), $[Fe(bipy)_3]_2[\{Ge(H_2O)(\mu\text{-}Tart)_2Ge(H_2Tart)\}(S_2O_7)]\cdot 9H_2O$ (7), and $[Co(phen)_3]_2[\{Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2\}Cl]\cdot 11H_2O$ (8) belong to the effective antimicrobial agents. Their advantage is the ability to

inhibit the activity of gram-positive and, to a less degree, gram-negative microorganisms. This can be explained by the structural features (cation-anionic type, variability of intermolecular interactions, combination of different biologically active units, free chelating groups in tartaric ligands) of complexes (1)—(8), which determines a set of action mechanisms and excludes the possibility of strain resistance. The development of antimicrobial agents based on the coordination of supramolecular compounds is a potential strategy to overcome the global bacterial resistance to antibiotics due to the more effective interaction of complexes with biomolecules, their higher selectivity, and lower toxicity.

Conclusions. Structural features such as the cation-anionic type of compounds, variability of intermolecular interactions, joint of different biologically active units, and free chelating groups in tartaric ligands lead to the combination of different action mechanisms and exclude the possibility of strain resistance.

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ПОДВІЙНІ КООРДИНАЦІЙНІ СПОЛУКИ КАТІОНІВ Fe(II)/Co(II)/Ni(II)/Cu(II) 1,10-ФЕНАНТРОЛІН/2,2′-БІПІРИДИН З АНІОНАМИ ТАРТРАТОГЕРМАНАТУ(IV) ЯК НОВІ НЕРЕЗИСТЕНТНІ АНТИМІКРОБНІ ЗАСОБИ

Мета. Представлена робота присвячена дослідженню антимікробної активності нових подвійних координаційних сполук з комплексними 1,10-фенантроліновими/2,2'-біпіридиновими катіонами d-металів (II) (Fe, Co, Ni, Cu) та різними тартратогерманатними аніонами. **Методи.** Розроблено оригінальний метод синтезу, який дозволив одержати три різних тартратогерманатних аніони, що існують у розчині і можуть бути селективно розпізнані певним типом 1,10-фенантролінового/2,2'-біпіридинового катіона. Антимікробна активність сполук була досліджена методом подвійного розведення в стандартному рідкому поживному середовищі (бульйон Хоттінгера) для визначення мінімальної інгібуючої концентрації (MIC) та мінімальної бактерицидної концентрації (МБС). **Результати.** Комплексна природа досліджених сполук, катіон-аніонний тип структури, синергізм їх біологічно активних складових та наявність різних типів внутрішньомолекулярних зв'язків зумовлює високу активність проти широкого ряду мікроорганізмів: грам-позитивних *Planococcus citreus*, *Micrococcus luteus*, *Bacillus cereus*, *Staphylococcus aureus*, *Streptococcus lactis* і, в меншій мірі, грам-негативних *Escherichia coli ma Agrobacterium tumefaciens*. Комплекси (1)—(8) проявили високу антимікробну дію, адже всі вони відносяться до типу подвійних координаційних сполук і містять однакові структурні юніти — катіон (електрофільний агент) та аніон (нуклеофільний агент), що не конкурують за зв'язування з різними частинами протеїнів мікроорганізмів. При цьому комплекси (1) (23,44 μг/мл), (3) (46,9 μг/мл), (4) (23,44 μг/мл), (8) (46,9 μг/мл) виявились найефективнішими, в той час як (6) (>500 μг/мл) і (7) (>500 μг/мл) — менш продуктивними. Сполуки з аніонами $[Ge_2(OH)(H_2Tart)(\mu\text{-}Tart)_2]^{3-}$ (1), (8) та $[Ge_2(OH)(HTart)(\mu\text{-}Tart)_2]^{4-}$ (4)містять у своїй структурі вільні гідроксильні і карбоксильні групи, що здатні зв'язуватися з металами в ензимах мікроорганізмів і, як наслідок, є кращими антимікробними агентами. **Висновки.** Такі структурні особливості як катіон-аніонний тип сполуки, різноманітність міжмолекулярних взаємодій, комбінація різних біологічно активних юнітів та вільні хелатні групи тартратного ліганду забезпечують поєднання різних механізмів інгібування, що сприяє посиленню активності та виключає можливість появи резистентності мікроорганізмів.

Ключові слова: *антимікробна активність, нерезистентність, координаційні сполуки, германій(IV), 1,10-фенантролін, 2,2′-біпіридин, d-метал.*