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Antibacterial and Antifungal Activity of Synthesized Potassium Dithiocarbazinates: A Preliminary In Vitro Study

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Abstract

Background: The spread of drug-resistant microbial strains has led many studies for identifying, designing, and synthesizing new antimicrobial agents. The aim of this study was to evaluate antimicrobial effects of some synthesized potassium dithiocarbazinate derivatives against 6 Gram-negative and 4 Gram-positive bacteria as well as 2 molds and 1 yeast. Potassium salts of dithiocarbazinic acids were prepared in good yields from the reaction of various hydrazides with carbon disulfide. Potassium hydroxide and diethyl ether were used as base and solvent, respectively.

Methods: Broth microdilution and streak plate methods were applied according to the Clinical and Laboratory Standards Institute (CLSI) guidelines to determine the minimum inhibitory concentration (MIC), the minimum bactericidal concentration (MBC), and the minimum fungicidal concentration (MFC) values.

Results: Good to excellent inhibitory effects especially on fungi were observed with the tested compounds. Dithiocarbazinates 3b and 3f containing 4-nitrophenyl and 3-hydroxy-2-naphthyl substituents could effectively inhibit the growth of all tested bacterial strains. In addition, all synthesized derivatives were effective against fungal pathogens.

Conclusion: Based on the data obtained from antimicrobial susceptibility testing, designed derivatives are especially potent antifungal agents. Potassium 2-(3-hydroxy-2-naphthoyl) hydrazine-1-carbodithioate was introduced as a new wide-spectrum antimicrobial agent. Other biological activities of these water-soluble derivatives can be studied in living organisms.

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Introduction

Infectious diseases annually lead to the death of many people around the world. Current therapeutics are not so effective due to the prevalence of drug-resistant pathogens. Design and synthesis of new antimicrobial agents along with improving public health can be helpful in solving this crisis. Dithiocarbazinates are organic compounds containing –C=ONHNHC=SS- group. Dithiocarbazinates and their derivatives possess a wide variety of biological activities including antifungal, acetylcholinesterase and tyrosinase inhibitors, antitubercular, antibacterial, antioxidant, H_1-receptor antagonist, antiproliferative, antiparasitic, and anti-

inflammatory (1-9). These derivatives were also applied as fluorescent agents, fungicides, and ionic liquids (10-12). They are key starting materials in the preparation of *S*-alkyl or dialkylcarbodithioates, 2-thioxothiazolidin-4-ones, 1,2,4-triazoles, and 5-substituted-2-mercapto-1,3,4-oxadiazoles (13-15). Dithiocarbazinates were usually synthesized via reaction of alkyl/aryl hydrazides with carbon disulfide in alkaline media. The bases such as potassium hydroxide, sodium hydroxide, ammonia, and triethylamine are used for this purpose (3, 16-18).

To prevent spreading bacterial and fungal pathogens and develop conveniently synthesized antimicrobial agents, in this study, eight known dithiocarbazinate derivatives and a new compound were prepared via reaction of various alkyl/aryl/heteroaryl hydrazides with carbon disulfide in the presence of potassium hydroxide. Then, in vitro inhibitory properties of prepared salts were evaluated against a variety of Gram-positive and Gram-negative pathogenic bacteria in genera *Staphylococcus*, *Streptococcus*, *Bacillus*, *Listeria*, *Klebsiella*, *Pseudomonas*, *Escherichia*, *Shigella*, *Salmonella*, and *Acinetobacter*, and some fungal pathogens in genera *Aspergillus*, *Candida*, and *Fusarium*.

Materials and Methods

Chemicals

All reagents and solvents were purchased from Merck and Sigma-Aldrich, and used without further purification. Melting points were determined with a melting point meter (KRÜSS, model: KSP1N) and were uncorrected. Reaction progress was monitored by aluminum TLC plates with Silica gel 60 coated with fluorescent indicator F254, which were visualized under UV radiation of 254 nm. The absorption spectra were determined using a UV-Vis spectrophotometer (UV-2100 Rayleigh). FTIR spectra of the products as potassium bromide (KBr) disks were collected using an FTIR spectrometer (Bruker Tensor-27) in the wavenumber (ν) range of 400-4000 cm^{-1}. ^{1}H and ^{13}C NMR spectra were recorded at 400 and 100 MHz, respectively, on a Bruker FT-NMR Ultra Shield-400 spectrometer. NMR chemical shifts (δ) and coupling constants (J) were reported as parts per million (ppm) and Hertz (Hz), respectively. Abbreviations are s (singlet), d (doublet), m (multiplet), brs (broad), and Ar (aryl ring).

General procedure for the synthesis of dithiocarbazinates 3a-i

10 mmol of carbon disulfide (0.76 g) was added dropwise for 1 h to a stirred ice-cooled suspension containing 10 mmol of both hydrazides 1a-i and potassium hydroxide (0.56 g) in diethyl ether (25 mL). The mixture was stirred for another 3 hrs at room temperature. The resulting precipitate was filtered off, washed with 5 mL cold ethanol and 5 mL diethyl ether, respectively, and dried over P_2O_5 in vacuum desiccator to afford potassium dithiocarbazinates 3a-i without the need for further purification.

Spectral Data

For better understanding of ^{1}H and ^{13}C NMR spectral analyses, carbons of aryl ring of dithiocarbazinate 3b were numbered in Figure 1.

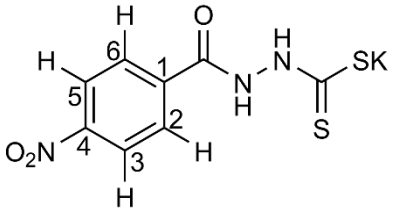


Figure 1. Numbering of carbons of aryl ring in dithiocarbazinate 3b.

Potassium 2-benzoylhydrazine-1-carbodithioate (3a)

IR *v*: 3420 (NH), 1620 (C=O), 1557, 1522, 1417 (C=S), 1385, 1137, 1069 (N-C=S), 1006, 943, 929, 876, 793, 769 (N-C=S), 700, 682, 610, 531, 498 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.43, 9.76 (2H, brs, 2×NH), 7.76 (2H, d, J = 6.6 Hz, H-2,6 Ar), 7.43-7.45 (3H, m, H-3,4,5 Ar) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 180.1 (C=S), 161.2 (C=O), 130.0 (C-4 Ar), 129.4 (C-3,5 Ar), 125.3 (C-2,6 Ar) ppm.

Potassium 2-(4-nitrobenzoyl) hydrazine-1-carbodithioate (3b)

IR *v*: 3417 (NH), 1646 (C=O), 1518, 1403 (C=S), 1110, 1061 (N-C=S), 1005, 955, 850, 775 (N-C=S), 707, 512, 441 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.62, 9.79 (2H, brs, 2×NH), 8.31 (2H, d, J = 7.8 Hz, H-3,5 Ar), 8.10 (2H, d, J = 7.8 Hz, H-2,6 Ar) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 181.9 (C=S), 160.0 (C=O), 147.7 (C-4 Ar), 130.9 (C-1 Ar), 126.0 (C-2,6 Ar), 124.9 (C-3,5 Ar) ppm.

Potassium 2-(4-hydroxybenzoyl) hydrazine-1-carbodithioate (3c)

IR *v*: 3456 (OH), 3414 (NH), 2369, 1609 (C=O), 1493, 1427 (C=S), 1256, 1143, 1074 (N-C=S), 1001, 939, 843, 768 (N-C=S), 625, 522 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.12 (1H, brs, OH), 10.55, 9.48 (2H, brs, 2×NH), 7.58 (2H, d, J = 7.3 Hz, H-2,6 Ar), 6.83 (2H, d, J = 7.3 Hz, H-3,5 Ar) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 179.1 (C=S), 161.4 (C=O), 159.4 (C-4 Ar), 129.2 (C-1 Ar), 127.2 (C-2,6 Ar), 116.2 (C-3,5 Ar) ppm.

Potassium 2-(4-(tert-butyl) benzoyl) hydrazine-1-carbodithioate (3d)

IR *v*: 3414 (NH), 2368, 1625 (C=O), 1428 (C=S), 1124, 1065 (N-C=S), 1003, 771 (N-C=S), 619 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.58, 9.62 (2H, brs, 2×NH), 7.67 (2H, d, J = 7.7 Hz, H-2,6 Ar), 7.46 (2H, d, J = 7.7 Hz, H-3,5 Ar), 1.27 (9H, s, 3×CH_3) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 179.9 (C=S), 161.2 (C=O), 152.4 (C-4 Ar), 141.0 (C-1 Ar), 126.2 (C-2,6 Ar), 125.1 (C-3,5 Ar), 34.9 ($\underline{C}(CH_3)_3$), 31.3 (3×CH_3) ppm.

Potassium 2-(3-methoxybenzoyl) hydrazine-1-carbodithioate (3e)

IR *v*: 3419 (NH), 1641 (C=O), 1586, 1475 (C=S), 1388, 1255, 1157, 1028 (N-C=S), 918, 872, 812, 725 (N-C=S), 675, 631, 520, 442 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.82, 9.76 (2H, brs, 2×NH), 7.39 (3H, m, H-4,5,6 Ar), 7.07 (1H, m, H-2 Ar), 3.77 (3H, s, CH_3) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 179.9 (C=S), 161.0 (C=O), 159.9 (C-3 Ar), 130.7 (C-5 Ar), 126.7 (C-1 Ar), 117.8 (C-6 Ar), 116.3 (C-4 Ar), 110.1 (C-2 Ar), 55.6 (CH_3) ppm.

Potassium 2-(3-hydroxy-2-naphthoyl) hydrazine-1-carbodithioate (new compound) (3f)

IR *v*: 3472 (OH), 3413 (NH), 1651 (C=O), 1582, 1513, 1401 (C=S), 1304, 1226, 1155, 1055 (N-C=S), 1000, 944, 873, 793, 740 (N-C=S), 574, 476 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.98 (1H, s, OH), 10.05, 9.94 (2H, brs, 2×NH), 7.22-7.90 (6H, m, Ar-H) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 179.9 (C=S), 161.1 (C=O), 152.9 (C-3 Ar), 135.2 (C-5 Ar), 129.4 (C-8a Ar), 128.8 (C-8 Ar), 128.1 (C-6 Ar), 127.6 (C-2 Ar), 126.4 (C-5 Ar), 124.2 (C-7 Ar), 110.8 (C-4 Ar) ppm.

Potassium 2-(furan-2-carbonyl) hydrazine-1-carbodithioate (3g)

IR *v*: 3413 (NH), 2357, 1611 (C=O), 1559, 1436 (C=S), 1217, 1055 (N-C=S), 808, 758 (N-C=S), 653, 538 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.80, 9.60 (2H, brs, 2×NH), 7.80 (1H, s, H-5 Ar), 7.04 (1H, s, H-3 Ar), 6.61 (1H, s, H-4 Ar) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 169.9 (C=S), 152.6 (C=O), 148.1 (C-2 Ar), 145.4 (C-5 Ar), 114.2 (C-3 Ar), 112.5 (C-4 Ar) ppm.

Potassium 2-isonicotinoylhydrazine-1-carbodithioate (3h)

IR *v*: 3417 (NH), 2360, 1672 (C=O), 1519, 1475, 1411 (C=S), 1325, 1260, 1159, 1090 (N-C=S), 1002, 897, 844, 753 (N-C=S), 676, 549 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.57, 9.35 (2H, brs, 2×NH), 8.69 (2H, d, J = 4.8 Hz, H-3,5 Ar), 7.75 (2H, d, J = 4.8 Hz, H-2,6 Ar) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 212.0 (C=S), 161.7 (C=O), 150.6 (C-3,5 Ar), 141.0 (C-1 Ar), 121.7 (C-2,6 Ar) ppm.

Potassium 2-acetylhydrazine-1-carbodithioate (3i)

IR *v*: 3414 (NH), 1662 (C=O), 1522, 1477, 1422 (C=S), 1365, 1324, 1255, 1135, 1083 (N-C=S), 1002, 943, 882, 787 (N-C=S), 670, 606, 510 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 10.57, 9.40 (2H, brs, 2×NH), 2.14 (3H, s, CH_3) ppm; ^{13}C NMR (100 MHz, DMSO-d_6) δ: 213.7 (C=S), 168.3 (C=O), 21.1 (CH_3) ppm.

Biological evaluation

Culture media and microorganisms

Mueller-Hinton broth (MHB), Mueller-Hinton agar (MHA), RPMI 1640 medium (Roswell Park Memorial Institute 1640) buffered at pH 7.0 with morpholine propane sulfonic acid (MOPS), gentamicin, and terbinafine were purchased from HiMedia and Sigma-Aldrich companies. Gram-negative bacterial strains including *Pseudomonas aeruginosa* (PTCC 1310), *Salmonella enterica subsp. enterica* (PTCC 1709), *Shigella dysenteriae* (PTCC 1188), *Klebsiella pneumoniae* (PTCC 1290), *Acinetobacter baumannii* (PTCC 1855), *Escherichia coli* (PTCC 1399), Gram-positive bacterial strains including *Streptococcus pyogenes* (PTCC 1447), *Staphylococcus epidermidis* (PTCC 1435), *Listeria monocytogenes* (PTCC 1297), *Bacillus cereus* (PTCC 1665), molds including *Aspergillus fumigatus* (PTCC 5009) and *Fusarium oxysporum* (PTCC 5115), and yeast *Candida albicans* (PTCC 5027) were prepared from the Persian Type Culture Collection (PTCC), Karaj, Iran. All selected bacterial and fungal strains belong to important pathogens, which cause numerous infections in humans including pneumonia, salmonellosis, shigellosis, meningitis, cholecystitis, cholangitis, pharyngitis, tonsillitis, endocarditis, listeriosis, chronic pulmonary aspergillosis, keratitis, onychomycosis, and candidiasis. Broth microdilution and streak plate methods were applied to assay antimicrobial susceptibility testing (AST) according to the Clinical and Laboratory Standards Institute (CLSI) guidelines including M07-A9, M27-A2, M38-A2, and M26-A (19). Yeast, molds, and bacterial suspensions were respectively prepared in appropriate broth media with concentrations of 0.5-2.5 × 10^3, 0.4-5 × 10^4, and 5 × 10^5 $CFU.mL^{-1}$. All experiments were independently repeated three times, and expressed as their average. No standard deviation was observed at mean MIC, MBC, and MFC values.

Minimum inhibitory concentration (MIC) testing

20 µL of each dithiocarbazinate with concentration of 20480 $\mu g.mL^{-1}$ in distilled water was added to the first and

second wells in a row of a 96-well microplate. 20 µL distilled water was added to wells 2-12, and two-fold serial dilutions were carried out in the wells. 80 µL of Mueller-Hinton broth or RPMI 1640 with 100 µL of microbial suspensions were added to all wells. Finally, a concentration range of 2048-1 $\mu g.mL^{-1}$ of all derivatives was prepared in each row. Microplates were incubated with shaking at 100 rpm and temperature of 37°C for 20 hrs for bacteria and temperature of 35°C for 48 hrs for fungi. The lowest concentration of derivatives that resulted in no visible turbidity was considered as the MIC value.

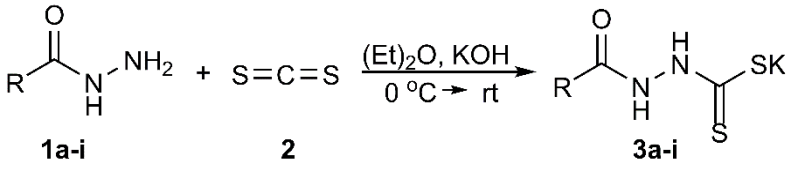
Minimum bactericidal concentration (MBC) and minimum fungicidal concentration (MFC) testing

Samples of all clear wells in the MIC testing were streaked by swab across the surface of Mueller-Hinton agar or RPMI 1640 agar media plates. The plates were incubated for 24 hrs under similar conditions with this difference that 45-55% relative humidity must be supplied during incubation of fungi. The MBC or MFC was identified as the lowest concentration of derivatives at which no microorganisms survived.

Results

Synthesis and characterization

Dithiocarbazinate salts 3a-i were synthesized from the reaction of hydrazides 1a-i with carbon disulfide (CS_2) in the presence of potassium hydroxide in diethyl ether ($(C_2H_5)_2O$) as solvent (Scheme 1). The melting points and yields of target products are presented in Table 1.



Scheme 1. Reaction of hydrazides with CS2.

Table 1. The results of synthesized dithiocarbazinic acid potassium salts

Entry	Product	R	Yield (%)	M. P. (°C)	
				Found	Lit. (Ref.)
1	3a	C_6H_5	86	294-296 (decomp.)	292-296 (decomp.) (20)
2	3b	4-O_2N-C_6H_4	94	152-154	155 (21)
3	3c	4-HO-C_6H_4	91	288-290	- (22)
4	3d	4-$(CH_3)_3C$-C_6H_4	92	276-277	- (23)
5	3e	3-CH_3O-C_6H_4	90	245-247	- (24)
6	3f	3-HO-2-naphthyl	94	291-293	-
7	3g	2-furyl	85	242-244	240 (25)
8	3h	4-pyridinyl	88	301-303	304 (26)
9	3i	CH_3	82	176-178 (decomp.)	180-182 (decomp.) (20)

Melting points of products 3c-f were not reported in literature, 3f is a new compound.

The chemical structures of all products were characterized by Fourier-transform infrared (FTIR) and nuclear magnetic resonance (NMR) spectroscopy, to determine the functional groups and molecular structures, respectively. Thiocarbonyl and carbonyl groups were verified by FTIR (~ 1420 and 1600 cm^{-1}) and ^{13}C NMR (~ 180 and 160 ppm), respectively.

Antimicrobial Activity of Dithiocarbazinates

Antimicrobial activity of dithiocarbazinates has been less studied in previous studies. For this reason, inhibitory activities of prepared salts were evaluated against a variety of bacterial and fungal pathogens, and the results are shown in Tables 2 and 3.

The MIC values of 2-2048 $\mu g.mL^{-1}$ were observed with dithiocarbazinates (3a-i) against tested bacterial strains. Potassium 2-(furan-2-carbonyl) hydrazine-1-carbodithioate (3g) showed the best inhibitory effect on *Staphylococcus epidermidis*.

Dithiocarbazinates (3a-i) could inhibit the growth of all tested fungi with MIC values of 1-1024 $\mu g.mL^{-1}$. They were more successful in inhibiting the growth of *Aspergillus fumigatus* strain.

Table 2. Antibacterial properties of dithiocarbazinates 3a-i

Bacterial Species		Products									Antibiotic
		3a	3b	3c	3d	3e	3f	3g	3h	3i	Gentamicin
Pseudomonas	MIC	1024	256	2048	-	1024	2048	2048	2048	-	0.063
aeruginosa	MBC	1024	256	2048	-	1024	2048	2048	2048	-	0.063
Klebsiella	MIC	-	512	2048	256	2048	2048	2048	2048	-	4
pneumoniae	MBC	-	512	2048	256	2048	2048	2048	2048	-	4
Escherichia coli	MIC	-	2048	-	-	-	1024	2048	-	-	8
	MBC	-	2048	-	-	-	1024	2048	-	-	8
Shigella dysenteriae	MIC	512	128	2048	1024	128	256	-	2048	-	0.031
	MBC	512	128	2048	1024	128	256	-	2048	-	0.063
Salmonella enterica	MIC	-	32	512	1024	1024	2048	1024	1024	-	8
subsp. enterica	MBC	-	32	512	2048	1024	2048	1024	1024	-	8
Acinetobacter	MIC	-	2048	2048	-	2048	256	-	256	-	16
baumannii	MBC	-	2048	2048	-	2048	256	-	256	-	32
Streptococcus	MIC	-	128	-	1024	256	256	-	2048	-	0.063
pyogenes	MBC	-	256	-	1024	256	256	-	2048	-	0.125
Bacillus cereus	MIC	-	128	1024	1024	512	1024	1024	256	1024	0.25
	MBC	-	128	1024	1024	512	1024	1024	256	2048	4
Listeria	MIC	-	256	2048	-	128	256	-	2048	-	2
monocytogenes	MBC	-	256	2048	-	256	256	-	2048	-	2
Staphylococcus	MIC	512	256	512	-	32	512	2	512	-	1
epidermidis	MBC	512	256	512	-	32	512	4	512	-	2

– No significant antibacterial effect at concentration of 2048 $\mu g.mL^{-1}$, MIC ($\mu g.mL^{-1}$), MBC ($\mu g.mL^{-1}$).

Table 3. Antifungal properties of dithiocarbazinates 3a-i

		Products									Antifungal
Fungal Species		**3a**	**3b**	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**	**3i**	**Terbinafine**
Candida	MIC	2048	*256*	256	256	128	64	512	1024	1024	32
albicans	MFC	2048	*512*	256	256	256	64	512	1024	2048	64
Fusarium	MIC	2	1024	4	1024	256	16	16	1024	1	32
oxysporum	MFC	4	2048	8	2048	256	32	32	1024	2	64
Aspergillus	MIC	2	*256*	256	1	128	64	4	4	1	32
fumigatu	MFC	4	*256*	512	2	256	64	8	8	2	32

– No significant antifungal effect at concentration of 2048 µg.mL^{-1}, MIC (µg.mL^{-1}), MFC (µg.mL^{-1}).

Discussion

Antimicrobial activity of derivatives 3c, 3d, 3e, 3f, 3g, and 3i has not been evaluated yet. Tiperciuc et al. (2012) evaluated antimicrobial activity of some synthetic hetaryl-azoles derivatives and heterocyclic dithiocarbazinates via measuring inhibition zone diameter values; compound 3h with concentration of 10 mg.mL^{-1} was ineffective against *E. coli* and *Salmonella typhymurium*, while inhibited the growth of *S. aureus* and *C. albicans* (27). Also, no inhibitory activity was observed with our synthesized compound 3h against *E. coli*, while it was effective on other tested bacteria with MIC values of 256-2048 µg.mL^{-1}, as well as all tested fungi with MIC values of 4-1024 µg.mL^{-1}. Pandeya et al. (2012) studied inhibitory effects of some 1,2,4-triazoles, 1,2,4-triazolo[3,4-*b*][1,3,4]thiadiazoles, and dithiocarbazinates (3a and 3b) on *Helicobacter pylori*, *P. aeruginosa*, *S. aureus*, *A. niger*, *Agastache foeniculum*, and *Penicillium chrysogenum*; MIC values higher than 100 µg.mL^{-1} were recorded with compounds 3a and 3b in all tests (28). In the present study, synthesized compounds 3a and 3b could also inhibit the growth of *P. aeruginosa* strain with MICs of 1024 and 256 µg.mL^{-1}, respectively.

According to the obtained data, dithiocarbazinates (3b) and (3f) as a new compound, could effectively inhibit the growth of all tested bacterial strains; they contain 4-nitrophenyl and 3-hydroxy-2-naphthyl substituents, respectively. Nitro groups are present in the structure of many biologically active compounds. Their action mechanism is based on the redox biotransformation. Nitro group is enzymatically reduced to form an anion radical. The initial compound is regenerated due to the reaction with O_2. Finally, produced superoxide anions can inhibit bacteria via inactivation of enzymes, oxidation of lipids, fragmentation of the DNA sequence, and damage of cellular walls (29). It is believed that interaction of phenolic compounds with cytoplasmic membrane of bacterial cells leads to an increase in permeability (30). In antibacterial testing, dithiocarbazinate (3i) containing alkyl substituent only affected *Bacillus cereus*. Also, no desirable antibacterial effects were observed with dithiocarbazinate (3a) containing phenyl substituent; it was effective on three bacteria with MICs higher than 512 µg.mL^{-1}. It seems that the sterically bulky tert-butyl group on phenyl ring of derivative 3d reduced antibacterial properties. All synthesized derivatives are effective on fungal

pathogens. They have significant blocking effects against molds.

Conclusion

Potassium dithiocarbazinates (3a-i) were synthesized via an efficient procedure and evaluated for their antibacterial and antifungal effects. Derivative 3f as a broad-spectrum antimicrobial agent was prepared for the first time. Dithiocarbazinates including alkyl and phenyl with/without bulky groups could inhibit the growth of limited numbers of bacteria. Antimicrobial susceptibility testing showed that synthesized salts are the potential antifungal agents. They are useful starting materials for the synthesis of biologically active molecules. These potent fungicides and rich sources of nitrogen and sulfur may be able to speed up the growth of the plants.

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