

Original article:**ANTIMICROBIAL AND ANTIOXIDATIVE ACTIVITIES
OF 1-ADAMANTYLTHIO DERIVATIVES OF 3-SUBSTITUTED PYRIDINES**

Supaluk Prachayasittikul^{1*}, Thummaruk Suksrichavalit²,
Chartchalerm Isarankura-Na-Ayudhya², Somsak Ruchirawat³,
Virapong Prachayasittikul^{2*}

¹Department of Chemistry, Faculty of Science, Srinakharinwirot University, Bangkok 10110 Thailand,

²Department of Clinical Microbiology, Faculty of Medical Technology, Mahidol University, Bangkok 10700 Thailand, ³Chulabhorn Research Institute, Bangkok 10210, Thailand

¹Telephone: 662-664-1000 ext 8209, Fax: 662-259-2097,

²Telephone: 662-418-0227, Fax: 662-412-4110,

E-mail: supaluk@swu.ac.th, mtvpr@mahidol.ac.th (* corresponding authors)

ABSTRACT

Diverse biological activities of sulfur containing pyridines were reported. To investigate for new lead compounds, thus, 1-adamantylthiopyridines bearing 3-substituents (OEt, OAc, NAc₂, Br and OH) were prepared and evaluated for antimicrobial and antioxidative activities. The antimicrobial assay against 27 strains of microorganisms was performed using agar dilution method. The results show that all the tested 2-(1-adamantylthio)-3-ethoxypyridine (**4a**), 2-(1-adamantylthio)-3-acetoxypyridine (**4b**), *N*-acetyl-2-(1-adamantylthio)-3-acetamidopyridine (**4c**), 2-(1-adamantylthio)-3-bromopyridine (**4d**), 2-(1-adamantylthio)-5-hydroxypyridine (**5**) and 3-(1-adamantylthio)-5-bromopyridine (**6**) exhibit antigrowth activity on *Streptococci* at 30 µg/mL. Particularly, the thiopyridines **4c**, **5** and **6** are the most active compounds, displaying complete inhibition against β-hemolytic *Streptococcus* group A at 30 µg/mL. These pyridyl sulfides **4a-d**, **5** and **6** represent a new group of antimicrobial agents. Antioxidative activity was analyzed using the DPPH assay. The sulfides **4a-d**, **5** and **6** show only a weak antioxidative activity. In contrast the 2-(1-adamantylthio)-3-bromopyridine (**4d**) shows the highest radical scavenging activity.

Keywords: 1-adamantylthiopyridines, antimicrobial and antioxidative activities

INTRODUCTION

A number of sulfur (Ballell et al., 2005; Scozzafava et al., 2001), sulfonyl (Scozzafava et al., 2001; Centrone and Lowary, 2004) and sulfonamide (Joshi et al., 2004) containing pyridines are active antimicrobial agents and herbicides (Parrish et al., 2001; Doweiko et al., 1983; Lee, 1981; Plant and Bell, 1976). For example, 2-alkyl- or 2-arylthiopyridines and *N*-oxides have been reported to possess diverse biological activities (Bauer and Prachayasittikul, 1987). Cyclic thionehydroxamic acids (**1**, R=H shown in the tautomeric form) are antibacterials (Shaw et al., 1950). The best known example is the zinc salt of 1-

hydroxy-2-pyridithione which is the active ingredient in many popular shampoos. The oxidation products of pyridyl sulfides, such as *N*-oxides, sulfoxides **2** and sulfones **3** have proved to be herbicides (Doweiko et al., 1983; Lee, 1981; Plant and Bell, 1976) (Figure 1).

Methyl sulfide and sulfoxide of acetamidopyridines show antituberculous activity (Ozawa, 1957). 3,5-Diamino, 3,5-dialkylthio and 3,5-dialkoxypyridines and their pyridinium salts of cephalosporin are antibacterials (Yamazaki et al., 1986).

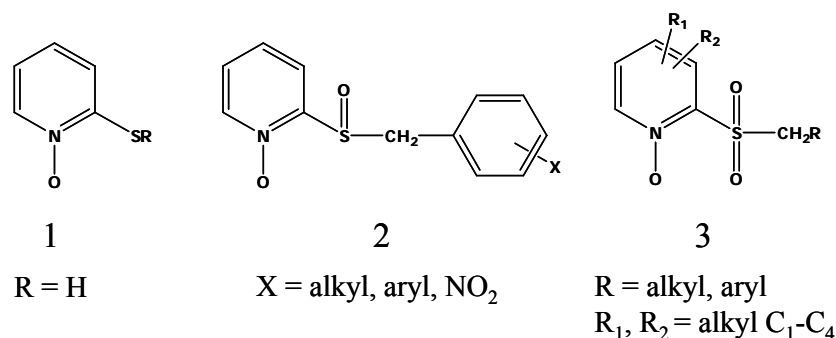


Figure 1: Sulfides, sulfoxides and sulfones of pyridine *N*-oxides

3-Alkoxy sulfonylpyridine derivatives of carbapenem and their *N*-oxides are antibacterials (Guthikonda and Dininno, 1992). Furthermore, 3-hydroxypyridine analogs are antioxidants (Wijtmans et al., 2003). In addition, a number of 3-pyridithiol based compounds are theoretically proposed as novel antioxidants (Nam et al., 2006). To discover new lead compounds for medicinal uses, 1-adamantylthiopyridines have drawn much of our attentions. So far no bioactivities of 1-adamantylthiopyridines have been reported. Based on the reported bioactive pyridyl sulfides and the rational of drug design, thus, it prompted us to investigate on antimicrobial and antioxidative activities of 1-adamantylthio analogs of 3-substituted pyridines **4-6** as shown in Figure 2.

Generally, alkyl or arylthiopyridines are prepared by various methods (Bauer and Prachayasittikul, 1987) such as aromatic nucleophilic substitution (Abramovitch et al., 1969; Abramovitch and Newman, 1974) of halopyridines by thiolates, deoxydative substitution (Bauer and Prachayasittikul, 1986) of pyridine *N*-oxides by thiols, and *S*-alkylation (Bauer and Prachayasittikul, 1987) of pyridithiones with alkylating agents. In this study, the pyridyl sulfides **4-6** were prepared using the deoxydative substitution (Prachayasittikul et al., 1991) of pyridine *N*-oxides by thiol.

MATERIALS AND METHODS

The tested compounds 4-6

2-(1-adamantylthio)-3-ethoxypyridine (**4a**),
2-(1-adamantylthio)-3-acetoxypyridine (**4b**),

N-acetyl-2-(1-adamantylthio)-3-acetamidopyridine (**4c**), 2-(1-adamantylthio)-3-bromopyridine (**4d**), 2-(1-adamantylthio)-5-hydroxypyridine (**5**) and 3-(1-adamantylthio)-5-bromopyridine (**6**).

These compounds **4-6** were prepared according to the literature (Prachayasittikul et al., 1991) using the reaction of 3-substituted pyridine *N*-oxides **7** with 1-adamantanethiol in refluxing acetic anhydride (Figure 2).

Microorganisms

Twenty seven strains of microorganisms (shown as follows) were used for antimicrobial activity assay:

- *Escherichia coli* ATCC 25922
- *Edwardsiella tarda*
- *Shigella dysenteriae*
- *Shigella flexneri*
- *Salmonella paratyphi A*
- *Salmonella typhi*
- *Salmonella enteritidis*
- *Citrobacter diversus*
- *Citrobacter freundii*
- *Klebsiella pneumoniae* ATCC 700603
- *Enterobacter aerogenes*
- *Enterobacter cloacae*
- *Serratia marcescens* ATCC 8100
- *Serratia rubidaca*
- *Morganella morganii*
- *Providencia rettgeri*
- *Providencia alcalifaciens*
- *Pseudomonas aeruginosa* ATCC 27853
- *Vibrio cholera*
- *Vibrio parahaemolyticus*
- *Aeromonas hydrophila*
- *Bacillus subtilis* ATCC 6633

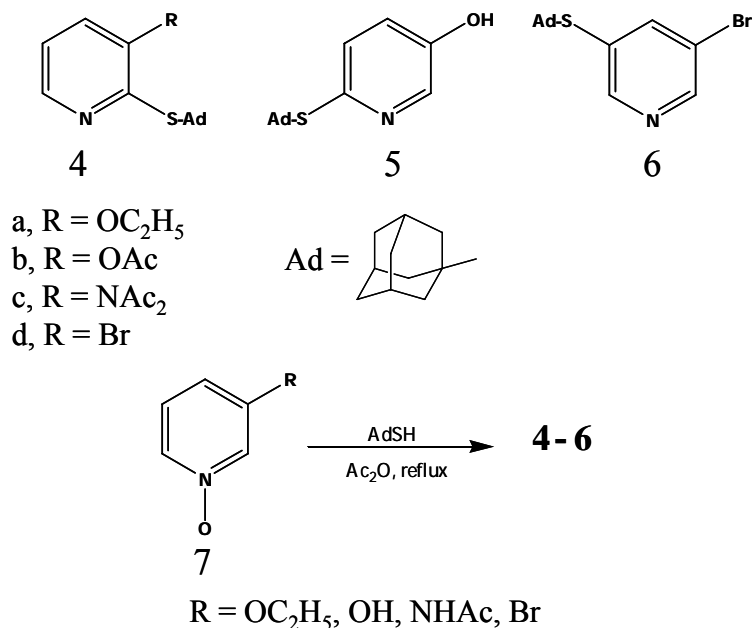


Figure 2: 1-Adamantylthiopyridines 4-6

- *Staphylococcus aureus* ATCC 25923
- *Staphylococcus saprophyticus*
- β -hemolytic *Streptococcus* group A
- α -hemolytic *Streptococcus* spp.
- *Streptococcus* group D enterococcus

Antimicrobial assay (Baron et al., 1994)

Antimicrobial activity of 1-adamantylthiopyridine derivatives was investigated by using agar dilution method (Baron et al., 1994). Briefly, the tested compounds dissolved in DMSO were individually mixed with 1 mL Müller Hinton (MH) broth. The solution was then transferred to the MH agar solution to yield the final concentrations of 15 and 30 $\mu\text{g/mL}$. Twenty seven strains of microorganisms, cultured in MH broth at 37 °C for 24 h, were diluted with 0.9 % normal saline solution to adjust the cell density of 3×10^9 cell/mL. The organisms were inoculated onto each plate and further incubated at 37 °C for 18-48 h. Compounds which possessed high efficacy to inhibit bacterial cell growth were analyzed.

Antioxidative assay (Yen and Hsieh, 1997)

Antioxidative activity of 1-adamantylthio derivatives of 3-substituted pyridines was elucidated by DPPH (2,2-diphenyl-1-

picrylhydrazyl) radical scavenging assay. When DPPH (a stable purple color) reacts with an antioxidant compound, it is reduced to yield a light-yellow color of diphenylpicrylhydrazine. Changes of the color can be spectrophotometrically measured. In this study, experiment was initiated by preparing 0.2 mM solution of DPPH in methanol. One millilitre of this solution was added into 0.5 mL of sample solution (1 mg/mL dissolved in methanol). After 30 min, absorbance was measured at 517 nm and the percentage of radical scavenging activity was calculated from the following equation:

$$\% \text{ Radical scavenging} = (1 - \text{Abs. sample} / \text{Abs. cont}) \times 100$$

where Abs. cont is the absorbance of the control reaction and Abs. sample is the absorbance in the presence of sample.

RESULTS AND DISCUSSION

Chemistry

As described in the literature (Prachayasittikul et al., 1991), the reaction of 3-substituted pyridine *N*-oxide **7** (R=OC₂H₅) with 1-adamantanethiol in boiling acetic anhydride gave 2-(1-adamantylthio)-3-ethoxypyridine (**4a**). Similarly, the *N*-oxide

7 (R=OH) afforded 2-(1-adamantylthio)-3-acetoxypyridine (**4b**) and 2-(1-adamantylthio)-5-hydroxypyridine (**5**). *N*-acetyl-2-(1-adamantylthio)-3-acetamidopyridine (**4c**) was obtained from the reaction of *N*-oxide **7** (R=NHAc). 3-Bromopyridine *N*-oxide (**7**, R=Br) furnished a mixture of 2-(1-adamantylthio)-3-bromopyridine (**4d**) and 3-(1-adamantylthio)-5-bromopyridine (**6**). The structures of pyridyl sulfides **4a-d**, **5** and **6** were confirmed by ¹H NMR and melting points.

Antimicrobial assay

The pyridyl sulfides **4-6** were tested for antimicrobial activity against 27 strains of microorganisms using agar dilution method (Baron et al., 1994). The results (Table 1) show that all the tested pyridyl sulfides **4-6** inhibit the growth of *Streptococci* at 30 μg/mL. The structures of these active sulfides **4-6** (Figure 2) constitute 1-adamantylthio group at various positions

Table1: Antimicrobial activity of 1-adamantylthiopyridines **4-6**

Compounds	4a (μg/mL)		4b (μg/mL)		4c (μg/mL)		4d (μg/mL)		5 (μg/mL)		6 (μg/mL)	
	15	30	15	30	15	30	15	30	15	30	15	30
<i>Escherichia coli</i> ATCC 25922	4	4	4	4	4	4	4	4	4	4	4	4
<i>Edwardsiella tarda</i>	4	2	4	3	4	1	4	4	3	2	3	2
<i>Shigella dysenteriae</i>	4	4	4	4	4	4	4	4	4	4	4	4
<i>Shigella flexneri</i>	4	4	4	4	4	3	4	4	3	4	4	4
<i>Salmonella paratyphi A</i>	2	1	4	2	4	1	4	2	4	3	4	3
<i>Salmonella typhi</i>	4	3	4	4	4	2	4	3	4	4	4	4
<i>Salmonella enteritidis</i>	4	4	4	4	4	3	4	4	4	4	4	4
<i>Citrobacter diversus</i>	4	4	4	4	4	3	4	4	4	4	4	4
<i>Citrobacter freundii</i>	4	4	4	4	4	3	4	4	4	4	4	4
<i>Klebsiella pneumoniae</i> ATCC 700603	4	4	4	4	4	4	4	4	4	4	4	4
<i>Enterobacter aerogenes</i>	4	4	4	4	4	4	4	4	4	4	4	4
<i>Enterobacter cloacae</i>	4	4	4	4	4	2	4	4	4	4	4	4
<i>Serratia marcescens</i> ATCC 8100	4	4	4	4	4	3	4	4	4	4	4	4
<i>Serratia rubidaca</i>	4	4	4	4	4	2	4	3	4	4	4	4
<i>Morganella morganii</i>	4	4	4	4	4	3	4	4	4	4	4	4
<i>Providencia rettgeri</i>	4	4	4	4	4	3	4	4	4	4	4	4
<i>Providencia alcalifaciens</i>	4	3	4	3	4	2	4	4	4	4	4	4
<i>Pseudomonas aeruginosa</i> ATCC 27853	4	3	4	4	4	3	4	3	4	4	4	4
<i>Vibrio cholerae</i>	4	4	4	4	4	3	4	3	4	4	4	4
<i>Vibrio parahaemolyticus</i>	4	4	4	4	3	4	4	2	4	4	4	4
<i>Aeromonas hydrophila</i>	4	4	4	4	4	4	4	3	4	4	4	4
<i>Bacillus subtilis</i> ATCC 6633	4	4	4	4	4	4	4	3	4	4	4	4
<i>Staphylococcus aureus</i> ATCC 25923	4	2	4	3	4	3	4	3	3	2	3	2
<i>Staphylococcus saprophyticus</i>	4	3	4	3	4	3	4	3	4	2	4	2
<i>β</i> -hemolytic <i>Streptococcus</i> group A	2	2	2	2	2	0	2	2	1	0	1	0
<i>α</i> -hemolytic <i>Streptococcus</i>	2	2	2	2	2	2	2	2	1	1	1	1
<i>Streptococcus</i> group D enterococcus	2	2	2	2	2	2	2	2	1	1	1	1

Note: 4 = no inhibition of bacterial cell growth
2 = 50 % inhibition of bacterial cell growth
0 = 100 % inhibition of bacterial cell growth

3 = 25 % inhibition of bacterial cell growth,
1 = 75 % inhibition of bacterial cell growth,

(2-, 5-, or 6-) on the rings of 3-substituted pyridines. The 3-substituted pyridines, **4c** (R=NAc₂), **5** (R=OH) and **6** (R=Br) having 1-adamantylthio group at 2-, 6- and 5- positions, respectively, exhibit complete inhibition against β -hemolytic *Streptococcus* group A at 30 μ g/mL. Thus, the sulfides **4c**, **5** and **6** are more active than the other compounds **4a**, **4b** and **4d**. However, the sulfide **4c** also displays antigrowth activity on *Edwardsiella tarda*, *Salmonella paratyphi* A, *Salmonella typhi*, *Enterobacter cloacae*, *Serratia rubidaca* and *Providencia alcalifaciens* at 30 μ g/mL. The growth of *Salmonella paratyphi* A is also inhibited by the sulfides **4a**, **4b** and **4d** at 30 μ g/mL. In addition, the sulfides **4a**, **5** and **6** at 30 μ g/mL are active against *Staphylococcus aureus* ATCC 25923. As a result, these pyridyl sulfides **4-6** represent a new group of antimicrobial agents.

It is interesting to note that *N*-acetyl-2-(1-adamantylthio)-3-acetamidopyridine **4c** exhibits activity against many microorganisms. However, bioactivity of sulfide of *N*-acetyl-3-acetamidopyridine has not been reported. Bioactivity of sulfur compounds of acetamidopyridines were reported, such as 2-methyl sulfide and sulfoxide of 3-acetamidopyridines showed antituberculous activity (Ozawa, 1957). In addition, 3-methyl sulfoxide of 2,6-diacetamidopyridine also produced antituberculous activity (Ozawa, 1957). Phenylthio analogs of aminopyridines such as 2-phenylthio-3- and 5-aminopyridines including 3-phenylthio-6-aminopyridine also showed antituberculous (Ozawa, 1957) activity. In the absence of thio moiety, *N*-acetyl-3-acetamidopyridine and its 2-isomer were reported to significantly inhibit the replication of influenza A virus (Pushkar-skaya et al., 1973) in a chick embryonic fibroblast culture at 200-300 μ g/mL. Other structural related compounds e.g. 3-, and 4-formamidopyridines as well as 4-acetamidopyridine and 4-propionamidopyridine were used as controlling birds (Reinert and Williams, 1969), and were less toxic to mammals. Salt of 3-aminopyridine such as 1-dodecyl-

methyl-3-dimethylamino pyridinium chloride showed strong antimicrobial activity and was a wide antimicrobial spectrum (Pernak and Branicka, 2003). When the 3-dimethylamino group was replaced by 3-hydroxy, the antimicrobial activity was lost. At this point, the sulfide **4c** is of interested target leads to be further developed in more details as therapeutic substances. Sulfides of 3-hydroxy, 3-acetoxy, 3-ethoxy and 3-bromopyridines have not been reported for any bioactivities. However, 3-acetoxy-2-pyridone was shown to be a potential antitumor agent (Hwang and Driscoll, 1979), displayed reproducible activity against murine P-388 lymphocytic leukemia. Antimicrobial activity of 3-hydroxypyridines has been reported. For example, 3-pyridinol is an active ingredient in antimicrobial composition (Tsuchida et al., 2007). 3-(2-Hydroxyphenyl) oxy-5-chloropyridine (Huang et al., 2007) is active against *Staphylococcus aureus*, *Streptococcus pneumoniae*, *Haemophilus influenzae* and *Escherichia coli* with MIC value of 15.7, ≤ 0.5 , 31.3 and 31.3 μ g/mL, respectively. In addition, an aqueous bamboo grass (*Sasa senamensis*) (Higo et al., 2007; Endo et al., 2006) extracts containing 3-pyridinol, acetic, formic, coumaric and ferulic acids (3.24, 18.62, 15.45, 2.74 and 0.97 mg/g, respectively) showed high antibacterial activity against *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* as well as antimutagenic activity.

Antioxidative assay

The sulfides **4-6** were evaluated for antioxidative activity using DPPH assay (Yen and Hsieh, 1997). The results (Table 2) show that the tested compounds **4-6** at 333.33 μ g/mL display weak antioxidative activity using vitamin E as a control, percentages of radical scavenging are in the range of 0.3-21.08 %. Antioxidative activity of 3-bromo-, 3-ethoxy-, 3-acetoxy- and *N*-acetyl-3-acetamidopyridines has not been reported. In this study, the corresponding 1-adamantylthio derivatives of such pyridines are **4d** and **6**, **4a**, **4b** and **4c**, respectively. Among the tested compounds, the 2-(1-

adamantylthio)-3-bromopyridine **4d** show highest activity, 21.08 % radical scavenging. The sulfide **5**, derivative of 3-pyridinol is almost inactive antioxidant (0.3 % radical scavenging). However, generally, 3-hydroxypyridines are active radical scavengers. For example, synthetic 3-hydroxypyridines bearing substituents at 2-, 4-, 5- and 6-positions showed antioxidative activity (Smirnov et al., 1999; Shabarchin et al., 1995; Lokhov et al., 1982) probably due to complexation of Fe^{2+} with ring N-atom or functional groups. 3-Hydroxypyridine derivatives (Tilekeeva et al., 1987) exhibited antihypoxic effect as active as sodium hydroxybutyrate, but less active than glutamine. This showed that 3-OH group was critical for activity, and substitution at 2-position was also important. From our results, it can be concluded that ring N-atom and 1-adamantylthio group may involve in the radical scavenging activity.

Table 2: Antioxidative activity of 1-adamantylthiopyridines **4-6**

Compounds (500 μg)	Radical scavenging (%)
4a	14.22
4b	7.03
4c	17.72
4d	21.08
5	0.30
6	17.07
α -Tocopherol (10 μg)	50.00

CONCLUSION

The investigated 1-adamantylthio analogs of 3-substituted (OEt, OAc, NAC_2 , Br, OH) pyridines **4-6** have shown to inhibit the growth of *Streptococci* at 30 $\mu\text{g}/\text{mL}$. Particularly, the compounds **4c**, **5** and **6** are the most active, displaying complete inhibition against β -hemolytic *Streptococcus* group A at very low concentration. The sulfide **4c** shows antigrowth activity against many microorganisms. Furthermore, 2-(1-adamantylthio)-3-substituted pyridines (OEt, OAc, NAC_2 and Br) **4a**, **4b**, **4c**, and **4d** selectively inhibit the growth of *Salmonella paratyphi*

A at 30 $\mu\text{g}/\text{mL}$. Additionally, the sulfides **4a**, **5** and **6** are active against *Staphylococcus aureus* ATCC 25923. All the tested sulfides show weak antioxidative activity. The sulfide **4d** is the most active antioxidant, 21.08 % radical scavenging activity. To evaluate for structure activity relationship, more derivatives are being made and tested for the antimicrobial and antioxidative activities. Other biological activities are under investigation.

Briefly, this study shows that 1-adamantylthio analogs of 3-substituted pyridines represent a new group of antimicrobial agents. In particular, the sulfide **4c** which is of great interest leads to be further developed for therapeutic applications. This result also paves a way to explore the synthesis and bioactivities of other related 1-adamantylthio derivatives.

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