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Antimicrobial and antibiofilm activity of iodo(telluro)-induced heterocyclization products of terminal 2-alkynylthioquinoline-3-carbaldehydes

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Antimicrobial resistance represents a major global public health challenge, causing increased morbidity and mortality from infectious diseases and imposing substantial economic burdens on healthcare systems worldwide. Our objective was to evaluate the activity of newly synthesized tellurium- and halogen-functionalized quinoline derivatives against planktonic and biofilm forms of opportunistic microorganisms. The antimicrobial activity of the newly synthesized compounds was evaluated using the broth microdilution method against clinical isolates of *Staphylococcus aureus*, *Candida albicans*, *Escherichia coli*, and *Enterococcus faecalis*. Compounds demonstrating the highest antimicrobial activity were subsequently assessed for antibiofilm efficacy using the 96-well microtiter plate assay. The most pronounced antimicrobial activity was demonstrated by 1-iodomethylidene-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide (4), the complex 1-{[dichloro(4-methoxyphenyl)-λ⁴-tellanyl]methylidene}-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium chloride with 4-methoxyphenyltellurium trichloride (6), 1-iodomethylidene-4-formyl-1,2-dihydro[1,3]thiazolo[3,2-a]quinolinium chloride (2), and 1-(dichloro-λ⁴-tellanylmethylidene)-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide (10). These compounds were therefore selected for evaluation of their antibiofilm properties. Compounds 2 and 10 exhibited the strongest antibiofilm activity, completely disrupting established biofilms formed by the tested microbial strains. By contrast, compound 4 demonstrated enhanced antibiofilm efficacy at higher dilutions (lower concentrations). A similar concentration-dependent pattern was observed for compound 6 against *E. faecalis* biofilms. Novel tellurium- and halogen-functionalized quinoline derivatives demonstrated pronounced antimicrobial and antibiofilm activity against clinical isolates of opportunistic microorganisms. The strongest inhibitory effects were observed against the microscopic fungus *Candida albicans*. These findings highlight the investigated compounds as promising candidates for further development as antiseptic and disinfectant agents to control infections, including biofilm-associated and healthcare-related infections.

Keywords: antimicrobial resistance; opportunistic microorganisms; microbial biofilms; thiazino[3,2-a]quinoline; thiazolo[3,2-a]quinoline; tellurium-containing heterocycles.

Introduction

The discovery of penicillin by Alexander Fleming and its purification by Ernst Chain and Howard Florey marked the beginning of the antibiotic era. During this period, a large number of antimicrobial agents were discovered, and the interval between the 1950s and 1970s became known as the "golden era" of antibiotic discovery. However, since that time, no fundamentally new classes of antibiotics have been introduced (Adedeji, 2016; Mohr, 2016).

Antibiotics, disinfectants, food preservatives, and other antimicrobial agents exert their effects through several major mechanisms of action. These include inhibition of bacterial cell wall synthesis (β-lactams and glycopeptides), disruption of cell membrane integrity (polymyxins), inhibition of protein synthesis (tetracyclines, macrolides, aminoglycosides, and lincosamides), interference with DNA replication (fluoroquinolones), and suppression of essential metabolic pathways (sulfonamides) (Reygaert, 2018; Abushaheen et al., 2020; Pulingam et al., 2022). Despite the diversity of antimicrobial targets and mechanisms, the misuse and overuse of antibiotics, together with natural evolutionary processes of resistance development, have led to the rapid global spread of antimicrobial resistance (AMR).

Thus, antimicrobial resistance (AMR) represents a natural and inevitable biological phenomenon driven by the ability of microorganisms to undergo genetic mutations and horizontal gene transfer (Watkins & Bonomo, 2016; Serwecińska, 2020). This problem has caused reduced antibiotic effectiveness, poorer treatment outcomes, and represents one of the leading causes of mortality and economic burden worldwide, making it one of the most significant global challenges facing humanity (Uddin et al., 2021; Nwobodo et al., 2022).

Although numerous strategies have been introduced over recent decades to combat AMR, its global spread continues unabated (Daddgostar, 2019; Cella et al., 2023; Pantyo et al., 2025). Advances in antibiotic development are increasingly offset by the rapid evolution and dissemination of resistance genes in both Gram-positive and Gram-negative pathogens (Gootz, 2010).

A promising strategy for combating infections caused by resistant microorganisms is the development and application of newly synthesized chemical compounds, particularly derivatives of small heterocyclic systems (Korol et al., 2020). The antimicrobial activity of heterocyclic compounds varies considerably and depends on both the nature of the heterocyclic core and the position of substituents within the molecule. These compounds exhibit pronounced activity against Gram-positive bacteria, including *Staphylococcus aureus* and methicillin-resistant *S. aureus* (MRSA), Gram-negative bacteria such as *Escherichia coli* and *Proteus vulgaris*, as well as fungal pathogens including *Candida albicans* and *Aspergillus niger*. Beyond antimicrobial effects, heterocyclic derivatives have attracted significant attention due to their potential antitumor and hepatoprotective properties (Sadek et al., 2011; Abu-Melha et al., 2019).

Newly synthesized compounds demonstrating broad-spectrum antimicrobial and antibiofilm activity may therefore represent promising candidates for the development of novel disinfectants and antiseptic agents capable of effectively interrupting the transmission chain of infections, including healthcare-associated infections. Nevertheless, overcoming antimicrobial resistance (AMR) requires a comprehensive and multidisciplinary strategy. Effective AMR control relies on coordinated actions at international, national, community, hospital, and individual patient levels (Murugaiyan et al., 2022; Cella et al., 2023).

The objective of this study was to evaluate the activity of newly synthesized tellurium- and halogen-functionalized quinoline derivatives against planktonic and biofilm forms of opportunistic microorganisms.

Material and methods

The antimicrobial activity was evaluated for 10 iodine- and tellurium-functionalized thiazolo(thiazino)quinolinium salt derivatives (1–6, 10) and for complexes of 2-alkynylthioquinoline-3-carbaldehyde with tellurium (IV) halogenides (7–9) (Fig. 1).

1H NMR (400 MHz) spectra were recorded in DMSO-d6 on a Varian VXR 400 instrument (Enamine Ltd, Kyiv, Ukraine). Melting points were determined on a Stuart Melting Point 30 instrument (UK). Elemental analyses were performed on an Elementar Vario analyzer (Elementar-Straße 1, Langenselbold, Germany).

4-Methoxyphenyltellurium trichloride was prepared according to the method described by Reichel & Kirschbaum (1936). 2-Butynyl-(pentynyl)thioquinoline-3-carbaldehyde was prepared according to the method described in the study by Sabo et al. (2024).

General procedure for the synthesis of complexes 6 and 7. A solution of 0.732 mmol of 4-methoxyphenyltellurium trichloride in 20 mL of acetic acid was added dropwise to a solution of 0.732 mmol of 2-butynyl(pentynyl)thioquinoline-3-carbaldehyde in 20 mL of glacial acetic acid. The reaction mixture was stirred at room temperature for 12 hours. The resulting precipitate was filtered and washed with glacial acetic acid.

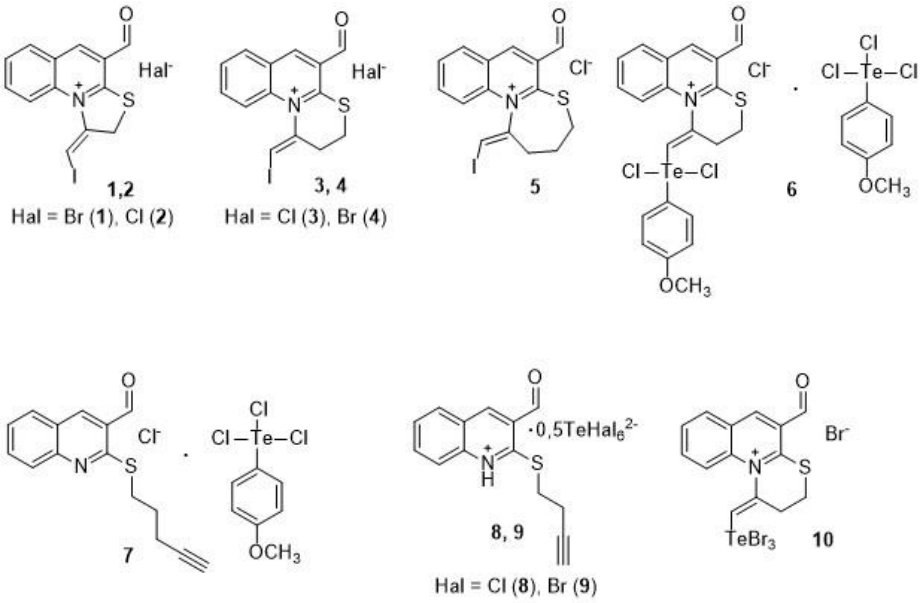

Fig. 1. Structures of the investigated halogen- and tellurium-containing quinoline derivatives

Complex 1-{[dichloro(4-methoxyphenyl)-λ⁴-tellanyl]methylidene}-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium chloride with 4-methoxyphenyltellurium trichloride 6. Yield: 42%. mp 139-141°C. 1H NMR (400 MHz, DMSO-d6) δ 10.27 (s, 1H), 9.58 (s, 1H), 8.50 (d, J = 7.9 Hz, 1H), 8.34 (t, J = 8.9 Hz, 3H), 8.22 (m, 1H), 8.00 (m, 3H), 7.90 (s, 1H), 7.10 (d, J = 8.7 Hz, 2H), 7.04 (d, J = 8.7 Hz, 2H), 4.08 (m, 1H), 3.87 (t, J = 9.3 Hz, 1H), 3.80 (s, 3H), 3.78 (s, 3H), 3.71 (m, 1H), 3.18 (m, 1H). Anal. Calcd for $C_{28}H_{25}Cl_6NO_3STe_2$: C, 36.42; H, 2.73; N, 1.52; S, 3.47. Found: C, 35.82; H, 2.58; N, 1.42; S, 3.38.

Complex 2-(pent-4-yn-1-ylthio)quinoline-3-carbaldehyde with 4-methoxyphenyltellurium trichloride 7. Yield: 48%. mp 123–125 °C. 1H NMR (400 MHz, DMSO-d6) δ 10.19 (s, 1H), 8.90 (s, 1H), 8.33 (d, J = 8.0 Hz, 2H), 8.09 (t, J = 9.3 Hz, 3H), 7.91 (m, 4H), 7.61 (t, J = 7.2 Hz, 1H), 7.12 (d, J = 7.1 Hz, 2H), 7.04 (d, J = 8.0 Hz, 2H), 3.80 (s, 6H), 3.37 (t, J = 6.9 Hz, 2H), 2.86 (s, 1H), 2.35 (t, J = 6.3 Hz, 2H), 1.90 (t, J = 6.9 Hz, 2H). Anal. Calcd for $C_{29}H_{27}Cl_6NO_3STe_2$: C, 37.15; H, 2.90; N, 1.49; S, 3.42. Found: C, 36,98; H, 2.75; N, 1.40; S, 3.26.

The antimicrobial activity of tellurium- and halogen-functionalized quinoline derivatives was investigated against clinical strains of *Staphylococcus aureus*, *Candida albicans*, *Escherichia coli*, and *Enterococcus faecalis* using the broth microdilution method with serial twofold dilutions in liquid nutrient medium, in accordance with EUCAST (European Committee on Antimicrobial Susceptibility Testing) guidelines. The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of the compounds were determined. Following inoculation with the microbial suspension, the concentrations of the tested compounds ranged from 250 µg/mL to 15.625 µg/mL. Dimethyl sulfoxide (DMSO) was used as the solvent. The MIC was defined as the lowest concentration that inhibited visible microbial growth, whereas the MBC was defined as the lowest concentration that completely inhibited microbial growth.

Clinical isolates were recovered from periodontal pockets of patients diagnosed with chronic generalized periodontitis treated at the University Dental Clinic, Uzhhorod National University. Isolation of pure cultures and preliminary identification of microorganisms were performed using standard bacterioscopic and bacteriological procedures. Final species identification was confirmed by biochemical characterization using commercially available diagnostic test systems: STAPHYtest 16, ENTEROtest 16, and CANDIDAtest 21 (PLIVA-Lachema a.s., Czech Republic) according to the manufacturer's instructions.

Compounds demonstrating the most pronounced antimicrobial activity were further evaluated for antibiofilm activity. Biofilm assays were performed using the 96-well microtiter plate method (Azeredo et al., 2017; Tsukatani et al., 2020). Suspensions of 16–24 h agar cultures or 5–6 h broth cultures of microorganisms were prepared and adjusted to an optical density corresponding to 0.5 McFarland standard. Each well of a 96-well microtiter plate was inoculated with 190 µL of nutrient broth and 10 µL of the microbial suspension. The plates were incubated at 37 °C for 5 days under thermostatic conditions. On day 4 of cultivation, planktonic cells were removed from the wells. Then, the wells were gently rinsed with distilled water, and 200 µL of the tested compounds were added to each well. Five-day-old untreated microbial biofilms served as controls. Biofilm density in both control and experimental groups was assessed by scraping the biofilms from the bottom of the wells, followed by serial dilution and plating onto solid nutrient media in Petri dishes.

To compare the antimicrobial activity of newly synthesized quinoline derivatives with that of conventional antimicrobial agents, we evaluated the susceptibility of the tested bacterial strains to amikacin, gentamicin, lincomycin, levofloxacin, and ceftriaxone. The *C. albicans* isolate was additionally tested for susceptibility to fluconazole. The antimicrobial activity of the solvent (DMSO) was also assessed. All susceptibility testing was performed using the serial broth microdilution method.

Results

The tested bacterial strains demonstrated the highest susceptibility to levofloxacin, a fluoroquinolone antibiotic, with a minimum inhibitory concentration (MIC) of 3.9 μg/mL and minimum bactericidal concentration (MBC) values ranging from 3.9 to 15.625 μg/mL. By contrast, lincomycin exhibited the lowest antimicrobial activity, with MIC and MBC values ranging from 31.25 to 250 μg/mL (Table 1).

DMSO completely inhibited the growth of *S. aureus* and *E. faecalis* at a 1:1 ratio of solvent to inoculum. For *E. coli*, the MIC of DMSO was achieved at a solvent-to-inoculum ratio of 0.5:1, while the MBC was observed at a 1:1 ratio. In the case of *C. albicans*, both MIC and MBC values were recorded at a DMSO-to-inoculum ratio of 0.25:1, indicating the highest antimicrobial activity of DMSO against the tested *C. albicans* isolate.

The results of the antimicrobial activity of the tested compounds are presented in Table 2.

The studied tellurium- and halogen-functionalized quinoline derivatives exerted the most pronounced antimicrobial activity against *C. albicans*, with MIC values ranging from 15.625 to 62.5 μg/mL and MBC values from 15.625 to 250 μg/mL. Slightly lower antimicrobial activity was observed against *E. coli* and *E. faecalis*, with MIC and MBC values ranging from 15.625 to 250 μg/mL and from 15.625 to 500 μg/mL, respectively. The lowest activity was detected against *S. aureus*, for which MIC and MBC values ranged from 31.25 to 500 μg/mL and from 62.5 to 500 μg/mL, respectively. Comparative analysis of the antimicrobial efficacy of the newly synthesized compounds revealed that the strongest activity was exhibited by 1-iodomethylidene-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide (4); the complex of 1-{[dichloro(4-methoxyphenyl)-λ⁴-tellanyl]methylidene}-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium chloride with 4-methoxyphenyltellurium trichloride (6); 1-iodomethylidene-4-formyl-1,2-dihydro[1,3]thiazolo[3,2-a]quinolinium chloride (2); and 1-(dichloro-λ⁴-tellanylmethylidene)-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide (10). These compounds were therefore selected for further evaluation of antibiofilm activity.

Table 1
Minimal inhibitory (MIC) and minimal bactericidal (MBC) concentrations of antibiotics against the investigated microorganisms

Antibiotic	*Staphylococcus aureus*		*Enterococcus faecalis*		*Escherichia coli*		*Candida albicans*	
	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
Amikacin	31.3	250.0	31.3	62.5	62.5	125.0	–	–
Gentamycin	15.6	62.5	31.3	31.3	31.3	62.5	–	–
Lincomycin	31.3	31.3	62.5	125.0	250.0	250.0	–	–
Levofloxacin	3.9	31.3	3.9	3.9	3.9	7.8	–	–
Ceftriaxone	62.5	125.0	15.6	15.6	15.6	15.6	–	–
Fluconazole	–	–	–	–	–	–	62.5	62.5

Note. "–" indicates not tested; *C. albicans* was not evaluated with antibacterial agents, whereas bacterial strains were not evaluated with antifungal agents.

Table 3 presents the growth intensity of suspended biofilm-derived cells following subculturing different dilutions from control and experimental microbial groups onto Petri plates.

Table 2
Minimal inhibitory (MIC) and minimal bactericidal (MBC) concentrations of examined tellurium- and halogen-functionalized quinoline derivatives against the investigated microorganisms

№	*Staphylococcus aureus*		*Enterococcus faecalis*		*Escherichia coli*		*Candida albicans*	
	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
1	125.0	125.0	125.0	250.0	125.0	250.0	62.5	125.0
2	31.3	62.5	125.0	125.0	125.0	250.0	62,5	62.5
3	250.0	250.0	125.0	500.0	125.0	250.0	62.5	125.0
4	125.0	250.0	62.5	62.5	125.0	500.0	15.6	15.6
5	250.0	500.0	250.0	250.0	250.0	500.0	62.5	125.0
6	125.0	125.0	15.6	31.3	15.6	15.6	62.5	125.0
7	500.0	500.0	15.6	31.3	31.3	62.5	62.5	125.0
8	125.0	250.0	62.5	125.0	62.5	125.0	62.5	62.5
9	250.0	500.0	31.3	125.0	31.3	62.5	62.5	125.0
10	125.0	250.0	125.0	250.0	125.0	125.0	15.6	31.3

Table 3
Growth intensity of suspended biofilm samples on Petri plates

Compound	*Staphylococcus aureus*			*Enterococcus faecalis*			*Escherichia coli*			*Candida albicans*		
(concentracion, μg/mL)	10^{-1}	10^{-2}	10^{-3}	10^{-1}	10^{-2}	10^{-3}	10^{-1}	10^{-2}	10^{-3}	10^{0}	10^{-1}	10^{-2}
Control	++++	++++	+++	++++	++++	+++	++++	++++	+++	++++	+++	+++
2 (1000)	–	–	–	–	–	–	–	–	–	–	–	–
2 (500)	–	–	–	–	–	–	–	–	–	–	–	–
2 (250)	–	–	–	–	–	–	–	–	–	–	–	–
2 (125)	–	–	–	–	–	–	–	–	–	–	–	–
4 (1000)	++	+	+	+++	+++	++	+	+	–	+	–	–
4 (500)	++	+	+	+++	++	+	++	+	–	+	–	–
4 (250)	++	+	+	+++	++	+	+	+	–	–	–	–
4 (125)	+	–	–	++	+	–	–	–	–	–	–	–
6 (1000)	–	–	–	+	+	–	–	–	–	–	–	–
6 (500)	–	–	–	+	–	–	–	–	–	–	–	–
6 (250)	–	–	–	+	–	–	–	–	–	–	–	–
6 (125)	–	–	–	–	–	–	–	–	–	–	–	–
10 (1000)	–	–	–	–	–	–	–	–	–	–	–	–
10 (500)	–	–	–	–	–	–	–	–	–	–	–	–
10 (250)	–	–	–	–	–	–	–	–	–	–	–	–
10 (125)	–	–	–	–	–	–	–	–	–	–	–	–

Note. "–" indicates absence of microbial growth; "+" indicates growth of a small number of microbial colonies (≤10 colonies); "++" indicates moderate growth (10–40 colonies after subculturing); "+++" indicates intensive growth with a large number of colonies; "++++" indicates confluent microbial growth.

Thus, the tested compounds demonstrated the highest antimicrobial activity against *C. albicans* biofilms. Growth of single colonies was observed only after subculturing suspended biofilm scrapings at a 1:10 dilution from wells treated with compound 4 at concentrations of 1,000 and 500 μg/mL. Visible growth was observed in the control *C. albicans* group (Fig. 2a) that was not exposed to the tested compounds. By contrast, inoculation of different dilutions of suspended biofilms from wells exposed to various dilutions of compounds 2, 6, and 10, as

well as compound 4 at concentrations of 125 and 250 µg/mL, demonstrated complete absence of microbial growth, indicating total suppression of *C. albicans* biofilms by these compounds. Growth of microorganisms at different dilutions of *S. aureus* biofilm scrapings (Fig. 2b) was observed in the control samples as well as at various dilutions of compound 4. Similar to the findings obtained for *C. albicans*, a 24-hour exposure to compounds 2, 6, and 10 resulted in complete inhibition of biofilms formed by the examined strain.

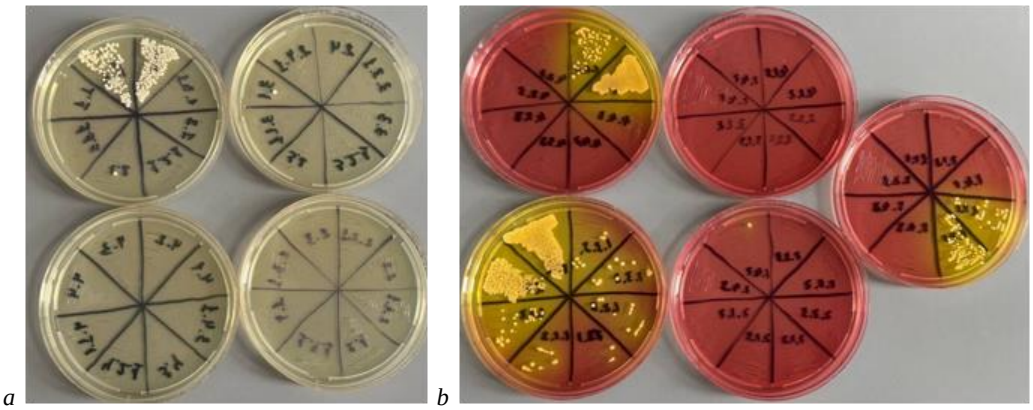

Fig. 2. Growth of *C. albicans* on Petri dishes containing Sabouraud agar supplemented with chloramphenicol (*a*) and *S. aureus* on Petri dishes with mannitol salt agar (*b*) following subculture of suspended biofilm scrapings

In the case of *E. coli*, compounds 2, 6, and 10 inhibited biofilms at different concentrations, whereas compound 4 completely eradicated the biofilms only at a concentration of 125 µg/mL (Fig. 3a). Finally, in the case of the examined *E. faecalis* strain, compound 4 demonstrated the weakest antibiofilm activity. Compound 6 eradicated biofilms only at the lowest tested concentration (125 µg/mL). Meanwhile, compounds 2 and 10 inhibited the biofilm formation across a range of concentrations (Fig. 3b), indicating the highest antibiofilm activity among the investigated compounds.

The reactions between long-chain terminal alkynylthioethers and methoxyphenyltellurium trichloride were carried out in acetic acid at room temperature for 12 hours, resulting in new tellurium-containing quinolones 6, 7 (Fig. 4). It was established that the course of tellurium-induced heterocyclization depends on the length of the alkynyl substituent. As a result, 2-butynylthioquinolinecarbaldehyde efficiently cyclizes to form a thiazinoquinolinium halide as a complex with p-methoxyphenyltellurium trichloride 6.

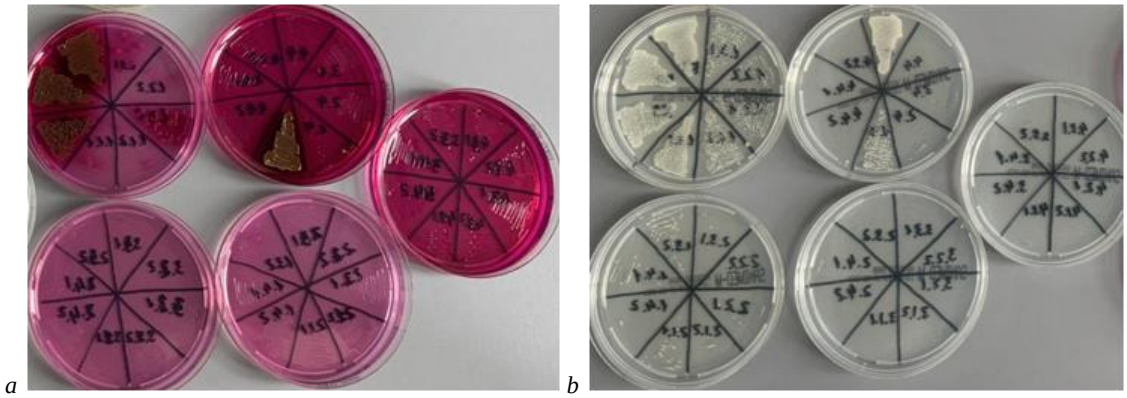

Fig. 3. Growth of *E. coli* on Petri dishes containing Endo agar (*a*) and *E. faecalis* on Petri dishes with nutrient agar (*b*) following subculture of suspended biofilm scrapings

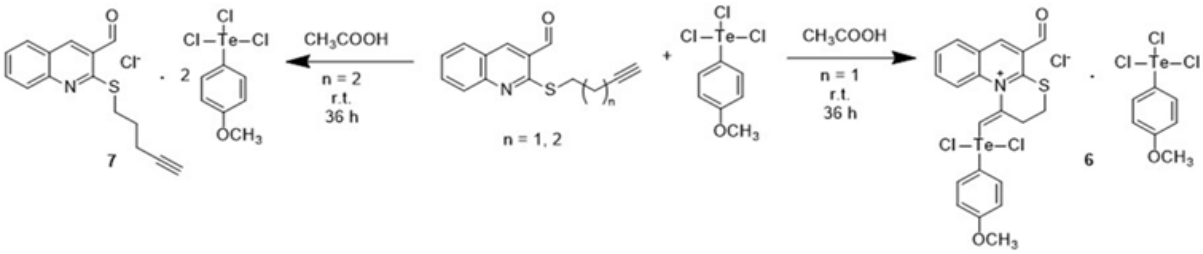

Fig 4. Synthesis of tellurium-containing quinoline salts 6 and 7

Discussion

The formation of such complexes as products of tellurium-induced cyclization is in good agreement with the studies by Kut & Onysko (2020) and Sabo et al. (2021, 2022). Elongation of the alkynyl substituent in the quinoline thioether prevents cyclization under the given conditions; instead, complex 7 is formed with a 1:2 ratio of thioether to electrophile, similarly to oxadiazole thioethers (Kut et al., 2023). The structures of compounds 6 and 7 were confirmed by NMR spectroscopy, and the compositions by elemental analysis.

A wide variety of quinoline derivatives exhibiting diverse biological activities has been described, including compounds with anticancer, antimycobacterial, antimicrobial, anticonvulsant, anti-inflammatory, and cardiovascular effects. The enhanced activity of quinoline salts reported in the literature (Chanawanno et al., 2010; Kim et al., 2017; Empel et al., 2018) may be attributed to the structural characte-

ristics of the bacterial cell envelope. In particular, the positively charged quinolinium moiety facilitates electrostatic interactions with negatively charged components of the bacterial cell wall, promoting increased antimicrobial efficacy. Another target for quinolinium derivatives is GTP hydrolysis and polymerization of filamenting temperature-sensitive mutant Z (FtsZ), leading to disruption of bacterial cell division (Cai et al., 2019). The mechanism of antimicrobial and antibiofilm activity of some novel quaternary quinolone derivatives can be explained by their ability to inhibit glutathione activity, promote massive intracellular accumulation of reactive oxygen species, and subsequently disrupt the bacterial antioxidant defense system, resulting in a bactericidal effect (Qu et al., 2025).

Thiazolo(thiazino-, thiazepino-)quinolinium halogenides 1–5 were synthesized via iodine-induced heterocyclization of 2-propargyl(butynyl-, pentynyl-)thioquinolinecarbaldehydes under the action of hybrid halogens (monobromide and monochloride), as described in the study by Sabo et al. (2024). The product of tellurium-induced heterocyclization of 2-butynylthioquinolinecarbaldehyde 10 and its hexahalogenotellurates 8, 9 are reported by Sabo et al. (2025). By contrast, the interaction of 2-butynyl(pentynyl)thioquinolinecarbaldehyde with 4-methoxyphenyltellurium trichloride has been investigated for the first time. The tested clinical isolates of *S. aureus*, *C. albicans*, *E. coli*, and *E. faecalis* were highly sensitive to compounds 2, 4, 6, and 10, which contain quaternized nitrogen atom.

A "structure–activity" relationship can be established. Tellurium-containing thiazinoquinolinium salts 6 and 10 exhibited higher activity than iodine-containing salts 2 and 4. The activity is also influenced by the size of the ring annelated to the quinoline moiety and by the nature of the anion. The lowest antibiofilm activity was observed for thiazinoquinolinium bromide 4.

The higher antibiofilm activity of compound 4 at lower concentrations against biofilms of all studied microorganisms, as well as compound 6 at lower concentrations against *E. faecalis* biofilms, may be explained by the higher content of DMSO in the more diluted samples. It was established that the solvent DMSO itself exhibited antimicrobial activity against the investigated clinical isolates, which could additionally contribute to the observed antibiofilm effects under experimental conditions.

Conclusions

Newly synthesized compounds obtained via iodo(telluro)-induced heterocyclization of terminal 2-alkynylthioquinoline-3-carbaldehydes demonstrated antimicrobial activity against the studied clinical isolates of *S. aureus*, *C. albicans*, *E. coli*, and *E. faecalis*. The degree of antimicrobial activity depended on both the chemical structure of the tested compounds and the species of microorganisms. The most pronounced antimicrobial and antibiofilm effects were exerted by tellurium-containing thiazinoquinolinium salts, particularly against *C. albicans*. MIC and MBC of compounds 1-iodomethylidene-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide and 1-(dichloro-λ⁴-tellanylmethylidene)-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide against the studied *C. albicans* strain were lower compared with those of fluconazole, indicating their potential for further development as antifungal agents. These findings suggest that the investigated compounds may be considered promising candidates for the development of novel antiseptic and disinfectant agents. Promising directions for future research include the investigation of the antimicrobial activity of tellurium- and halogen-functionalized quinoline derivatives against a broad spectrum of opportunistic and pathogenic microorganisms, as well as the evaluation of the antibiofilm activity of dimethyl sulfoxide. Such studies may provide a clearer explanation for the enhanced antibiofilm activity of compound 1-iodomethylidene-5-formyl-2,3-dihydro[1,3]thiazino[3,2-a]quinolinium bromide at lower concentrations.

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The authors declare that they have no potential conflict of interest concerning the authorship or publication of this article.

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