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3-Alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium salts-based chiral ionic liquids

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ABSTRACT

A new group of imidazolium salt-based chiral ionic liquids have been prepared and characterized. The chiral ionic liquids obtained are stable in air, in contact with water and popular organic solvents. Their physicochemical properties, single-crystal X-ray structures, antimicrobial activities, and antielectrostatic effects have been determined. The chiral ionic liquids synthesized have proven to represent not only potential new solvents in asymmetric synthesis but also effective disinfectants with antielectrostatic activity.

1. Introduction

Ionic liquids are organic salts (built with an organic cation and organic or inorganic anion) that are generally liquid at ambient temperatures or melt below 100 °C. This general definition makes the cation–anion combinations enormous. The popularity of ionic liquids has resulted in the emergence of new groups such as room temperature ionic liquids,[1–4] energetic ionic liquids,[5–7] task-specificity ionic liquids,[8,9] and chiral ionic liquids,[10–16] among others.

There are a growing numbers of papers indicating that chiral ionic liquids may be useful in many areas of science and technology but the synthesis and use of these liquids are still in their infancy. Chiral pool material may be located in the cation or anion or in both the cation and anion. Obviously, the chirality arising from the starting material is kept in the ionic liquids. Numerous groups have selected strategies to prepare chiral ionic liquids from chiral starting materials including chiral cations by metathesis reactions. Cations can be constructed without modification[17,18] or with modification of the side chain.[19–21] We have already described chiral ionic liquids obtained directly from the natural chiral pool of (1*R*,2*S*,5*R*)-(−)-menthol based. Herein we report the synthesis and properties of new imidazolium chiral ionic liquids with two substituents in the imidazolium ring: (1*R*,2*S*,5*R*)-(−)-menthoxymethyl and alkoxymethyl.

2. Results and discussion

Several 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium salts were prepared (Scheme 1) and their properties were determined. First, the 1-alkoxymethylimidazoles shown in Table 1 were prepared in toluene, according to Scheme 2. In the first step, triethylamine was reacted with the appropriate chloromethyl alkyl ether to give (alkoxymethyl)triethylammonium chlorides. The second step consisted of the N-alkoxymethylation of the imidazole with the appropriate (alkoxymethyl)triethylammonium chloride. The 1-alkoxymethylimidazoles, which were formed in 74–82% yields, were distilled from the reaction mixture.

Quaternization was achieved using freshly distilled 1-alkoxymethylimidazole and distilled chloromethyl (1*R*,2*S*,5*R*)-(−)-menthyl ether, which was obtained from (1*R*,2*S*,5*R*)-(−)-menthol, an inexpensive and commercially available (−)-isomer. This ether is an excellent reagent for quaternization, but it is readily hydrolyzed to HCl, CH_2O, and menthol. As a result of this, these reactions should be conducted under strictly anhydrous conditions. Herein, a suitable solvent proved to be anhydrous hexane; from which the product precipitated.

Quaternization takes place immediately and proceeds readily at room temperature according to an S_N1 mechanism.[22–24] Table 2 contains a list of the chiral 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides **1**, which have been prepared by this procedure. The chlorides used as precursors of the new chiral ionic liquids were obtained in very good yields and their specific rotations were measured. The synthesized 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides **1**, which are presented in Table 2, are colorless oils, except for **1a** which is a low melting crystal chloride.

The purities of these salts were determined by a direct two-phase titration technique (EN ISO 2871-2: 1994) and ranged from 97.1% to 99.9% (Table 2). The remainder was essentially water, since the chlorides are hygroscopic. All of these precursors of chiral ionic liquids **1** are soluble at room temperature in acetone, chloroform,

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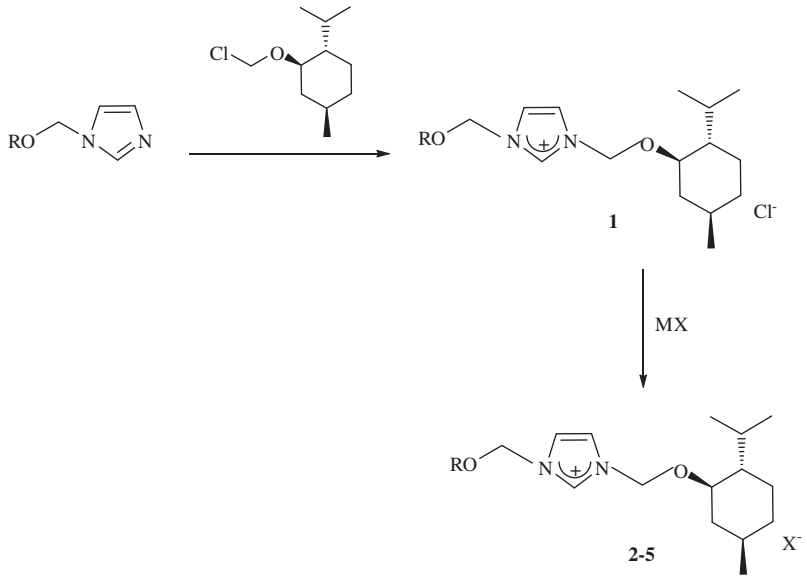


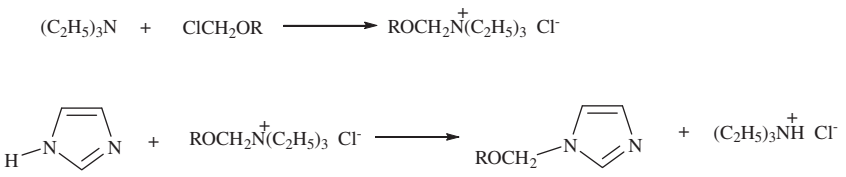
Scheme 1.

Table 1
1-Alkoxymethylimidazoles prepared

R	Yield (%)	Bp (°C)
C_2H_5	80	97–98 at 20 mmHg
C_3H_5	82	115–116 at 17 mmHg
C_4H_9	81	138–139 at 21 mmHg
C_5H_{11}	79	155–156 at 18 mmHg
C_6H_{13}	81	168–169 at 20 mmHg
C_7H_{15}	78	178–179 at 19 mmHg
C_8H_{17}	78	184–185 at 23 mmHg
C_9H_{19}	76	177–178 at 13 mmHg
$C_{10}H_{21}$	78	232–234 at 43 mmHg
$C_{11}H_{23}$	78	205–206 at 17 mmHg
$C_{12}H_{25}$	74	215–216 at 13 mmHg

DMF, THF, methanol, ethanol, 1-propanol, 2-propanol, and water. Aqueous solutions of chlorides **1d**–**1k** were observed to form a foam. At elevated temperatures, the chlorides **1** were found to dissolve in ethyl acetate but not in hexane or ether.

In the asymmetric part of the unit cell of **1a**, there are two cations, two chloride anions, and two water molecules. Interestingly, both symmetry-independent cations have quite similar geometries: bond lengths and bond angles but their conformations differ fundamentally. Figure 1 shows the anisotropic ellipsoid representation of one of the molecules, while Figure 2 shows the comparison of both molecules. It is evident that the orientation of substituents with respect to the imidazole ring plane is opposite by the comparison of the appropriate torsion angles. For instance, C2–N1–C11–O12 is 67.6(5)° in A and −77.9(4)° in B, C2–N3–C31–O32: −81.3(4)° in A, 73.8(4)°. The absolute values of the angles are



Scheme 2.

Table 2
3-Alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides **1**

Chloride	R	Yield (%)	Mp (°C)	Specific rotation[b] $[\alpha]_D^{20}$	Surfactant content (%)
1a	C_2H_5	98.5	55–58[a]	−137.6 (*c* 0.45)	99.8
1b	C_3H_5	98.0	Oil	−86.1 (*c* 0.9)	99.9
1c	C_4H_9	99.0	Oil	−59.7 (*c* 1.0)	99.8
1d	C_5H_{11}	97.5	Oil	−76.0 (*c* 1.7)	99.7
1e	C_6H_{13}	97.5	Oil	−71.6 (*c* 0.8)	98.5
1f	C_7H_{15}	96.0	Oil	−72.0 (*c* 0.7)	98.1
1g	C_8H_{17}	95.0	Oil	−67.6 (*c* 1.4)	98.4
1h	C_9H_{19}	94.5	Oil	−60.65 (*c* 0.9)	98.2
1i	$C_{10}H_{21}$	94.0	Oil	−59.9 (*c* 1.5)	97.5
1j	$C_{11}H_{23}$	95.0	Oil	−61.5 (*c* 1.2)	97.1
1k	$C_{12}H_{25}$	94.5	Oil	−65.2 (*c* 0.95)	97.9

[a] From ethyl acetate + acetone + ethanol; needles.
[b] *c* in ethanol.

quite similar but the signs are opposite, and as there are no symmetry elements which can reverse these signs, this means that there are two different conformers in the crystal structure.

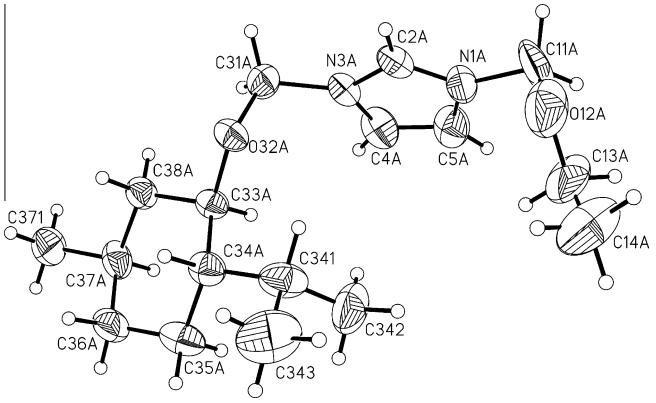


Figure 1. A perspective view of the cation A with the labeling scheme; the ellipsoids are drawn at the 33% probability level, hydrogen atoms are shown as spheres of arbitrary radii.[25]

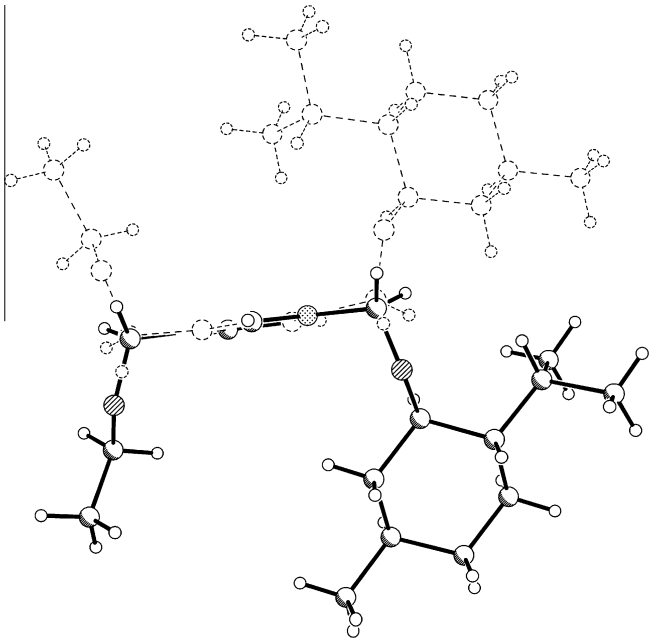


Figure 2. A comparison of the two symmetry-independent cations; the imidazolium planes were fitted one onto another.[25]

The cyclohexane rings are very close to an ideal chair conformation, with all substituents in equatorial positions (Table 3 lists the relevant torsion angles). In the crystal structure the chloride anions and water molecules make isolated helices (Fig. 3) around the two-fold screw axes along *y*. It should be noted that there are two types of helices; one made by O1W water and Cl1A, and the other by O2W and Cl1B (Fig. 4, Table 4). These helices have different types of screw features: one kind is left-handed and the other is right-handed. Hence, the same feature: the presence of pseudo-enantiomeric pairs, which were observed at the level of conformation of the cations, is also observed at the level of the crystal packing. The cations and ion-water helices are linked by electrostatic interactions and some weak, hydrogen-bond-type C–H···O, and C–H···Cl^- interactions (cf. Table 4).

The final synthesis step involves the metathesis of the chlorides with an appropriate inorganic salt in water or water/menthol solution. The ion exchange reaction proceeds smoothly, with satisfactory yield. All of the $[BF_4]^-$ **2**, $[ClO_4]^-$ **3**, and $[PF_6]^-$ **4** salts are solid and the majority of them crystallized easily to form plates or needles with a sharp melting point. All of the new 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium salts are insoluble in water. Thus, by changing the counter anion, all of the hydrophilic oil chlorides (with the exception **1a**) are transformed to hydrophobic crystal salts. All of the salts that were prepared would qualify as ionic liquids. Table 5 contains the melting points, specific rotations, and surfactant contents as estimated by a direct two-phase titration technique, using ethanol as the solvent for **2**–**4**. These chiral ionic liquids are not soluble in water, hexane,

Table 3
Selected torsion angles

	A	B
C2–N1–C11–O12	67.6(5)	−77.9(4)
C5–N1–C11–O12	−109.8(5)	100.4(5)
N1–C11–O12–C13	82.8(4)	−75.9(4)
C11–O12–C13–C14	175.2(3)	−174.6(3)
C2–N3–C31–O32	−81.3(4)	73.8(4)
C4–N3–C31–O32	93.6(4)	−100.9(4)
N3–C31–O32–C33	−89.2(3)	74.2(4)
C31–O32–C33–C34	158.1(3)	124.2(3)
C36–C35–C34–C341	177.1(3)	177.3(3)
C33–C38–C37–C371	178.3(3)	174.9(3)

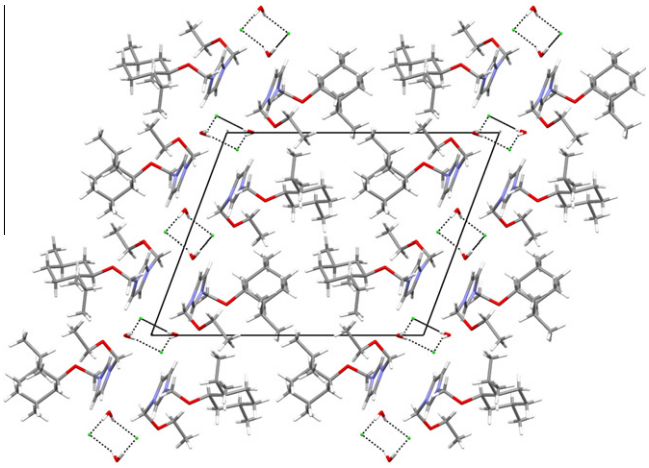


Figure 3. The crystal packing as seen along [0 1 0] direction.[26]

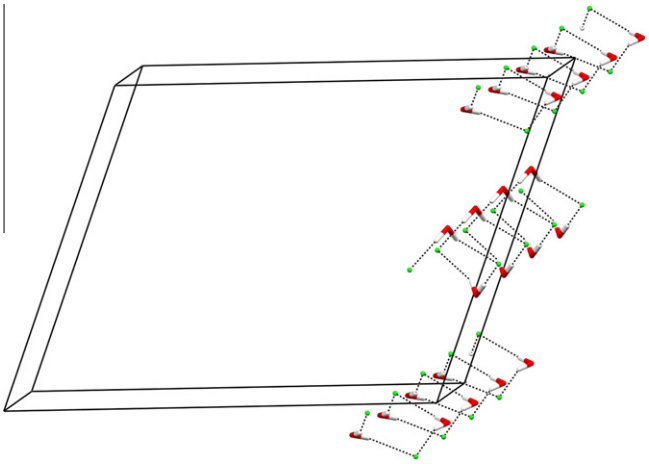


Figure 4. The neighboring hydrogen-bonded helices of different screw senses.[26]

Table 4
Hydrogen bond data (Å, °)

D	H	A	D–H	H···A	D···A	D–H···A
O1W	H1W1	Cl1A	0.85	2.33	3.144(2)	161
O1W	H1W2	Cl1A^{i}	0.85	2.30	3.113(2)	161
O2W	H2W2	Cl1B	0.85	2.36	3.201(3)	169
O2W	H2W2	Cl1B^{ii}	0.85	2.34	3.140(3)	156
C31A	H31A	O1W^{iii}	0.97	2.42	3.304(4)	151
C5A	H5A	O1W^{iv}	0.93	2.32	3.198(5)	158
C2B	H2B	Cl1B	0.93	2.56	3.389(4)	148

Symmetry codes: (i) $-x$, $1/2+y$, $-z$; (ii) $1-x$, $1/2+y$, $-z$; (iii) $1+x$, y, z; (iv) x, $y-1$, z.

and ether but are soluble in acetone, chloroform, DMF, THF, toluene, and low molecular weight alcohols. At elevated temperatures, salts **2**–**4** have been found to dissolve in ethyl acetate.

On the other hand, room temperature ionic liquids can be obtained by converting the anion from chloride into $[Tf_2N]^-$. Removal of chloride ions from the hydrophobic ionic liquid was carried out by rinsing them with distilled water. In Table 6, eleven chiral ionic liquids **5** are presented, including 8 which are room temperature ionic liquids. All room temperature ionic liquids are colorless liquids, which are non-volatile, non-flammable, and miscible with acetone, chloroform, ethyl acetate, DMF, THF, toluene, and low molecular weight alcohols. They are not soluble in hexane or ether and are immiscible with water. They are stable in air, and in contact with water and popular organic solvents. These chiral room temperature ionic liquids can be made anhydrous by heating at 80 °C in vacuo and storing them over P_4O_{10}. The water content was determined to be less than 500 ppm by coulometric Karl–Fisher titration. After 41 days, these anhydrous chiral ionic liquids absorbed water from the atmosphere to a maximum level of about 1.0%.

We noticed that 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium bis(trifluoromethanesulfonyl)imides absorbed less water than the analogous alkylimidazolium bis(trifluoromethanesulfonyl)imides.[24] For example after 41 days, 1-(1*R*,2*S*,5*R*)-(−)-menthoxymethyl-3-octylimidazolium $[Tf_2N]^-$ absorbed 1.51% of water whereas its corresponding 1-(1*R*,2*S*,5*R*)-(−)-menthoxymethyl-3-hexyloxymethylimidazolium $[Tf_2N]^-$ **5e** just 0.89%, which is about 41% less.

The specific rotation, density, viscosity, thermal degradation, and glass transition temperature for anhydrous and chloride-free room temperature ionic liquids have been measured. The results are presented in Table 6. The chiral ionic liquids are more dense than water (1.29–1.15 g mL^{-1}) and decrease with increasing molar mass. Figure 5 shows that there is a linear relationship between the molar volume (calculated from the equation $V_m = M/d$ where d = density) and the number of carbon atoms in the alkoxy group. The density of the dry chiral ionic liquids studied is weakly temperature dependent. As the temperature is varied from 35 to 45 °C, the density decreased by about 3%. Ionic liquids are inherently

Table 5
3-Alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium salts **2**–**4**

Chiral ionic liquids	R	Anion	Yield (%)	Mp (°C)	Specific rotation[d] $[\alpha]_D^{20}$	Surfactant content (%)
2a	C_2H_5	$[BF_4]^-$	99.5	80–82[a]	−83.7 (*c* 0.6)	99.1
2b	C_3H_5	$[BF_4]^-$	99.5	78–79[a]	−98.3 (*c* 0.9)	99.7
2c	C_4H_9	$[BF_4]^-$	99.5	91–92[b]	−104.9 (*c* 0.6)	99.7
2d	C_5H_{11}	$[BF_4]^-$	99.0	93–95[b]	−75.2 (*c* 0.7)	98.3
2e	C_6H_{13}	$[BF_4]^-$	99.0	72–74[b]	−78.6 (*c* 0.6)	98.5
2f	C_7H_{15}	$[BF_4]^-$	98.0	58–61[c]	−66.2 (*c* 1.5)	99.5
2g	C_8H_{17}	$[BF_4]^-$	98.5	46–47[c]	−62.1 (*c* 1.6)	99.1
2h	C_9H_{19}	$[BF_4]^-$	98.5	48–49[c]	−67.6 (*c* 1.4)	99.3
2i	$C_{10}H_{21}$	$[BF_4]^-$	99.0	32–33	−55.4 (*c* 1.1)	97.2
2j	$C_{11}H_{23}$	$[BF_4]^-$	97.0	36–38	−54.3 (*c* 1.9)	98.5
2k	$C_{12}H_{25}$	$[BF_4]^-$	87.5	47–48[c]	−52.6 (*c* 1.4)	98.1
3	CH_3	$[ClO_4]^-$	99.0	63–64[a]	−80.8 (*c* 0.6)	99.1
4	CH_3	$[PF_6]^-$	99.5	76–81[a]	−75.1 (*c* 0.5)	99.6

[a] From water + ethanol; needles.
[b] From water + 2-propanol; needles.
[c] From water + 2-propanol; plates.
[d] *c* in ethanol.

Table 6
3-Alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium bis(trifluoromethanesulfonyl)imides **5**

Chiral ionic liquids	R	Yield (%)	Mp (°C)	Specific rotation[b] $[\alpha]_D^{20}$	Density[c] (g mL^{-1})	Viscosity[c] (mm^2/s)	T_{onset}[d] (°C)	T_g[e] (°C)
5a	C_2H_5	99.5	45–46[a]	−55.2 (*c* 1.1)	—	—	—	—
5b	C_3H_5	99.0	58–59[a]	−54.1 (*c* 0.7)	—	—	—	—
5c	C_4H_9	99.0	33–35	−51.2 (*c* 0.95)	—	—	—	—
5d	C_5H_{11}	93.5	—	−49.3 (*c* 1.1)	1.29	600	230	−60.6
5e	C_6H_{13}	91.5	—	−47.6 (*c* 0.9)	1.27	612	225	−61.2
5f	C_7H_{15}	90.0	—	−45.7 (*c* 1.1)	1.25	630	225	−61.9
5g	C_8H_{17}	92.0	—	−44.4 (*c* 1.2)	1.23	666	230	−61.8
5h	C_9H_{19}	92.5	—	−41.3 (*c* 1.4)	1.21	703	230	−63.5
5i	$C_{10}H_{21}$	95.5	—	−40.7 (*c* 2.2)	1.18	728	230	−66.4
5j	$C_{11}H_{23}$	93.0	—	−34.4 (*c* 1.1)	1.16	756	230	−67.4
5k	$C_{12}H_{25}$	96.0	—	−32.1 (*c* 1.0)	1.15	779	230	−68.2

[a] From water + 2-propanol; plates.
[b] *c* in ethanol.
[c] At 35 °C.
[d] Decomposition temperature determined from onset to 50% mass loss.
[e] Glass transition temperature.

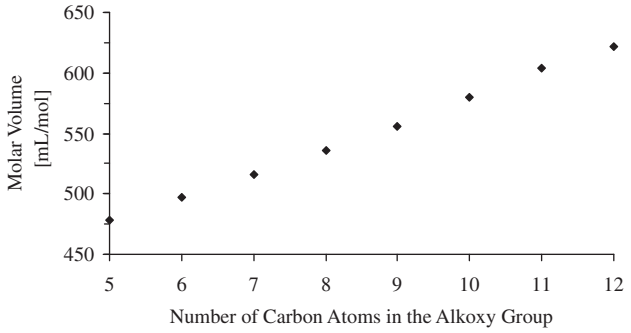


Figure 5. Molar volume as a function of the number of carbon atoms in the alkoxy group in chiral ionic liquids **5**.

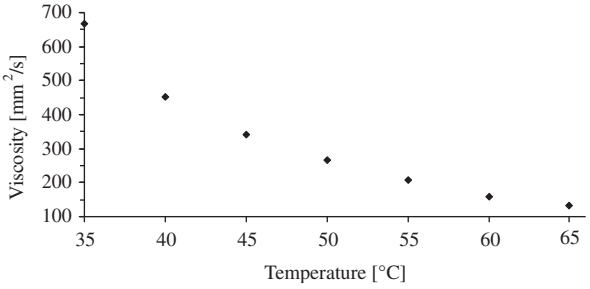


Figure 6. Viscosity of dry chiral ionic liquid **5g** as a function of increasing temperature.

much more viscous than popular organic solvents. Increases in molar mass were accompanied by increases in viscosity, while increasing the temperature resulted in a decrease in viscosity, as shown in Figure 6 for **5g**.

All room temperature ionic liquids have shown no measurable vapor pressure. The thermal properties for the chiral ionic liquids **5** were established by DSC and TGA analyses. The glass transition temperatures (T_g) are very low and oscillate between −60 °C and −68 °C (depends of number of carbon atoms in the alkoxymethylimidazolium substituent). All synthesized liquids $[Tf_2N]^-$—**5d–k** were thermally stable up to ca. 230 °C (a similar thermal stability was observed earlier for 1-alkyl-3-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium $[Tf_2N]^-$[24]). The $[Tf_2N]^-$ **5** could not be estimated by a direct two-phase titration technique, because the $[Tf_2N]^-$ anion in this salt is not interchangeable.

The synthesized salts were characterized by ^{1}H NMR, ^{13}C NMR, and elemental analysis. Protons of the H_2C13 group, which links the two rings, appear in the spectrum in the form of two doublets. The manifestation of the diasteroisotopic protons was typical for all the studied salts, for example, for **1a** 5.74 and 5.93 (d, J = 10.4 Hz, 2H, AB system, H13).

The ^{1}H NMR spectra of the chlorides and the other salts indicate different chemical shifts particularly for the imidazolium ring protons and methylene protons adjacent to the oxygen atoms. Table 7 shows a comparison of the ^{1}H NMR spectra of the 3-ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chloride **1a** with the following $[BF_4]^-$ **2a**, $[ClO_4]^-$ **3**, $[PF_6]^-$ **4**, and $[NTf_2]^-$ **5a**. A strong anion effect was evident. Substitution of the $[Cl]^-$ anion with the other anions named above resulted in changes in the imidazolium ring electron density. A shift of nearly 3 ppm between the $[Cl]^-$ salt and the $[PF_6]^-$ salt in the case of the HC12 group shows the dramatic effect of the change in electron density resulting from changing the anion. Similar results were noticed earlier for 1-alkylimidazolium salts,[24] but a shift of 2 ppm for the same anions (in the same conditions) has been observed there.

Comparing the differences between values of the chemical shifts, the anions can be ordered according to their increasing shielding capacities as follows: $[Cl]^- < [ClO_4]^- < [BF_4]^- < [Tf_2N]^- < [PF_6]^-$.

The most pronounced shielding abilities were noted for the $[PF_6]^-$ and $[Tf_2N]^-$ anions.

Additionally, the ^{13}C NMR spectra indicated notable differences in the chemical shifts depending on the anion used. These shifts were most evident for carbon C12. For example: the difference between 3-ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chloride **1a** and its corresponding $[NTf_2]^-$ **5a** is 2.6 ppm. Significant differences in the chemical shifts were also observed for carbon C9. In this case, the differences between the corresponding $[Cl]^-$ and $[PF_6]^-$ salts achieve nearly 1 ppm.

The antielectrostatic effect was determined following the criteria listed in Table 8. The antielectrostatic effect of salts **1**–**5** and **7** reflects two quantities: the surface resistance and the half-charge decay time. The surface resistance R_s was calculated from the formula:

$$R_s = \frac{Ul}{is}[\Omega]$$

where U is the applied voltage (U = 100 V), l is the length of the electrode (l = 100 mm), i is the measured current intensity, and s is the distance between the electrodes (s = 10 mm).

The half-charge decay time has been calculated as follows:

$$\tau_{1/2} = \sqrt{\frac{\tau_+^2 + \tau_-^2}{2}}[s]$$

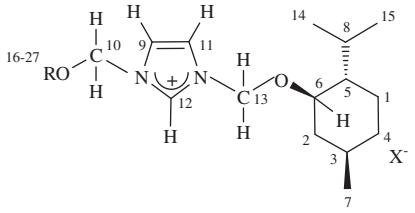
where τ_+ and τ_- are the mean half decay times of positive and negative charges, respectively.

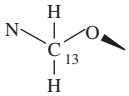
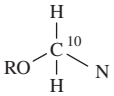
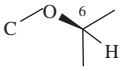
The reported antielectrostatic effects are presented in Table 9. All synthesized chlorides **1a**–**1k** demonstrated excellent antielectrostatic effects. Their ability to drain the surface charge reflected their strong hygroscopic properties. On the other hand, the $[BF_4]^-$, $[ClO_4]^-$ and $[PF_6]^-$ salts lost their capacity to drain surface electric charge, while, $[Tf_2N]^-$ salts **5a**–**5k**, even if strongly hydrophobic, demonstrated a strong tendency to drain the surface charge. Bis(trifluoromethanesulfonyl)imides penetrate the polymer surface because they have unique solvent capabilities and are better able to discharge the electric charge.

The chiral chlorides prepared were tested for antimicrobial activity against rods, cocci, and fungi. The minimum inhibitory concentration (MIC) and minimum bactericidal or fungicidal concentration (MBC or MFC) determined for chiral chlorides **1h** and **1i** are given in Table 10. Additionally, MIC, MBC, and MFC values are presented for benzalkonium chloride (BAC, in which alkyl represents a mixture of alkyls from C_8H_{17} to $C_{18}H_{37}$).

Our previous biological research on 3-alkyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides has given us the best results for nonyl, decyl, undecyl, and dodecyl substituents.[24] Those chlorides should be regarded as superactive. This is why in order to check the antimicrobial activities of 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides we have selected chlorides with nonylmethyl **1h** and decylmethyl **1i** substituents. Similarly as for alkylimidazolium chlorides, these two alkoxymethylimidazolium chlorides **1h** and **1i** should be regarded as superactive. The MIC and MBC values of each alkoxymethylimidazolium chloride are comparable, indicating not only a strong biostatic effect but also high biocidal activity. Furthermore, the activities for the majority of examples were higher than the ones shown by BAC and these alkoxymethylimidazolium chlorides broaden the range of activities against microbes. The results achieved are in agreement with the literature data. Both alkyl[27] and alkoxymethyl[28,29] substituents in the imidazolium ring influenced the antimicrobial activity.

Table 7
The chemical shifts[a] in ^{1}H NMR



Salt	Anion	Characteristic protons					
							
1a	$[Cl]^-$	11.88 (t)	7.66 (t)	7.58 (t)	5.74 and 5.93 (d)	5.85 (s)	3.41 (td)
2a	$[BF_4]^-$	9.12 (m)	7.55 (t)	7.53 (t)	5.62 (m)		3.41 (td)
3	$[ClO_4]^-$	9.24 (m)	7.56 (t)		5.65 (m)		3.37 (td)
4	$[PF_6]^-$	8.92 (m)	7.46 (m)	7.45 (m)	5.58 (m)		3.32 (td)
5a	$[NTf_2]^-$	9.05 (m)	7.57 (m)		5.57 i 5.64 (d)	5.58 (s)	3.31 (td)

[a] Shift in ppm and *J* in Hertz.

Table 8
Criteria for the estimation of the antielectrostatic effect based on the surface resistance R_s [Ω] and half-charge decay time $\tau_{1/2}$ [s]

log R_s	$\tau_{1/2}$	Antielectrostatic effect
<9	<0.5	Excellent
9–9.99	0.51–2	Very good
10–10.99	2.1–10	Good
11–11.99	10.1–100	Sufficient
12–12.99	>100	Insufficient
>13	>600	Lack of antielectrostatic properties

Table 9
Surface resistance R_s [Ω], half-charge decay time $\tau_{1/2}$ [s], and antielectrostatic effects of the salts prepared

Salt	log R_s	$\tau_{1/2}$	Effect	Salt	log R_s	$\tau_{1/2}$	Effect
1a	7.9	0.2	Excellent	**2h**	12.9	>100	Insufficient
1b	7.5	0.2	Excellent	**2i**	12.8	>100	Insufficient
1c	7.3	0.25	Excellent	**2j**	12.9	>100	Insufficient
1d	7.0	0.25	Excellent	**2k**	12.9	>100	Insufficient
1e	7.0	0.2	Excellent	**3**	>13	>600	Lack
1f	7.3	0.2	Excellent	**4**	>13	>600	Lack
1g	7.3	0.2	Excellent	**5a**	9.9	0.8	Very good
1h	7.3	0.2	Excellent	**5b**	9.5	0.9	Very good
1i	7.3	0.2	Excellent	**5c**	9.8	1.0	Very good
1j	7.3	0.2	Excellent	**5d**	9.7	1.0	Very good
1k	7.5	0.25	Excellent	**5e**	9.5	1.0	Very good
2a	>13	>600	Lack	**5f**	9.3	0.2	Very good
2b	>13	>600	Lack	**5g**	8.9	0.25	Excellent
2c	>13	>600	Lack	**5h**	8.9	0.2	Excellent
2d	>13	>600	Lack	**5i**	8.8	0.2	Excellent
2e	12.3	73	Insufficient	**5j**	8.8	0.25	Excellent
2f	12.8	85	Insufficient	**5k**	8.9	0.2	Excellent
2g	12.8	95	Insufficient				

3. Conclusion

By applying Menschutkin reaction conditions, a number of chiral alkoxymethylimidazolium-based ionic liquids were synthesized, in which the chirality originates from the cation, which was derivatized from the chiral pool of (1*R*,2*S*,5*R*)-(−)-menthol. The type of anion determines the consistency and hygroscopic character of the salt. Salts with a $[Tf_2N]$ anion are room temperature ionic liquids. The important attributes of the chiral ionic liquids include not only negligible vapor pressure, compatibility with various organic compounds, ease of separation in aqueous-liquid separations, antielectrostatic and antimicrobial activities but also their potential application in asymmetric synthesis.

The proposed method of the synthesis of chiral ionic liquids with chirality on the cation is effective and provides the possibility to use chiral alcohols. The introduction of oxygen atoms to substituents causes a fall in the thermal stability of synthesized salts but at the same time improves susceptibility to biodegradation and hydrolysis. The synthesized high biological active chlorides are potential substitutes for benzalkonium chloride, which is used for mouthwash.

Further research to fully evaluate the potential of these new chiral compounds in synthetic and analytical applications is currently ongoing in our laboratories. We are currently studying the use of chiral ionic liquids as solvents, as well as chiral catalysts for a variety of asymmetric reactions. We envision that these new ionic liquids will serve as effective solvents, especially since a successful example in this area has already been reported in the literature for a similar compound, with a (1*R*,2*S*,5*R*)-(−)-menthoxymethyl substituent in a chiral ionic liquid.[30] In 2005, Ding et al. reported that several chiral ionic liquids have been successfully used as chiral solvents in the photoisomerization of dibenzobicyclo[2.2.2]octatriene diacid to induce enantiomeric excesses. The observed enantioselectivities, although modest in an absolute sense, are among the highest achieved for unimolecular photochemical reactions by the use of a chiral environment.

4. Experimental

4.1. General methods

^{1}H NMR spectra were recorded on a Mercury Gemini 300 spectrometer at 300 MHz with tetramethylsilane as the standard; ^{13}C NMR spectra were recorded on the same instrument at 75 MHz. Two-dimensional spectra were performed using standard pulse sequences from the Bruker Drx puls library at 600 MHz.

Elemental analyses were performed at Poznań Adam Mickiewicz University. Melting points were determined by using an electrothermal digital-melting-point apparatus model JA 9100. A Mettler Toledo DA 110 M scale was used for the mass/density measurements. A Mikro-Ostwald-Viskosimeter was used to viscosity

Table 10
MIC and MBC values (μM) of 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides **1h** and **1i**

Strain		Chloride			Strain		Chloride		
		1h	**1i**	**BAC**[a]			**1h**	**1i**	**BAC**
M. luteus	MIC	1.2	0.5	1.4	*S. marcescens*	MIC	145	282	175
	MBC	19	4.5	11		MBC	145	282	175
S. aureus	MIC	0.2	0.2	2.8	*P. vulgaris*	MIC	37	18	88
	MBC	0.5	0.5	23		MBC	37	18	88
S. epidermidis	MIC	2.3	1.1	1.4	*P. aeruginosa*	MIC	145	282	175
	MBC	2.3	4.5	5.6		MBC	145	565	175
E. faecium	MIC	4.7	0.2	5.6	*B. subtilis*	MIC	2.3	1.1	2.8
	MBC	19	9	23		MBC	2.3	2.3	2.8
M. catarrhalis	MIC	1.2	0.5	0.6	*C. albicans*	MIC	19	4.5	11
	MBC	1.2	2.3	1.4		MFC	72	36	88
E. coli	MIC	1.2	0.5	2.8	*R. rubra*	MIC	9	9	23
	MBC	2.3	0.5	2.8		MFC	19	18	88

[a] Benzalkonium chloride.

measurements. Optical rotations were measured with a Perkin Elmer 243B polarimeter. The water content was determined by using an Aquastar volumetric Karl-Fischer titration with Composite 5 solution as the titrant and anhydrous methanol as solvent.

4.2. Syntheses

Chloromethyl (1*R*,2*S*,5*R*)-(−)-menthyl ether was prepared by passing HCl through a mixture of formaldehyde and (1*R*,2*S*,5*R*)-(−)-menthol.[22] Chloromethyl alkyl ethers were prepared by passing HCl through a mixture of formaldehyde and the appropriate alcohol. Imidazole was freshly recrystallized from benzene; mp 90–91 °C.

4.2.1. Preparation of 1-alkoxymethylimidazoles

The appropriate chloromethyl alkyl ether (0.05 mol) was slowly added to a stirred anhydrous solution of triethylamine (5.06 g, 0.05 mol) in toluene (50 mL), and stirring was continued at 80 °C for 15 min. Imidazole (3.4 g, 0.05 mol) was then added. After 30 min, the mixture was refluxed. After cooling to room temperature, the triethylamine hydrochloride produced was filtered off and the toluene was evaporated. The product was purified by vacuum distillation.

4.2.2. General procedure for quaternization

Chloromethyl (1*R*,2*S*,5*R*)-(−)-menthyl ether (0.03 mol) was added dropwise into a round-bottomed flask, which contained a vigorously stirred mixture of 30 mL of dry hexane and 0.03 mol of freshly distilled 1-alkoxymethylimidazole. The reaction mixture was stirred at room temperature for 60 min. After 120 min, the phases were separated and the crude product was washed with dry hexane (3 × 30 mL). The volatile materials were removed under reduced pressure at 60 °C overnight.

4.2.2.1. 3-Ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chloride 1a. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 9H, Ha-4, H7, H14 or H15, Ha-2 and Ha-1), 1.25 (m, 4H, H5 and H17), 1.46 (m, 1H, H3), 1.63 (m, 2H, Hb-1 and Hb-4), 1.97 (sept d, $J^{1,3}$ = 7.1 Hz, $J^{1,2}$ = 2.5 Hz, 1H, H8), 2.08 (m, 1H, Hb-2), 3.41 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.68 (q, J = 7.1 Hz, 2H, H16), 5.85 (s, 2H, H10), 5.74 and 5.93 (d, J = 10.4 Hz, 2H, AB system, H13), 7.58 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.6 Hz, 1H, H11), 7.66 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.6 Hz, 1H, H9), 11.88 (t, J = 1.4 Hz, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.6 (C17), 15.4 (C14 or C15), 20.8 (C7), 22.0 (C14 or C15), 22.6 (C1), 25.3 (C8), 31.0 (C3), 33.8 (C4), 40.2 (C2), 47.5 (C5), 66.0 (C16), 76.6 (C6), 79.0 (C10), 79.8 (C13), 121.4 (C11), 122.5 (C9), 137.6 (C12). Elemental Anal. Calcd for $C_{17}H_{31}ClN_2O_2$ (330.5): C, 61.69; H, 9.46; N, 8.47. Found: C, 61.39; H, 9.55; N, 8.59.

4.2.2.2. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-propoxymethylimidazolium chloride 1b. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.52 (d, J = 6.9 Hz, 3H, H14 or H15), 0.90 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H18), 1.27 (m, 1H, H5), 1.44 (m, 1H, H3), 1.63 (m, 3H, Hb-1 and H17), 2.10 (m, 3H, Hb-4, H8 and Hb-2), 3.51 (m, 3H, H6 and H16), 5.77 (m, 4H, H10 and H13), 9.42 (m, 1H, H11), 10.12 (t, $J^{1,2}$ = 1.8 Hz, $J^{2,1'}$ = 1.7 Hz, 1H, H9), 10.87 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 10.3 (C18), 15.6 (C14 or C15), 20.9 (C7), 22.1 (C14 or C15), 22.4 (C1), 22.8 (C17), 25.4 (C8), 31.15 (C3), 34.0 (C4), 40.4 (C2), 47.8 (C5), 72.25 (C16), 76.6 (C6), 79.5 (C10), 80.0 (C13), 121.2 (C11), 136.1 (C9), 137.7 (C12). Elemental Anal. Calcd for $C_{18}H_{33}ClN_2O_2$ (344.98): C, 62.66; H, 9.66; N, 8.12. Found: C, 62.84; H, 9.71; N, 7.92.

4.2.2.3. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-pentyloxymethylimidazolium chloride 1d. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 6.9 Hz, 3H, H14 or H15), 0.90 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H20), 1,26 (m, 5H, H5, H18 and H19), 1.42 (m, 1H, H3), 1.59 (m, 4H, Hb-1, Hb-4 and H17), 1.97 (sept d, $J^{1,3}$ = 6.9 Hz, $J^{1,2}$ = 2.5 Hz, 1H, H8), 2.10 (d, J = 11.8 Hz, 1H, Hb-2), 3.41 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.59 (m, 2H, H16), 5.84 (s, 2H, H10), 5.76 and 5.94 (m, 2H, H13), 7.71 (m, 1H, H11), 7.75 (m, 1H, H9), 10.74 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 13.5 (C20), 15.2 (C14 or C15), 20.6 (C7), 21.8 (C19), 21.9 (C14 or C15), 22.4 (C1), 25.0 (C8), 27.6 (C18), 28.5 (C17), 30.7 (C3), 33.6 (C4), 40.0 (C2), 47.3 (C5), 70.3 (C16), 76.6 (C6), 79.0 (C10), 79.4 (C13), 121.4 (C11), 121.6 (C9), 137.1 (C12). Elemental Anal. Calcd for $C_{20}H_{37}ClN_2O_2$ (330.5): C, 64.39; H, 10.02; N, 7.51. Found: C, 64.48; H, 10.13; N, 7.35.

4.2.3. General procedure for ion exchange

Chiral 3-alkoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium chlorides were dissolved in water or methanol and a saturated aqueous stoichiometric solution of $NaBF_4$, $NaClO_4$, KPF_6 or Tf_2NLi was added. The reaction mixture was stirred at room temperature (for 24 h) producing a heterogeneous mixture. The crude product was separated and washed with distilled water until the chloride ions were no longer detected using $AgNO_3$. The salt obtained was dried at 80 °C for 24 h in vacuo. In the cases of water-soluble salts, the water was first evaporated and the remnants were dissolved in dry acetone. The inorganic salt was separated and the solvent was evaporated to give the product.

4.2.3.1. 3-Ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium tetrafluoroborate 2a. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51

(d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 9H, Ha-4, H7, H14 or H15, Ha-2 and Ha-1), 1.23 (m, 4H, H5 and H17), 1.42 (m, 1H, H3), 1.62 (m, 2H, Hb-1 and Hb-4), 1.97 (m, 2H, H8 and Hb-2), 3.41 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.62 (q, J = 7.1 Hz, 2H, H16), 5.62 (m, 4H, H10 and H13), 7.53 (t, J = 1.6 Hz, 1H, H11), 7.55 (t, J = 1.6 Hz, 1H, H9), 9.12 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.7 (C17), 15.4 (C14 or C15), 20.9 (C7), 22.1 (C14 or C15), 22.8 (C1), 25.4 (C8), 31.0 (C3), 34.0 (C4), 40.2 (C2), 47.7 (C5), 66.1 (C16), 76.6 (C6), 79.2 (C10), 79.9 (C13), 121.6 (C11), 121.8 (C9), 135.9 (C12). Elemental Anal. Calcd for $C_{17}H_{31}BF_4N_2O_2$ (382.3): C, 53.41; H, 8.19; N, 7.33. Found: C, 53.10; H, 8.27; N, 7.40.

4.2.3.2. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-propoxymethylimidazolium tetrafluoroborate 2b. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.54 (d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H18), 1.26 (m, 1H, H5), 1.43 (m, 1H, H3), 1.61 (m, 4H, Hb-1, Hb-4 and H17), 2.01 (m, 2H, H8 and Hb-2), 3.36 (td, $J^{1,3}$ = 10.5 Hz, $J^{1,2}$ = 4.2 Hz, 1H, H6), 3.51 (m, 2H, H16), 5.63 (m, 4H, H10 and H13), 7.51 (m, 2H, H11 and H9), 9.19 (t, J = 1.6 Hz, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 10.3 (C18), 15.7 (C14 or C15), 21.0 (C7), 22.1 (C14 or C15), 22.45 (C1), 22.8 (C17), 25.5 (C8), 31.1 (C3), 34.1 (C4), 40.2 (C2), 47.9 (C5), 72.2 (C16), 76.6 (C6), 79.6 (C10), 80.2 (C13), 121.5 (C11), 121.7 (C9), 136.4 (C12). Elemental Anal. Calcd for $C_{18}H_{33}BF_4N_2O_2$ (396.33): C, 54.54; H, 8.41; N, 7.07. Found: C, 54.23; H, 8.57; N, 7.15.

4.2.3.3. 3-Butoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium tetrafluoroborate 2c. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 7.0 Hz, 3H, H14 or H15), 0.89 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H19), 1.33 (m, 3H, H5 and H18), 1.60 (m, 4H, H3, Hb-1 and H17), 1.91 (m, 1H, Hb-4), 1.98 (m, 2H, H8 and Hb-2), 3.36 (td, $J^{1,3}$ = 10.5 Hz, $J^{1,2}$ = 4.2 Hz, 1H, H6), 3.55 (t, J = 6.4 Hz, 2H, H16), 5.63 (m, 4H, H10 and H13), 7.48 (m, 2H, H11 and H9), 9.16 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 13.7 (C19), 15.5 (C14 or C15), 19.0 (C7), 20.95 (C18), 22.1 (C14 or C15), 22.8 (C1), 25.5 (C8), 31.0 (C17), 31.2 (C3), 34.1 (C4), 40.2 (C2), 47.8 (C5), 70.5 (C16), 76.6 (C6), 79.6 (C10), 80.0 (C13), 121.4 (C11), 121.8 (C9), 136.3 (C12). Elemental Anal. Calcd for $C_{19}H_{35}BF_4N_2O_2$ (410.36): C, 55.61; H, 8.61; N, 6.83. Found: C, 55.30; H, 8.82; N, 6.79.

4.2.3.4. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-pentyloxymethylimidazolium tetrafluoroborate 2d. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.50 (d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H20), 1.25 (m, 5H, H5, H18 and H19), 1.41 (m, 1H, H3), 1.59 (m, 4H, Hb-1, Hb-4 and H17), 1.98 (m, 2H, H8 and Hb-2), 3.35 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.53 (t, J = 6.6 Hz, 2H, H16), 5.59 (s, 2H, H10), 5.58 and 5.67 (d, J = 10.7 Hz, 2H, AB system, H13), 7.50 (m, 1H, H11), 7.51 (m, 1H, H9), 9.1 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.0 (C20), 15.5 (C14 or C15), 21.0 (C7), 22.1 (C19), 22.4 (C14 or C15), 22.8 (C1), 25.4 (C8), 28.0 (C18), 28.8 (C17), 31.0 (C3), 34.0 (C4), 40.2 (C2), 47.7 (C5), 70.7 (C16), 76.6 (C6), 79.5 (C10), 79.9 (C13), 121.3 (C11), 121.7 (C9), 136.0 (C12). Elemental Anal. Calcd for $C_{20}H_{37}BF_4N_2O_2$ (424.39): C, 56.60; H, 8.81; N, 6.60. Found: C, 56.37; H, 8.72; N, 6.77.

4.2.3.5. 3-Hexyloxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium tetrafluoroborate 2e. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 7.0 Hz, 3H, H14 or H15), 0.90 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H21), 1.27 (m, 7H, H5, H18, H19 and H20), 1.62 (m, 5H, H3, Hb-1, Hb-4 and H17), 1.99 (m, 2H, H8 and Hb-2), 3.35 (td, $J^{1,3}$ = 10.55 Hz, $J^{1,2}$ = 4.3 Hz, 1H, H6), 3.53 (t, J = 6.5 Hz, 2H, H16), 5.62 (m, 4H, H10 and H13), 7.47 (m, 2H, H11 and H9), 9.16 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.0 (C21), 15.5 (C14 or C15), 21.0 (C7), 22.1 (C20), 22.5 (C14 or C15), 22.8 (C1), 25.5 (C8), 25.55 (C19), 29.1 (C18), 31.0 (C3), 31.5 (C17), 34.1 (C4), 40.2 (C2), 47.8 (C5), 70.8 (C16), 76.6 (C6), 79.65 (C10), 80.0 (C13), 121.3 (C11), 121.7 (C9), 136.3 (C12). Elemental Anal. Calcd for $C_{21}H_{39}BF_4N_2O_2$ (438.42): C, 57.53; H, 8.98; N, 6.39. Found: C, 57.27; H, 9.19; N, 6.48.

4.2.3.6. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-octyloxymethylimidazolium tetrafluoroborate 2g. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 7.0 Hz, 3H, H14 or H15), 0.90 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H23), 1.25 (m, 11H, H5, H18, H19, H20, H21 and H22), 1.39 (m, 1H, H3), 1.59 (m, 4H, Hb-1, Hb-4 and H17), 1.99 (m, 2H, H8 and Hb-2), 3.35 (td, $J^{1,3}$ = 10.5 Hz, $J^{1,2}$ = 4.3 Hz, 1H, H6), 3.54 (t, $J^{1,2}$ = 6.3 Hz, 2H, H16), 5.62 (m, 4H, H10 and H13), 7.47 (m, 2H, H11 and H9), 9.16 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.1 (C23), 15.5 (C14 or C15), 20.95 (C7), 22.1 (C14 or C15), 22.6 (C1), 22.8 (C22), 25.5 (C8), 25.9 (C21), 29.2 (C20), 29.25 (C19), 29.3 (C18), 31.0 (C3), 31.8 (C17), 34.1 (C4), 40.2 (C2), 47.9 (C5), 70.9 (C16), 76.6 (C6), 79.6 (C10), 80.0 (C13), 121.5 (C11), 121.75 (C9), 136.3 (C12). Elemental Anal. Calcd for $C_{23}H_{43}BF_4N_2O_2$ (466.48): C, 59.21; H, 9.31; N, 6.01. Found: C, 58.90; H, 9.44; N, 6.12.

4.2.3.7. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-nonyloxymethylimidazolium tetrafluoroborate 2h. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.50 (d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H24), 1.25 (m, 13H, H5, H18, H19, H20, H21, H22 and H23), 1.38 (m, 1H, H3), 1.58 (m, 4H, Hb-1, Hb-4 and H17), 1.99 (m, 2H, H8 and Hb-2), 3.35 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.53 (t, $J^{1,2}$ = 6.6 Hz, 2H, H16), 5.64 (m, 4H, H10 and H13), 7.57 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.4 Hz, 1H, H11), 7.58 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.4 Hz, 1H, H9), 9.14 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 13.9 (C24), 15.2 (C14 or C15), 20.7 (C7), 21.9 (C14 or C15), 22.4 (C1), 22.6 (C23), 25.1 (C8), 25.6 (C22), 29.0 (C21), 29.05 (C20), 29.1 (C19), 29.3 (C18), 30.8 (C3), 31.6 (C17), 33.8 (C4), 39.9 (C2), 47.5 (C5), 70.5 (C16), 76.6 (C6), 79.3 (C10), 79.6 (C13), 121.6 (C11), 121.9 (C9), 135.8 (C12). Elemental Anal. Calcd for $C_{24}H_{45}BF_4N_2O_2$ (480.51): C, 59.99; H, 9.46; N, 5.83. Found: C, 60.20; H, 9.52; N, 5.76.

4.2.3.8. 3-Ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium perchlorate 3. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (d, J = 6.9 Hz, 3H, H14 or H15), 0.91 (m, 9H, Ha-4, H7, H14 or H15, Ha-2 and Ha-1), 1.24 (m, 4H, H5 and H17), 1.44 (m, 1H, H3), 1.62 (m, 2H, Hb-1 and Hb-4), 1.98 (m, 2H, H8 and Hb-2), 3.37 (td, $J^{1,3}$ = 10.4 Hz, $J^{1,2}$ = 4.1 Hz, 1H, H6), 3.64 (q, J = 7.1 Hz, 2H, H16), 5.65 (m, 4H, H10 and H13), 7.56 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.6 Hz, 2H, H11 and H9), 9.24 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.7 (C17), 15.5 (C14 or C15), 20.9 (C7), 22.1 (C14 or C15), 22.7 (C1), 25.4 (C8), 31.0 (C3), 34.0 (C4), 40.2 (C2), 47.7 (C5), 66.2 (C16), 76.6 (C6), 79.3 (C10), 79.9 (C13), 121.6 (C11), 121.8 (C9), 135.9 (C12). Elemental Anal. Calcd for $C_{17}H_{31}ClN_2O_6$ (394.95): C, 51.69; H, 7.93; N, 7.09. Found: C, 52.01; H, 7.75; N, 7.05.

4.2.3.9. 3-Ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium hexafluorophosphate 4. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.55 (d, J = 6.6 Hz, 3H, H14 or H15), 0.93 (m, 9H, Ha-4, H7, H14 or H15, Ha-2 and Ha-1), 1.24 (m, 4H, H5 and H17), 1.45 (m, 1H, H3), 1.63 (m, 2H, Hb-1 and Hb-4), 2.00 (m, 2H, H8 and Hb-2), 3.32 (td, $J^{1,3}$ = 7.1 Hz, $J^{1,2}$ = 3.8 Hz, 1H, H6), 3.60 (kw, J = 7.1 Hz, 2H, H16), 5.58 (m, 4H, H10 and H13), 7.45 (m, 1H, H11), 7.46 (m, 1H, H9), 8.92 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.7 (C17), 15.4 (C14 or C15), 21.0 (C7), 22.1 (C14 or C15), 22.8 (C1), 25.5 (C8), 31.0 (C3), 34.1 (C4), 40.2 (C2), 47.9 (C5), 66.2 (C16), 76.6 (C6), 79.3 (C10), 80.1 (C13), 121.3 (C11), 121.6 (C9), 135.6 (C12). Elemental Anal. Calcd for $C_{17}H_{31}F_6N_2O_2P$ (440.47): C, 46.35; H, 7.11; N, 6.36. Found: C, 46.10; H, 7.03; N, 6.51.

4.2.3.10. 3-Ethoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium bis(trifluoromethanesulfonyl)imide 5a. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.50 (d, J = 7.1 Hz, 3H, H14 or H15), 0.93 (m, 9H, Ha-4, H7, H14 or H15, Ha-2 and Ha-1), 1.26 (m, 4H, H5 and H17), 1.43 (m, 1H, H3), 1.63 (m, 2H, Hb-1 and Hb-4), 1.95 (m, 2H, H8 and Hb-2), 3.31 (td, $J^{1,3}$ = 10.7 Hz, $J^{1,2}$ = 4.4 Hz, 1H, H6), 3.59 (q, J = 7.1 Hz, 2H, H16), 5.58 (s, 2H, H10), 5.57 and 5.64 (d, J = 10.7 Hz, 2H, AB system, H13), 7.57 (m, 2H, H11 and H9), 9.05 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.3 (C17), 15.1 (C14 or C15), 20.6 (C7), 21.7 (C14 or C15), 22.6 (C1), 25.2 (C8), 30.9 (C3), 33.8 (C4), 40.0 (C2), 47.5 (C5), 66.0 (C16), 76.6 (C6), 79.1 (C10), 80.0 (C13), 122.0 (C11), 122.2 (C9), 135.0 (C12); anion: 113.2, 117.5, 121.7, 126.0. Elemental Anal. Calcd for $C_{19}H_{31}F_6N_3O_6S_2$ (575.73): C, 39.63; H, 5.44; N, 7.30. Found: C, 39.54; H, 5.56; N, 7.43.

4.2.3.11. 1-(1*R*,2*S*,5*R*)-(−)-Menthoxymethyl-3-propoxymethylimidazolium bis(trifluoromethanesulfonyl)imide 5b. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.51 (m, 3H, H14 or H15), 0.91 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H18), 1.27 (m, 1H, H5), 1.44 (m, 1H, H3), 1.62 (m, 3H, Hb-1 and H17), 1.95 (m, 2H, Hb-4 and H8), 2.20 (m, 1H, Hb-2), 3.32 (td, $J^{1,3}$ = 10.6 Hz, $J^{1,2}$ = 4.3 Hz, 1H, H6), 3.50 (q, J = 6.6 Hz, 2H, H16), 5.63 (m, 4H, H10 and H13), 7.51 (m, 2H, H11 and H9), 9.20 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 10.1 (C18), 15.5 (C14 or C15), 20.9 (C7), 21.9 (C14 or C15), 22.4 (C1), 22.8 (C17), 25.5 (C8), 31.1 (C3), 34.0 (C4), 40.2 (C2), 47.7 (C5), 72.4 (C16), 76.6 (C6), 79.7 (C10), 80.4 (C13), 121.65 (C11), 121.8 (C9), 135.6 (C12); anion: 113.2, 117.6, 121.7, 126.0. Elemental Anal. Calcd for $C_{20}H_{33}F_6N_3O_6S_2$ (589.76): C, 40.73; H, 5.65; N, 7.13. Found: C, 40.99; H, 5.51; N, 7.04.

4.2.3.12. 3-Butoxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium bis(trifluoromethanesulfonyl)imide 5c. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.50 (d, J = 7.0 Hz, 3H, H14 or H15), 0.91 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H19), 1.33 (m, 3H, H5 and H18), 1.60 (m, 5H, H3, Hb-1, H17 and Hb-4), 1.97 (m, 2H, H8 and Hb-2), 3.32 (td, $J^{1,3}$ = 10.5 Hz, $J^{1,2}$ = 4.3 Hz, 1H, H6), 3.53 (t, J = 6.5 Hz, 2H, H16), 5.63 (m, 4H, H10 and H13), 7.50 (m, 2H, H11 and H9), 9.21 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 13.6 (C19), 15.4 (C14 or C15), 18.95 (C7), 20.9 (C18), 21.95 (C14 or C15), 22.8 (C1), 25.5 (C8), 31.0 (C17), 31.1 (C3), 34.0 (C4), 40.2 (C2), 47.7 (C5), 70.6 (C16), 76.6 (C6), 79.6 (C10), 80.4 (C13), 121.6 (C11), 121.9 (C9), 135.7 (C12); anion: 117.6, 121.7, 121.8, 122.1 Elemental Anal. Calcd for $C_{21}H_{35}F_6N_3O_6S_2$ (603.79): C, 41.77; H, 5.85; N, 6.96. Found: C, 41.98; H, 5.79; N, 7.08.

4.2.3.13. 3-Decyloxymethyl-1-(1*R*,2*S*,5*R*)-(−)-menthoxymethylimidazolium bis(trifluoromethanesulfonyl)imide 5i. ^{1}H NMR ($CDCl_3$, 25 °C): δ = 0.49 (d, J = 6.9 Hz, 3H, H14 or H15), 0.89 (m, 12H, Ha-4, H7, H14 or H15, Ha-2, Ha-1 and H25), 1.32 (m, 16H, H5, H18, H19, H20, H21, H22, H23, H24 and H3), 1.61 (m, 4H, Hb-1, Hb-4 and H17), 1.99 (m, 2H, H8 and Hb-2), 3.34 (m, 1H, H6), 3.51 (m, 2H, H16), 5.61 (m, 4H, H10 and H13), 7.56 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.6 Hz, 1H, H11), 7.58 (t, $J^{1,2}$ = 1.9 Hz, $J^{2,1'}$ = 1.6 Hz, 1H, H9), 9.06 (m, 1H, H12); ^{13}C NMR ($CDCl_3$): δ = 14.0 (C25), 15.2 (C14 or C15), 20.7 (C7), 21.8 (C14 or C15), 22.6 (C1), 25.3 (C24), 25.7 (C8), 25.7 (C23), 29.0 (C22), 29.1 (C21), 29.2 (C20), 29.4 (C19), 29.45 (C18), 31.0 (C3), 31.8 (C17), 33.9 (C4), 40.0 (C2), 47.5 (C5), 70.6 (C16), 76.6 (C6), 79.3 (C10), 79.9 (C13), 121.8 (C11), 122.1 (C9), 135.0 (C12); anion: 113.1, 117.4, 121.6, 125.9. Elemental Anal. Calcd for $C_{27}H_{47}F_6N_3O_6S_2$ (687.97): C, 47.13; H, 6.90; N, 6.11. Found: C, 46.92; H, 6.69; N, 6.28.

4.3. X-ray structure determination

Diffraction data for **1a** were collected at room temperature by the ω-scan technique on an Oxford Diffraction KM4 four-circle diffractometer with Sapphire CCD-detector with graphite-monochromatized Mo Kα radiation (λ = 0.71073 Å). The data were corrected for Lorentz-polarization as well as for absorption effects.[31] Accurate unit-cell parameters were determined by a least-squares fit of 2137 reflections of highest intensity, chosen from the whole experiment. The structures were solved with SIR92[32] and refined with the full-matrix least-squares procedure on F^2 by SHELXL97.[33] Scattering factors incorporated in SHELXL97 were used. The function $\sum w(|F_o|^2 - |F_c|^2)^2$ was minimized, with $w^{-1} = [\sigma^2(F_o)^2 + (0.001 \cdot P)^2]$ (P = [Max $(F_o^2, 0) + 2F_c^2$]/3). All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were placed geometrically, in idealized positions, and refined as rigid groups with their U_{iso}'s as 1.2 (OH) or 1.5 (methyl) times U_{eq} of the appropriate carrier atom. Relevant crystal data are listed in Table 11, together with refinement details.

Table 11
Crystal data, data collection and structure refinement

	1a
Formula	$(C_{17}H_{33}N_2O_2)^+ \cdot Cl^- \cdot H_2O$
Formula weight	348.90
Crystal system	Monoclinic
Space group	$P2_1$
a (Å)	13.838(3)
b (Å)	9.132(2)
c (Å)	17.367(4)
β (°)	110.46(3)
V (Å^3)	2056.2(8)
Z	4
d_x (g cm^{-3})	1.13
F(0 0 0)	760
μ (mm^{-1})	0.20
Θ Range (°)	2.45–25.00
hkl Range	$-16 \leqslant h \leqslant 15$ $-10 \leqslant k \leqslant 10$ $-13 \leqslant l \leqslant 20$
Reflections	
Collected	11266
Unique (R_{int})	6778 (0.042)
With $I > 2\sigma(I)$	2436
No. of parameters	423
$R(F)$ [$I > 2\sigma(I)$]	0.036
$wR(F^2)$ [$I > 2\sigma(I)$]	0.029
$R(F)$ [all data]	0.145
$wR(F^2)$ [all data]	0.034
Goodness of fit	0.67
Max/min $\Delta\rho$ (e Å^{-3})	0.10/−0.13

Crystallographic data (excluding structure factors) for the structural analysis have been deposited with the Cambridge Crystallographic Data Centre, No. CCDC-786077. Copies of this information may be obtained free of charge from: The Director, CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK. Fax: +44(1223)336-033, e-mail: deposit@ccdc.cam.ac.uk, or www: www.ccdc.cam.ac.uk.

4.4. Thermal analysis

Glass temperature was determined by DSC, Mettler Toledo DSC Instruments model cooled with a intracooler. The calorimeter was calibrated for temperature and cell constants using indium (melting point 156.61 °C, ΔH 28.71 J g^{-1}). Data were collected at constant atmospheric pressure, using samples between 10 and 40 mg in aluminum sample pans. Experiments were performed heating at the rate of 10 °C min^{-1}. An empty sample pan was used as reference.

Thermal decomposition temperatures were measured in the dynamic heating regime using a TGA (TA Instruments 2950) under air atmosphere. Samples between 2 and 10 mg were heated from 40 to 500 °C under constant heating at 10 °C min^{-1}. Decomposition temperatures ($T_{onset5\%}$ and T_{onset}) were determined from onset to 5 mass loss and 50% mass loss, respectively, under nitrogen.

4.5. Antielectrostatic properties

The antielectrostatic effect was measured on a Wigofil polyethylene film with a density of 150 g/m^2 that did not contain any lubricants or antioxidants. From this 0.25 mm film, 12.5 mm diameter disks were cut. The disks were washed in acetone and then dried by placing them in an air-conditioned room. A disk was rubbed on the surface with a cotton-swab soaked with a 0.5% chloroform solution of each studied salt. Next, the disk was hung up so that the chloroform could evaporate spontaneously.

The disks, covered with chiral imidazolium salts, were stored for 24 h in an air-conditioned room at 20 ± 2 °C and a relative humidity of 55 ± 5%. Finally, the surface resistance and half-life decay time were measured. The measuring apparatus and the method have recently been described elsewhere.[34] The relative error in the determination of these two quantities did not exceed 5%.

4.6. Test microorganisms

The microorganisms were: *Micrococcus luteus* NCTC 7743, *Staphylococcus aureus* NCTC 4163, *Staphylococcus epidermidis* ATCC 49134, *Enterococcus faecium* ATCC 49474, *Moraxella catarrhalis* ATCC 25238, *Escherichia coli* ATCC 25922, *Serratia marcescens* ATCC 8100, *Proteus vulgaris* NCTC 4635, *Pseudomonas aeruginosa* NCTC 6749, *Bacillus subtilis* ATCC 6633, *Candida albicans* ATCC 10231, *Rhodothorula rubra* (Demml 1889, Lodder 1934). Standard strains were supplied by the National Collection of Type Cultures (NCTC) and London and American Type Culture Collection (ATCC). *Rhodothorula rubra* was obtained from the Department of Pharmaceutical Bacteriology, University of Medical Sciences, Poznań.

4.7. Antimicrobial activity test procedure

Antimicrobial activity was determined by the tube dilution method and described earlier.[35] Bacteria strains were cultured on a Müller-Hinton broth for 24 h. and fungi on Sabouraud agar for 48 h. A suspension of the microorganisms at a concentration of 10^6 cfu mL^{-1} was prepared from each culture. This suspension was then used to inoculate each dilution of the broth medium at a 1:1 ratio. Growth of the microorganisms (or lack thereof) was determined visually after incubation for 24 h at 37 °C (bacteria) or 48 h at 29 °C (fungi).

The lowest concentration at which there was no visible growth (turbidity) was taken as the MIC (minimal inhibitory concentration). Then an aliquot taken from each tube in a sample loop was cultured in an agar medium with inactivates (0.3% lecithin. 3% polysorbate 80. and 0.1% cysteine L) and incubated for 48 h at 37 °C (bacteria) or for 5 d at 29 °C (fungi). The lowest concentration of the studied salt supporting no colony formation was defined as the MBC (minimal bactericidal concentration) or MFC (minimal fungicifal concentration).

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