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Liquid–liquid biphasic synthesis of long chain wax esters using the Lewis acidic ionic liquid choline chloride·$2ZnCl_2$☆

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Abstract—The first liquid–liquid biphasic synthesis of wax esters in a Lewis acidic ionic liquid, choline chloride·$2ZnCl_2$ by the esterification of long chain carboxylic acids with long chain alcohols is described. The reported reaction system has the advantages of both homogeneous and heterogeneous catalysis with high product yield and the ease of product as well as catalyst separation without the use of an organic solvent. The ionic liquid studied plays the dual role of solvent as well as catalyst and is recycled up to six times without any significant loss of activity.

1. Introduction

Esters of long chain carboxylic acids and long chain alcohols, typically referred to as 'wax esters' are an important class of fine organics that are widely used as base materials in cosmetics, pharmaceuticals, lubricants, paints, wood coatings and perfumery products.[1–4] Many attractive features such as biodegradability, non-toxicity and preparation from vegetable oils make wax esters industrially important chemicals. Speciality liquid wax esters such as jojoba and sperm whale oil have wide industrial applications as premium lubricants, parting agents, anti foaming agents and in cosmetics.

Esterification of carboxylic acids with alcohols using homogeneous and heterogeneous catalysts is well known in the literature.[4–12] However, several limitations such as an excess of the catalysts or amounts of reactants to achieve efficient conversion, removal of water during the reaction, long reaction times and large amounts of effluent generation during work-up are associated with these processes. A recent report[4] on the synthesis of wax esters using $ZrOCl_2{\cdot}8H_2O$ has an additional limitation of lower yields in the case of acids and alcohols with greater than C_{14} chain length.

Ionic liquids (IL) are an extensively used eco-friendly, non-conventional reaction medium for many chemical and biochemical transformations.[13] Fraga-Dubreuil et al.[14] reported the first esterification of acetic acid and methyl malonic acid with alcohols of chain lengths C_5–C_{10} in imidazolium-based IL with acidic counterions, HSO_4^- and $H_2PO_4^-$. However, no attempt was made at the esterification of long chain carboxylic acids with long chain alcohols. A new approach using a Bronsted acidic IL in the dual role of solvent/catalyst for esterification has also been reported in the literature.[15–18] However, the success of this chemistry was limited to esters less than C_{10} in either carboxylic acid or alcohol chain length.

Thus there is a need to develop an environmentally benign synthetic method for the synthesis of long-chain wax esters. 'Liquid–liquid biphasic catalysis' can address effectively the advantages of both homogeneous and heterogeneous catalysis and an IL would be a potent 'biphasic catalyst' due to well-known physical properties.[19–24] Abott et al. reported[25] a new class of moisture insensitive IL composed of choline chloride and $ZnCl_2$ which has been utilized extensively as a Lewis acid catalyst as well as a reaction medium in carrying out Diels–Alder reactions,[26] Fischer indole annulation,[27] O-acetylation of cellulose and monosaccharides[28] and protection of carbonyls.[29] The Lewis acidic activity is primarily due to the presence of complex zinc chloride ions, $[ZnCl_3]^-$, $[Zn_2Cl_5]^-$ and $[Zn_3Cl_7]^-$ along with some higher clusters of low intensity as confirmed by FAB mass study.[26,30] In the present work, we report the first

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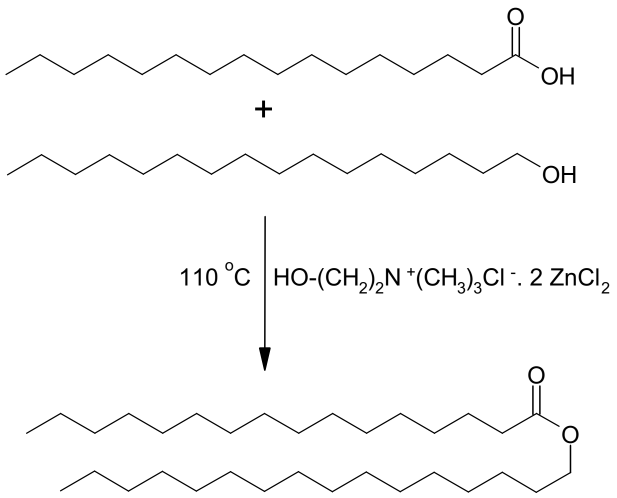
example of choline chloride·$2ZnCl_2$ as a recyclable green catalyst and reaction media for the practical and highly efficient liquid–liquid biphasic esterification of long chain aliphatic carboxylic acids with long chain alcohols. The IL remains in one phase and the reactants in the liquid or molten state remain in the other phase and the esterification reaction occurs at the interface. The synthesis of esters mimicking the natural liquid wax esters was also carried out in choline chloride·$2ZnCl_2$.

The esterification of palmitic acid with cetyl alcohol was chosen as a model reaction (Scheme 1) to standardize the reaction parameters such as the amount of choline chloride·$2ZnCl_2$, reaction temperature and time (Table 1). A good yield of cetyl palmitate was observed in the presence of 0.1 mol equiv of IL (Table 1, entry 1), demonstrating the efficacy of the IL as an esterification catalyst. However, most of these long chain wax esters are of high melting point and are poorly soluble in many commonly used organic solvents. To overcome the extraction related problems and also to fulfill the advantages of liquid–liquid biphasic catalysis, the synthesis of other wax esters was conducted by reacting equimolar amounts of acid, alcohol and IL at 110 °C.



Scheme 1.

Table 1. Optimization of the reaction conditions for the preparation of cetyl palmitate[a]

Entry	Acid:IL[b] (mol/mol)	Temperature (°C)	Time (h)	Isolated yield (%)
1	1.0:0.1	110	12	90
2	1.0:0.25	110	12	92
3	1.0:0.5	80	24	53
4	1.0:0.5	110	12	95
5	1.0:1.0	80	24	76
6	1.0:1.0	110	12	97
7	1.0:1.5	110	12	98.5

[a] Reaction conditions: palmitic acid (2.4 mmol), cetyl alcohol (2.4 mmol).

[b] Choline chloride·$2ZnCl_2$.

The condensation of carboxylic acids and alcohols of different chain lengths (C_8–C_{22}) were conducted and the results are outlined in Table 2. All the substrates reacted smoothly to give the corresponding esters in excellent yields. High conversions to liquid wax esters, such as erucyl erucate and oleyl oleate were also achieved (entries 18 and 19). The methodology was extended to the synthesis of long chain esters of dicarboxylic acids, namely behenyl sebacate, behenyl adipate and 2-ethylhexyl sebacate by esterification of 1:2 molar equivalents of dicarboxylic acid and long chain alcohol (Table 3).

The feasibility of any catalytic process depends on the reusability of the catalyst. In the present work, the IL plays the dual role of solvent and catalyst. In order to investigate the reusability of the IL, the esterification of octanoic acid and cetyl alcohol was conducted in choline chloride·$2ZnCl_2$ over six successive cycles without any pre-treatment of the IL. The results shown in Table 4, indicate no significant loss of the Lewis acidic nature of the IL.

In conclusion, a novel, efficient and environmentally benign method for the synthesis of long chain wax esters

Table 2. Esterification of carboxylic acids with alcohols of different chain lengths[a]

Entry	Acid	Alcohol	Time (h)	Isolated yield (%)
1	Palmitic acid	1-Octanol	4[b]	99
2	Palmitic acid	Capryl alcohol	6	99
3	Palmitic acid	Lauryl alcohol	6	99
4	Palmitic acid	Myristyl alcohol	8	99
5	Palmitic acid	Cetyl alcohol	10	97
6	Palmitic acid	Stearyl alcohol	10	96
7	Palmitic acid	Erucyl alcohol	12	94
8	Palmitic acid	Behenyl alcohol	12	95
9	Octanoic acid	Cetyl alcohol	6	99
10	Capric acid	Cetyl alcohol	6	99
11	Undecenoic acid	Cetyl alcohol	6	99
12	Lauric acid	Cetyl alcohol	8	99
13	Myristic acid	Cetyl alcohol	10	99
14	Stearic acid	Cetyl alcohol	12	96
15	Oleic acid	Cetyl alcohol	12	97
16	Behenic acid	Cetyl alcohol	12	95
17	Erucic acid[b]	Cetyl alcohol	12	95
18	Erucic acid[b]	Erucyl alcohol	12	93
19	Oleic acid	Oleyl alcohol	12	98

[a] Reaction conditions: acid (2.4 mmol), alcohol (2.4 mmol); choline chloride·$2ZnCl_2$ (2.4 mmol); reaction temperature: 110 °C.

[b] GC composition of technical grade erucic acid (in wt %): erucic acid, 94.6%; other fatty acids, 5.4%.

Table 3. Preparation of diesters using choline chloride·$2ZnCl_2$[a]

Entry	Acid	Alcohol	Time (h)	Isolated yield (%)
1	Sebacic acid	2-Ethylhexanol	16	99
2	Sebacic acid	Behenyl alcohol	24	88
3	Adipic acid	Behenyl alcohol	24	92

[a] Reaction conditions: acid (2.4 mmol), alcohol (4.8 mmol), choline chloride·$2ZnCl_2$ (2.4 mmol), reaction temperature 110 °C.

Table 4. Recycling of choline chloride·2ZnCl$_2$ in the synthesis of cetyl octanoate[a]

Cycle	Conversion[b] (%)	Time (h)
1	99	5
2	99	5
3	98	5
4	98	5
5	96	5
6	95	5

[a] Reaction conditions: octanoic acid (2.4 mmol), cetyl alcohol (2.4 mmol), choline chloride·2ZnCl$_2$ (1.2 mmol), reaction temperature 110 °C.

[b] Based on GC.

and diesters using the Lewis acidic IL, choline chloride·2ZnCl$_2$ as solvent/catalyst is reported. The present 'liquid–liquid biphasic' method has the following advantages over existing methods for wax ester synthesis: (a) choline chloride·2ZnCl$_2$ shows superior catalytic activity than reported systems; (b) this IL is cheap and easy to prepare compared to imidazolium based ILs; (c) as the IL is moisture insensitive, there is no need to remove water produced during the reactions and the IL can be reused for at least six cycles without any pre-treatment or significant loss of activity, and (d) liquid esters (as a separate phase) can be conveniently decanted above their melting point avoiding the use of volatile organic solvents.

2. Experimental

2.1. Preparation of choline chloride·2ZnCl$_2$

Choline chloride (20 mmol) was mixed with zinc chloride (40 mmol) and heated to 150 °C with stirring until a clear colourless liquid was obtained.[25]

2.2. General procedure for esterification

Equimolar amounts (2.4 mmol) of long chain acid and alcohol were taken in choline chloride·2ZnCl$_2$ (1.0 g; 2.4 mmol) and the resultant reaction mixture was heated to 110 °C, and stirred for the specified amount of time. The top layer containing the reactants and the product was decanted whilst hot and purified by column chromatography using silica gel (60–120 mesh) eluting with 10% EtOAc in hexane.

The spectral (^{1}H and ^{13}C NMR and IR) data of most of the esters matches with those reported in the literature.[4] The spectral data of three representative uncommon wax esters are given below.

2.3. Cetyl undecenoate (Table 2, entry 11)

^{1}H NMR (200 MHz, CDCl$_3$): δ 0.88 (3H, br t), 1.21–1.39 (38H, br s), 1.55–1.65 (2H, br m), 1.98–2.06 (2H, q, $J = 7.2$ Hz), 2.25 (2H, t, $J = 7.5$ Hz), 4.02 (2H, t, $J = 6.6$ Hz), 4.84–5.0 (2H, dd, $J = 12.2$, 16.99 Hz), 5.64–5.82 (1H, br m); ^{13}C NMR (75 MHz, CDCl$_3$): δ 22.59, 24.92, 25.84, 28.55, 28.78, 28.95, 29.02, 29.11, 29.16, 29.19, 29.27, 29.44, 29.48, 29.55, 29.58, 31.82, 33.68, 34.31, 64.31, 76.59, 76.90, 77.22, 114.03; IR (Film): v 1739, 1642, 1172, 1029 cm^{-1}. Anal. Calcd for C$_{27}$H$_{52}$O$_2$: C, 79.35; H, 12.82. Found: C, 78.89; H, 12.73. EI-MS: m/z 408 [M]$^+$, 269 [M−139]$^+$, 166 [M−241]$^+$.

2.4. Erucyl erucate (Table 2, entry 18)

^{1}H NMR (200 MHz, CDCl$_3$): δ 0.88–0.90 (6H, br t), 1.22–1.39 (56H, br s), 1.55–1.68 (4H, br m), 1.92–2.08 (10H, br m), 2.26 (2H, t, $J = 7.8$ Hz), 4.03 (2H, t, $J = 6.1$ Hz), 5.28–5.35 (4H, br m); ^{13}C NMR (75 MHz, CDCl$_3$): δ 14.33, 22.91, 25.26, 26.17, 27.44, 28.89, 29.40, 29.50, 29.55, 29.71, 29.75, 29.79, 29.87, 30.00, 32.13, 34.65, 64.63, 130.11, 130.13, 174.25; IR (KBr): v 1739, 1654, 1240, 1173 cm^{-1}. Anal. Calcd for C$_{44}$H$_{84}$O$_2$: C, 81.92; H, 13.12. Found: C, 79.33; H, 11.99. EI-MS: m/z 645 [M+1]$^+$, 321 [M−324]$^+$, 306 [M−338]$^+$.

2.5. Di-2-ethylhexyl sebacate (Table 3, entry 1)

^{1}H NMR (200 MHz, CDCl$_3$): δ 0.88–0.90 (12H, br t), 1.21–1.39 (24H, br s), 1.51–1.67 (6H, br m), 2.27 (4H, t, $J = 7.5$ Hz), 3.95 (4H, d, $J = 7.5$ Hz); ^{13}C NMR (75 MHz, CDCl$_3$): δ 10.89, 13.94, 22.87, 23.69, 24.9, 28.82, 29.0, 30.32, 34.31, 38.63, 66.53, 76.61, 76.93, 77.24, 173.86; IR (Film): v 1738, 1172, 1039 cm^{-1}. Anal. Calcd for C$_{26}$H$_{50}$O$_4$: C, 73.19; H, 11.81. Found: C, 73.05; H, 11.38. EI-MS: m/z 427 [M+1]$^+$, 315 [M−111]$^+$, 297 [M−129]$^+$, 185 [M−241]$^+$.

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