



Synthesis and properties of gallate ionic liquids



Kamil Czerniak^{a,*}, Agnieszka Biedziak^a, Krzysztof Krawczyk^b, Juliusz Pernak^a

^a Department of Chemical Technology, Poznan University of Technology, 60-965 Poznan, Poland

^b Virology and Bacteriology Department, Institute of Plant Protection-National Research Institute, 60-310 Poznan, Poland

ARTICLE INFO

Article history:

Received 12 May 2016

Received in revised form 20 August 2016

Accepted 5 September 2016

Available online 7 September 2016

Keywords:

Ionic liquids

Gallic acid

Antioxidant

Radical scavenging activity

ABSTRACT

An efficient method for the synthesis of novel antioxidants in the form of ionic liquids (ILs) was described in the framework of this study. The ILs were obtained by the reaction of quaternary ammonium hydroxides with gallic acid as well as the protonation of amphoteric betaine. The following physicochemical properties of the obtained ILs were characterized: solubility in water as well as in polar and non-polar organic solvents, octanol–water partition coefficient, thermal stability, and surface activity. The investigation of bactericidal activity indicated that the synthesized gallates exhibited high efficacy against bacteria, especially against *Bacillus subtilis*. The DPPH radical scavenging assay confirmed the antioxidant properties of gallate ILs.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Antioxidants are substances which are capable of preventing oxidation as a result of reducing the concentration of free radicals or chelating metal ions. Some well-known antioxidants include L-ascorbic acid (vitamin C), α -tocopherol (vitamin E), carotenoids or β -carotene.^{1,2} Among natural antioxidants occurring in plants in the form of polyphenols, gallic acid (GA) exhibits one of the strongest antiradical properties due to efficient protection against different reactive species.³ GA has also exhibited other forms of biological activity, such as anticancer properties, due to the inhibition of the growth of lung cancer or prostate cancer cells with stem-like properties.⁴ This natural phenolic acid can be used as a reductant for the preparation of highly reduced graphene oxide at room temperature,⁵ or can generate hydrogen peroxide in situ from air in slightly basic media.⁶

During recent years, ionic liquids (ILs) have been described as solvents with high chemical or thermal stability and low vapor pressure.⁷ ILs have found wide application in the synthesis of various forms of antioxidants. Primarily, they can be used as environmentally friendly catalysts for the preparation of GA esters,⁸ or act as the reaction solvent in the galloylation of catechins.⁹ ILs are applied as sustainable dual solvent-catalysts for the preparation of an α -tocopherol derivative.¹⁰ Moreover, they have been used in the preparation of novel compounds with antioxidant activity e.g., the synthesis of naphthoquinone—urazole hybrids.¹¹ In addition, ILs

have been used for the production of polypyrimidine-amide antioxidants by polycondensation in a mixture of IL and triphenyl phosphite.¹² Current research has demonstrated that imidazolium ILs could be potential candidates for antioxidants capable to neutralize the hydrogen peroxide or radicals.¹³

The rapid progress of studies in this field contributed to a steady advance from first generation ILs (with unique, designable physical properties), through the second generation (with targeted chemical properties, combined with selected physical properties), to the third generation (with targeted biological properties, combined with physical and chemical properties).¹⁴ The third generation of ILs has been discussed as active pharmaceutical ingredients.^{7c,15} Herbicidal ionic liquids were introduced in 2011.¹⁶ In recent years, widely applied formulations of antioxidants were esters, such as propyl or lauryl gallates.¹⁷ Moreover, it is possible to prepare water soluble antioxidants in the form of cholinium-based quaternary salts.¹⁸ The aim of this work was to improve activity and properties of gallic acid by turning it into multifunctional ILs. These compounds may have a wider range of tunable properties than traditional forms of antioxidants. Except high water solubility, ILs can also exhibit antibacterial properties and improved surface activity.

2. Result and discussion

2.1. Synthesis of ILs precursors

Quaternary ammonium salts and an amphoteric surfactant (Fig. 1) were applied as starting materials in order to obtain ILs with the gallate anion. Each bromide salt was obtained by the

* Corresponding author. E-mail address: kamil.z.czerniak@doctorate.put.poznan.pl (K. Czerniak).

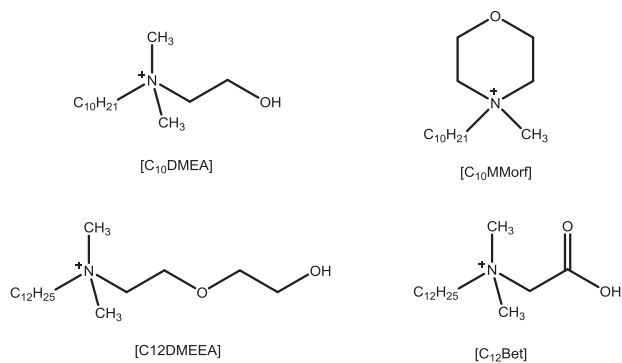


Fig. 1. Chemical structures of the cations.

quaternization (Menshutkin reaction) of tertiary amines and long chain alkyl bromides (Scheme S1, Supplementary data). The time of the reaction was optimized to achieve full conversion. Optimal time was determined with in situ IR spectroscopy (ReactIR 15, Mettler Toledo) and processed by iC IR software. This method let us monitor the direct alkylation of the amine and define the mechanism of the reaction.¹⁹ IR spectra of the reaction mixture at the beginning and end of the synthesis are shown in Fig. S1–S4, Supplementary data. In the case of [C₁₀DMEA][Br], the disappearance of band intensity at 1035 cm⁻¹ was mainly observed. This band can be assigned to the C–O out-of-phase stretching vibrations of 2-dimethylethanolamine.²⁰ During the quaternization of 1-methylmorpholine, stretching vibrations at 1145 and 1122 cm⁻¹ can be observed which are attributed to C–N stretching vibrations.²¹ Slight differences between the IR spectra were observed in the case of the reaction involving 2-[2-(dimethylamino)ethoxy] ethanol. Initially, a reduction of the intensity at 1055 cm⁻¹ occurred.

The reaction also results in the appearance of specific bands which can be assigned to the complexes with the quaternary ammonium ion.²² The new bands appeared in the region ranging from 1100 to 700 cm⁻¹ (1089, 970, 921 cm⁻¹ for [C₁₀DMEA][Br]; 1044, 917, 899 cm⁻¹ for [C₁₀MMorf]; and 1070, 977, 921 cm⁻¹ for [C₁₂DMEEA][Br]). The quaternization reaction between a fatty amine and the potassium salt of chloroacetic acid was applied for the preparation of alkyl betaines. The characteristic absorption peaks of C=O stretching vibrations of the carbonyl group appeared at 1648 cm⁻¹. The longest reaction time necessary to obtain the maximum concentration of the product was observed in the case of [C₁₀MMorf][Br] and was 23 h (Table 1). The other precursors of ILs could be synthesized more rapidly (in the range of 2–2.75 h). No major side products were observed. After the purification of products from the starting reactants, the compounds were obtained in yields ranging from 94 to 98%. The resulting bromides were white or yellow solids with a melting point in the range of 56–188 °C and the amphoteric surfactant had a greasy consistency.

2.2. Synthesis of ILs

Antioxidant ILs were prepared using the two methods presented in Scheme 1. The first method, based on a neutralization reaction,

Table 1
Prepared precursors of ILs

Compounds	R ¹	R ²	Time (h)	Yield(%)	T _m (°C)
[C ₁₀ DMEA][Br]	C ₁₀ H ₂₁	CH ₂ CH ₂ OH	2.75	94	156
[C ₁₀ MMorf][Br]	C ₁₀ H ₂₁	—	23.00	95	188
[C ₁₂ DMEEA][Br]	C ₁₂ H ₂₅	(CH ₂ CH ₂ O) ₂ H	2.50	98	56
[C ₁₂ Bet]	C ₁₂ H ₂₅	—	2.00	96	—

consists of two stages and can be used to synthesize various types of ILs.²³

The synthesis started by preparation of a solution of quaternary ammonium hydroxide in methanol using an anion exchange resin to replace the bromide ion. Next, a neutralization reaction with GA was conducted at low temperatures. In addition, a hydroxide solution was progressively introduced to the acid solution due to the low stability of GA at high pH.²⁴ The IL with [C₁₂Bet] cation was obtained using the second method, which involved a one-step protonation of the carboxylate group of betaine²⁵ in methanol with GA. An overview of the prepared ILs is shown in Table 2. In both methods the synthesized ILs do not require further purification after evaporation of the solvent. In addition, the products were dried under reduced pressure (5 mbar) for 24 h at ambient temperature and stored at a low temperature in the dark. The described methods gave the ILs with a yield exceeding 97%. Water content was determined by Karl–Fischer titration and amounted to 500–800 ppm. Two of the obtained ILs containing hydroxyl groups were liquids at room temperature. Other salts were waxes. The structure of the synthesized compounds was confirmed by ¹H and ¹³C NMR spectroscopic analysis. The obtained spectra are presented in Fig. S1–S4, Supplementary data. The synthesized ILs showed only one signal derived from the anion in the form of a singlet in the range of 6.84–6.93 ppm, which is generated by the protons of the gallic acid aromatic ring.²⁶ In the case of the cations, the protons of the long alkyl chain are located at 0.86 ppm for the methyl group and approximately 1.24 and 1.63 ppm for the methylene groups.²⁷

2.3. Thermal properties

Short-term thermal stabilities of the salts were determined by temperature-ramped TGA experiments.²⁸ As shown in Table 2, all the prepared ILs exhibited high thermal stability and manifested T_{onset50} in the range of 241–274 °C. Nonetheless, obtained compounds were less stable than GA.¹⁸ According to the literature, ILs containing short ether groups are less thermally stable compared to alkyl-substituted analogues.²⁹ However, the least stable salt among the antioxidant ILs was [C₁₀DMEA][Gal], without an ether linkage, which also exhibited the lowest value of T_{onset5} (174 °C). The obtained results indicate that the presence of long alkyl chains and their elongation does not affect the stability of ILs. The prepared antioxidant ILs with long alkyl chains mainly underwent a three-step decomposition (Fig. S20, Supplementary data). [C₁₂Bet][Gal] was an exception, with a clear two-step thermal degradation process.

No prepared ILs demonstrated melting points and their crystallization temperatures were in the range of –100 to 120 °C. Based on the results of DSC analyses, it could be concluded that gallate ILs have no tendency to crystallize upon cooling and mainly remain in the glass state. Additionally, they can exhibit high glass transition temperature e.g., T_g=35.8 °C in the case of a compound with a morpholinium cation. The lowest values (T_g=–3.6 °C and 6.7 °C) were observed for ILs [C₁₂DMEEA][Gal] and [C₁₀DMEA][Gal], which comprised the ethoxy or the hydroxyl substituent in the structure of the cation, respectively.

2.4. Octanol–water partition coefficient

The octanol–water partition coefficients (K_{ow}) were determined in order to describe the hydrophobicity of the gallate ILs. In addition, this parameter allows definition of the environmental risk as associated with bioaccumulation or toxicity, because it reflects the partition of the compounds in biotic systems. The K_{ow} values calculated for gallate ILs are shown in Table 3.

Based on the obtained data, it was established that ILs containing the [C₁₀MMorf] and [C₁₀DMEA] cations were the least

Download English Version:

<https://daneshyari.com/en/article/5213065>

Download Persian Version:

<https://daneshyari.com/article/5213065>

[Daneshyari.com](https://daneshyari.com)