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ARTICLE

Chemoselective hydrogen peroxide oxidation of primary alcohols to aldehydes by a water-soluble and reusable iron(III) catalyst in pure water at room temperature

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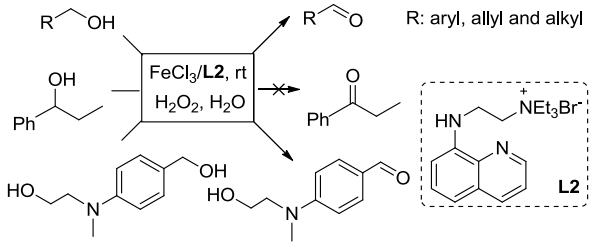
Hydrogen peroxide oxidation of primary alcohols to aldehydes is described, which is catalyzed by a novel, reusable and water-soluble $FeCl_3$ complex in situ-formed with quaternary ammonium salt-functionalized 8-aminoquinoline. The reaction exhibits unique chemoselectivity and broad functional-group tolerance, and it can operate efficiently in pure water at room temperature.

Introduction

The oxidation of primary alcohols to aldehydes, especially its chemoselective oxidation in the presence of secondary alcohols is a crucial process to synthesize fragrances and food additives as well as many intermediates.[1] Such reaction occurs typically with stoichiometric use of environmentally-harmful oxidants, such as CrO_3 and MnO_2.[2] Because of high atom efficiency and formation of water as the sole by-product, hydrogen peroxide (H_2O_2) has been used as a green oxidant in transition metal-catalyzed oxidation reactions.[3] In comparison with other catalysts (Pd, Cu, Ru, etc.),[4] the inexpensive and relatively non-toxic iron in combination with H_2O_2 has recently attracted interest as catalytic oxidation system.[5]

Iron(II/III) complexes are able to selectively catalyse various oxidation reactions,[6] such as sulfide oxidation, hydroxylation, epoxidation, etc., and in particular several type of iron catalysts have been recently developed for the oxidation of alcohols using H_2O_2 as an oxidant.[7,8] For example, nano-γ-Fe_2O_3,[7a,b] $[Fe(II)(N\text{-}N)_3](OTf)_2$,[7c] $[Fe(II)(Me\text{-}Pic)_3]$,[7d] $[Fe(II)(imine)_2(OTf)_2]$,[7e] a μ-oxo diiron(III) complex of N3Py-phenol ligand[7f] and Fe(III) complexes based on BTC[7g] and PPh_3/Schiff base[7h] ligands were effective catalysts for the oxidations of both secondary and primary alcohols to ketones and aldehydes/acids. In contrast, $FeBr_3$[8a] and the Fe(II)-benzimidazoylpyridine,[8b] Fe(III)-phen,[8c] as well as Fe(II)-bis(picoly)amine[8d] complexes provided selectivity for the preferential oxidation of secondary over primary alcohols. Due to the generally lower reactivity of primary alcohols in oxidation reactions,[9] however, to date few catalytic oxidation methods with H_2O_2 as an oxidant have been reported on the chemoselective oxidation of primary alcohols to aldehydes in the presence of secondary alcohols. As such, the development of an efficient iron(II/III) catalytic system capable of such transformation is highly required as well as remarkably challenging, because it must not only overcome the above-described lack of chemoselectivity towards primary alcohols, but also control the overoxidation of aldehydes to carboxylic acids, a major competitive reaction that occurs in the oxidation of primary alcohols.[9a,b,10] Water offers unique reactivity and selectivity that cannot be attained in organic solvents.[11] Therefore, we anticipated that the use of water instead of organic solvents required in alcohol oxidations (e.g., MeCN, CH_2Cl_2) could lead to an iron(II/III)-catalyzed H_2O_2-oxidation of primary alcohols to aldehydes with high chemoselectivity. Moreover, the use of pure water as solvent is an ideal process of green chemistry, as water is the cleanest, safest and cheapest solvent.



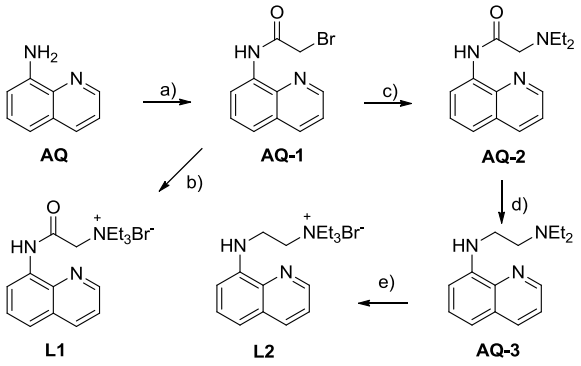
Scheme 1 The *in situ*-formed $FeCl_3$/**L2** complex and its chemoselectivity.

To achieve these goals, we have recently started exploring iron(III) catalysts suitable for the chemoselective oxidation of primary alcohols to aldehydes in pure water by H_2O_2 as oxidant. Considering that ligand solubility is the crucial factor to enhance the activity and selectivity of a catalyst in water,[12] and motivated by the fact that 8-aminoquinolines (**AQ**) have been shown to be strong iron-chelating agents containing the N-C-C-N linkage,[13] we developed two novel ligands by merging the **AQ** skeleton with highly water-soluble quaternary ammonium salts. Herein, we for the first time report the use of a highly active water-soluble $FeCl_3$ catalyst *in situ*-formed with an optimized ligand (**L2**) for such oxidation reaction in water at room temperature (Scheme 1). Apart from being an effective

oxidation in room temperature water, this method has substantial advantages. On the one hand, the catalyst exhibits several types of chemoselectivity, including (1) the oxidation of primary alcohols but not secondary ones, (2) the formation of aldehydes without overoxidation to carboxylic acids, and (3) the preferential oxidation of benzylic over aliphatic primary alcohols. On the other hand, the use of pure water as solvent provides an opportunity for facilitating recycle and reuse of the catalyst, because when a water-soluble catalyst is used in a biphasic system, the product can be separated by a simple decantation or extraction, and the catalyst solution can be recycled and reused.[1a,14]

Result and disscusion

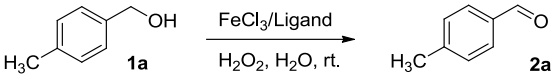
The ligand of **L1** or **L2** was prepared by a facile procedure. As shown in Scheme 2, the amidation of **AQ** led to the formation of **AQ-1**, then which was simply quaternized with TEA to give **L1**. Moreover, Ligand **L2** was obtained in a three step synthesis, involving the amination of **AQ-1** with DEA, reduction of **AQ-2** with $LiAlH_4$ and quaternization of **AQ-3** with C_2H_5Br. Despite the advantage of being easily carried out at room temperature, this procedure involved the use of CH_2Cl_2 or DMF as solvent, which is not green.



Scheme 2 The ligand preparation. Reaction conditions: (a) $BrCH_2COBr$, TEA, DCM, rt, 3h; (b) TEA, Me_2CO, rt, 8h; (c) DEA, K_2CO_3, DMF, rt, 12h; (d) $LiAlH_4$, THF, rt, 4h; (e) C_2H_5Br, Me_2CO, rt, 24h.

To explore the catalytic activity and selectivity of the new iron (III) catalysts, a typical reaction was carried out by using 4-methylbenzyl alcohol (**1a**) as a model substrate and 30 wt% H_2O_2 as oxidant (Table 1). In the absence of ligand, this $FeCl_3$-catalyzed reaction proceeded rather sluggishly in water at room temperature, and a noticeable overoxidation to 4-methylbenzoic acid was also observed after 8 h (Table 1, entry 1). The screening of ligands showed that 2,2'-bipyridine (**bpy**, Table 1, entry 2), which was reported as an attractive ligand for the copper-mediated O_2 oxidation of alcohols,[4b,11a] worked less efficiently than **AQ** and *N*-Methylated **AQ** (**AQ-Me**, Table 1, entries 3 and 4). Because the use of TBAB as an additive led to an increased yield in the $FeCl_3$/**AQ-Me** catalytic system (Table 1, entry 5), we reasoned that **L1** or **L2**, a water-soluble ligand based on the quaternization of **AQ-Me**, should facilitate much more an efficient catalytic oxidation of primary alcohols. Indeed, the use of **L1** or **L2** as ligand was shown to improve further the catalyst activity. By contrast, the *in situ*-formed $FeCl_3$/**L2** complex was a much more effective catalyst that led to complete conversion of **1a** into **2a** within 1.5 h (Table 1, entry 6 versus entry 7). Moreover, the optimal mol ratio of $FeCl_3$ to **L2** was investigated and found to be 1:1 (Table 1, entries 7-9). At this ratio, reduction in the amount of Fe to 2 mol% and of H_2O_2 to 2 mmol almost did not affect the yield (Table 1, entries 10 and 11). However, when the same reaction was carried out in MeCN instead of water, the overoxidation occurred significantly and resulted in a decreased yield (Table 1, entry 12). Hence, these results show that water as a solvent favours the activity and selectivity of such a catalytic system.

Table 1 Optimization of the reaction conditions.[a]



Entry	Catalyst (mol %)	H_2O_2 (equiv)	Time (h)	Yield (%)[b]
1	$FeCl_3$ (3)	3	8	9
2	$FeCl_3$ (3) + **bpy** (3)	3	3	37
3	$FeCl_3$ (3) + **AQ** (3)	3	3	48
4	$FeCl_3$ (3) + **AQ-Me** (3)	3	3	62
5[c]	$FeCl_3$ (3) + **AQ-Me** (3)	3	2	79
6	$FeCl_3$ (3) + **L1** (3)	3	3	74
7	$FeCl_3$ (3) + **L2** (3)	3	1.5	92
8	$FeCl_3$ (3) + **L2** (6)	3	5	53
9	$FeCl_3$ (3) + **L2** (9)	3	5	11
10	$FeCl_3$ (2) + **L2** (2)	3	1.5	90
11	**$FeCl_3$ (2) + L2 (2)**	**2**	**1.5**	**93**
12[d]	$FeCl_3$ (2) + **L2** (2)	2	2.5	49

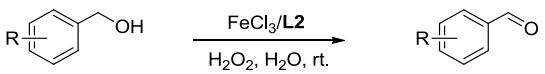
[a] 1) The catalyst was formed *in-situ* by stirring $FeCl_3{\cdot}6H_2O$ and Ligand in 1 mL H_2O to give a clear yellow solution after 10 minutes; 2) Reaction conditions: 4-methylbenzyl alcohol (**1a**, 1 mmol) and H_2O_2 (30 wt% in H_2O) were added dropwise into the above solution at room temperature with stirring within 10 minutes. [b] Isolated yield. [c] 10 mol% TBAB was added. [d] The same conditions as in *a*, but 1 mL MeCN was used instead of water as the solvent.

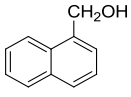
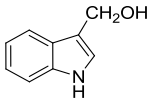
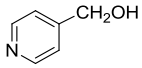
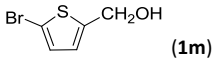
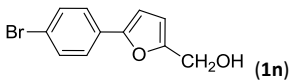
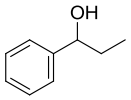
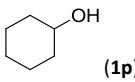
With the above optimized conditions in hand, we next investigated the substrate scope of the *in situ*-formed $FeCl_3$/**L2** complex and its chemoselectivity.

The oxidation of various benzylic primary alcohols were examined under the optimized conditions. As shown in Table 2, alcohols (**1b**-**j**) were smoothly oxidized to aldehydes (**2b**-**j**) in water at room temperature with little formation of carboxylic acids. Functionalized alcohols containing halogens (F or Cl), ethers, ester and di-*N*-methylated aniline underwent clean and efficient oxidations in excellent yields (Table 2, entries 1 and 3-8). 4-Biphenylmethanol and 1-naphthyl carbinol were also compatible with the reaction conditions (Table 2, entries 2 and 9). Thus, this catalytic system showed broad substrate scope and remarkable functional group tolerance. In addition, the catalyst was shown to be efficient for the selective oxidation of heteroaromatic primary alcohols. Under the above-optimized conditions, substrates including indole (**1k**), pyridine (**1l**), brominated thiophene (**1m**) and substituted furfural (**1n**) were

converted to exclusively the corresponding aldehydes (**2k**-**n**) (Table 2, entries 10-13), which suggested that functional group tolerance extends to this class of educts. It is worthwhile that after 5 h, both activated and non-activated secondary alcohols (**1o** and **1p**) were essentially unreactive at room temperature or even at 80 °C, and therefore can be recovered in high yields (Table 2, entries 14 and 15). Moreover, the presence of **1o** did not affect the oxidation rate and yield of a primary alcohol (**1b**, Table 2, entry 16). Therefore, these results displayed that such catalyst is exclusively active towards primary alcohols.

Table 2 The oxidation of benzylic primary alcohols to aldehydes.[a]



Entry	Substrate	Product	Time, Yield[b]
1	R = 2-OCH_3 (**1b**)	**2b**	2h, 87%
2	= 4-Ph (**1c**)	**2c**	2h, 91%
3	= 3-Cl (**1d**)	**2d**	3h, 89%
4	= 3,4-(OCH_2O) (**1e**)	**2e**	3h, 94%
5	= 4-NO_2 (**1f**)	**2f**	3h, 82%
6	= 2-F (**1g**)	**2g**	3h, 73%
7	= 4-$N(CH_3)_2$ (**1h**)	**2h**	3h, 85%
8	= 4-$COOCH_3$(**1i**)	**2i**	3h, 86%
9	 (**1j**)	**2j**	3h, 83%
10	 (**1k**)	**2k**	3h, 80%
11	 (**1l**)	**2l**	2h, 79%
12	 (**1m**)	**2m**	3h, 77%
13	 (**1n**)	**2n**	3h, 88%
14	 (**1o**)	**2o**	5h, trace[c] 91% recovery
15	 (**1p**)	**2p**	5h, trace[c] 89% recovery
16	**1b** + **1o**	**2b**	2h, 85%[d]

[a] Reaction conditions: the *in situ*-formed $FeCl_3$/**L2** complex (2 mol%) in 1 mL H_2O, substrate (1 mmol), H_2O_2 (30 wt% in H_2O, 2 mmol) at room temperature. [b] Isolated yield. [c] Apart from at room temperature, heating at 80 °C was also performed. [d] A mixture of **1b** and **1o** in a molar ratio of 1:1 was used.

In addition to benzylic primary substrates, allylic primary alcohols were also amenable to such oxidation. Representative examples were illustrated in Table 3, entries 1-3, where (s)-perillyl alcohol (**3a**) and (E)-cinnamyl alcohols (**3b** and **3c**) underwent facile oxidation to the corresponding aldehydes (**4a**-**4c**) in good yields. Interestingly, the C=C double bonds did not be affected and the overoxidation to carboxylic acids also did not occur during the reactions. On the other hand, the present procedure proved to be very easy to scale up by performing entry 3 on a 10-mmol scale, and found that the yield was almost identical to that obtained on a 1-mmol scale.

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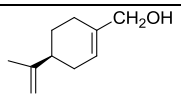
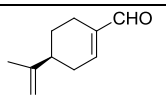
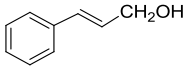
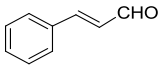
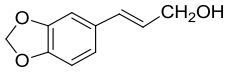
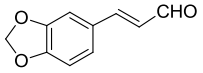
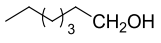
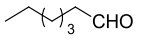
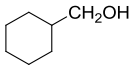
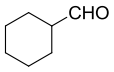
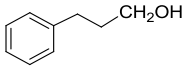
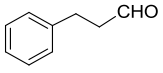
Different from most of the reported iron catalytic systems that were often limited to activated benzylic and/or allylic primary alcohol oxidations, this $FeCl_3$/**L2** complex was capable of catalysing the oxidation of non-activated aliphatic primary alcohols **3d**-**3f** to the corresponding aldehydes **4d**-**4f** (Table 3, entries 4-6), albeit after longer reaction times in comparison with benzylic primary alcohols. As a result, even in the presence of an aliphatic primary alcohol group, the chemoselective oxidation of a benzylic one could be achieved by the appropriate choice of the reaction time.

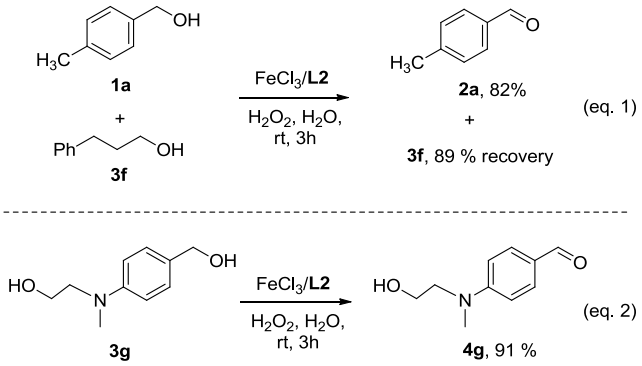
Table 3 Representative examples of allylic and aliphatic primary alcohol oxidations.[a]

Entry	Substrate	Product	Time, Yield[b]
1	 **3a**	 **4a**	5 h 81 %
2	 **3b**	 **4b**	5 h 84 %
3	 **3c**	 **4c**	5 h 88 % 85 %[c]
4	 **3d**	 **4d**	7 h 71 %
5	 **3e**	 **4e**	7 h 75 %
6	 **3f**	 **4f**	7 h 79 %

[a] Reaction conditions: the *in situ*-formed $FeCl_3$/**L2** complex (2 mol%) in 1 mL H_2O, substrate (1 mmol), H_2O_2 (30 wt% in H_2O, 2 mmol) at room temperature. [b] Isolated yield. [c] Reaction was performed on a 10-mmol scale: **3c** (10 mmol), H_2O_2 (30 wt% in H_2O, 20 mmol) at room temperature, 8 h.

The possibility of this chemoselectivity was investigated by a competition between benzylic and aliphatic primary alcohol oxidation. Thus, a mixture of **1a** and **3f** in a molar ratio of 1:1 was subjected to the $FeCl_3$/**L2**-catalyzed oxidation. Whereas the oxidation of **1a** was almost complete within 3 h to give an 82 % isolated yield of **2a**, the unreacted **3f** was recovered in 89 % yield (Scheme 3, eq. 1). Based on the results, we next turned to the synthetically more useful case of intramolecular competition between benzylic and aliphatic primary alcohols.

Therefore, the oxidation of diol (**3g**) was carried out under the same conditions. As expected, the chemoselective oxidation took place efficiently to afford the benzaldehyde **4g** in 91 % yield, where the aliphatic primary alcohol group remained completely intact (Scheme 3, eq. 2).



Scheme 3 The chemoselective oxidation of a benzylic primary alcohol in the presence of an aliphatic one. Reaction conditions: the *in situ*-formed $FeCl_3$/**L2** complex (2 mol%) in 1 mL H_2O, **1a**, **3f** or **3g** (1 mmol), H_2O_2 (30 wt% in H_2O, 2 mmol).

In this procedure, recovery of the water-soluble $FeCl_3$/**L2** complex was easy and efficient (by solvent extraction of the water layer after separating the organic layer). Furthermore, this catalyst was reused several times without obvious loss of activity, as shown in Table 4.

Table 4 Reusability of the catalyst in the oxidation of **1a**.[a]

Run	1	2	3
Time (h)	1.5	1.5	2
Yield[b] (%)	95	89	78

[a] Reaction was carried out on a 1- mmol scale. [b] Isolated yield.

Conclusions

In summary, we have developed a novel water-soluble iron(III) catalyst that is highly efficient, chemoselective and reusable for primary alcohol oxidations. It has demonstrated that in water at room temperature, the *in situ*-formed $FeCl_3$/**L2** complex catalyses the H_2O_2-oxidation of primary alcohols to aldehydes in good to high yields and where secondary alcohols do not react. The major advantages of this method apart from a very popular room-temperature water as solvent is that it enables the oxidation of a broad range of primary alcohols, including benzylic, allylic and aliphatic derivatives, and is not only highly selective for conversion of primary alcohols to aldehydes with little formation of carboxylic acids, but which also exhibits selectivity for a benzylic primary alcohol even in the presence of an aliphatic one.

Experimental

General Methods

All reagents were obtained from Sigma-Aldrich Chemical Co. or Alfa Aesar. ^{1}H-NMR spectra were recorded on a Bruker Avance DPX 400 (400 MHz) spectrometer at 400 MHz using $CDCl_3$ or D_2O as the solvent. The chemical shifts are reported in δ (ppm) values. Coupling constants are reported in hertz (Hz). The following abbreviations are used to designate the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet and m = multiplet. ^{13}C-NMR spectra were recorded on a Bruker Avance DPX 400 (400 MHz) spectrometer at 100 MHz using $CDCl_3$ or D_2O as the solvent. Elemental analyses were obtained on an Elementar Vario EI.

Procedures for the synthesis of ligands and substrates

N-methyl-8-aminoquinoline[15] (**AQ-Me**)

8-Aminoquinoline (**AQ**, 0.65 g, 4.5 mmol) and CH_3I (0.85 g, 6.0 mmol) were dissolved in 15 mL DMF, then K_2CO_3 (0.63 g, 4.5 mmol) was added to the solution and stirred at room temperature for 24 hours. After a routine workup including that the reaction mixture was extracted with EtOAc (3 × 10 mL), dried over Na_2SO_4, and concentrated in vacuo, the desired product of **AQ-Me** was afforded as a light yellow oil by purification with silica gel flash chromatography (0.48g, 67 % yield). ^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.77 (q, J = 5.8 Hz, 1H), 8.09 (q, J = 9.9 Hz, 1H), 7.48 (t, J = 15.8 Hz, 1H), 7.40 (q, J = 12.4 Hz, 1H), 7.11 (q, J = 9.1 Hz, 1H), 6.71 (d, J = 7.6 Hz, 1H), 6.23 (s, br, 1H), 3.09 (s, 3H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 146.80, 145.90, 138.31, 135.98, 128.61, 127.89, 121.38, 113.70, 104.14, 30.06.

2-bromo-*N*-(quinolin-8-yl)acetamide[16] (**AQ-1**)

AQ (0.65 g, 4.5 mmol) and Et_3N (0.46 g, 4.5 mmol) were dissolved in 15 mL CH_2Cl_2, then bromoacetyl bromide (0.91 g, 4.5 mmol) in 5 mL CH_2Cl_2 was added dropwise to the solution and stirred at room temperature for 3 hours. After a routine workup including that the reaction mixture was extracted with CH_2Cl_2 (3 × 20 mL), dried over $CaCl_2$ and concentrated in vacuo, the desired product of **AQ-1** was afforded as an off-white solid (0.87g, 95% yield), which was used in the next step without further purification.

2-(Diethylamino)-*N*-(quinolin-8-yl)acetamide (**AQ-2**)

AQ-1 (0.53 g, 2.0 mmol), Et_2N (0.18 g, 2.5 mmol) and K_2CO_3 (0.35g, 2.5 mmol) were added in 10 mL DMF and stirred at room temperature for 12 hours. After a routine workup including that the reaction mixture was extracted with EtOAc (3 × 20 mL), dried over Na_2SO_4 and concentrated in vacuo, the desired product of **AQ-2** was afforded as a light yellow oil by purification with silica gel flash chromatography (0.47g, 91% yield). ^{1}H-NMR (400 MHz, $CDCl_3$): δ 11.54 (s, 1H), 8.85 (q, J = 5.8 Hz, 1H), 8.80 (q, J = 8.9 Hz, 1H), 8.13 (q, J = 9.9 Hz, 1H), 7.56-7.51 (m, 2H), 7.49-7.41 (m, 1H), 3.31 (s, 2H), 2.73 (q, 4H),

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1.18 (t, 6H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 171.71, 149.01, 139.66, 136.53, 135.11, 128.59, 127.76, 122.13, 121.99, 117.02, 59.53, 49.28, 13.09.

N^1, *N*^{1}-diethyl-*N*^{2}-(quinolin-8-yl)ethane-1,2-diamine (**AQ-3**)

AQ-2 (0.52 g, 2.0 mmol) was added in 10 mL anhydrous THF with $LiAlH_4$ (0.11 g, 3.0 mmol) and stirred at room temperature for 4 hours. After quenching the reaction with water and filtration, **AQ-3** was afforded as a yellow oil by extraction with EtOAc (3 × 20 mL, which was then dried over Na_2SO_4 and concentrated in vacuo) and purification with silica gel flash chromatography (0.42 g, 87 % yield). ^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.72 (q, *J* = 5.8 Hz, 1H), 8.04 (q, *J* = 9.9 Hz, 1H), 7.40-7.33 (m, 2H), 7.03 (t, *J* = 8.1 Hz, 1H), 6.68 (d, *J* = 7.5 Hz, 1H), 6.40 (s, br, 1H), 3.31 (t, *J* = 12.8 Hz, 2H), 2.86 (q, 2H), 2.65 (q, 4H), 1.09 (t, 6H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 147.40, 145.54, 138.94, 136.40, 129.22, 128.30, 121.85, 114.22, 105.13, 52.32, 47.66, 41.82, 12.29.

[(C_9H_6N)-8-$NHCOCH_2NEt_3$]Br (**L1**)

Et_3N (0.25 g, 2.5 mmol) was added in the 20 mL acetone solution with **AQ-1** (0.53 g, 2.0 mmol) and stirred at room temperature for 8 hours until a white solid was formed. The resulting white solid was then filtered and washed several times with acetone to give the pure product **L1** (0.71 g, 97 % yield). ^{1}H-NMR (400 MHz, D_2O): δ 8.59 (q, *J* = 5.7 Hz, 1H), 8.01 (q, *J* = 9.7 Hz, 1H), 7.92 (d, *J* = 7.4 Hz, 1H), 7.46 (q, *J* = 7.9 Hz, 1H), 7.36-7.31 (m, 2H), 4.24 (s, 2H), 3.52 (q, 6H), 1.28 (t, 9H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 163.40, 150.33, 139.69, 137.75, 131.82, 128.69, 126.92, 126.12, 122.65, 121.98, 57.07, 55.30, 7.67. Calculated for $C_{17}H_{24}N_3OBr^-$: C, 55.74; H, 6.60; N, 11.47. Found: C, 55.72; H, 6.64; N, 11.44.

[(C_9H_6N)-8-$NHCH_2CH_2NEt_3$]Br (**L2**)

AQ-3 (0.49 g, 2.0 mmol) and C_2H_5Br (0.27 g, 2.5 mmol) were added in 10 mL acetone and stirred at room temperature for 24 hours until a white solid was formed. Then, the resulting white solid was filtered and washed several times with acetone to give the pure product **L2** (0.61g, 86 % yield). ^{1}H-NMR (400 MHz, D_2O): δ 8.59 (q, *J* = 5.6 Hz, 1H), 8.09 (q, *J* = 9.9 Hz, 1H), 7.40-7.35 (m, 2H), 7.14 (d, *J* = 7.8 Hz, 1H), 6.75 (d, *J* = 7.6 Hz, 1H), 3.63 (t, 2H), 3.31 (t, 2H), 3.24 (q, 6H), 1.13 (t, 9H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 148.83, 143.11, 138.11, 137.79, 129.32, 128.21, 122.66, 117.10, 107.23, 54.85, 53.81, 36.81, 7.26. Calculated for $C_{17}H_{26}N_3Br^-$: C, 57.95; H, 7.44; N, 11.93. Found: C, 57.94; H, 7.33; N, 11.95.

(*E*)-3,4-(Methylenedioxy)cinnamyl alcohol[17](**3c**)

The aldehyde of **4c** (0.35 g, 2.0 mmol) was added in the 10 mL MeOH with $NaBH_4$ (0.11 g, 3.0 mmol) and stirred at room temperature for 10 hours. After quenching the reaction with water, **3c** was afforded as a white solid by extraction with EtOAc (3 × 20 mL, which was then dried over Na_2SO_4 and concentrated in vacuo) and purification with silica gel flash chromatography (0.33 g, 92 % yield). m.p. 70.1-70.7 °C. ^{1}H-NMR (400 MHz, $CDCl_3$): δ 6.90 (s, 1H), 6.79 (d, *J* = 8.0 Hz, 1H), 6.73 (d, *J* = 8.0 Hz, 1H), 6.48 (q, *J* = 15.8 Hz, 1H), 6.20-6.13 (m, 1H), 5.93 (s, 2H), 4.25 (q, *J* = 6.8 Hz, 2H), 2.25 (s, br, 1H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 148.53, 147.79, 131.71, 131.37, 127.28, 121.68, 108.81, 106.28, 101.60, 64.10.

2-((4-(hydroxymethyl)phenyl)(methyl)amino)ethanol (**3g**)

The aldehyde of **4g** (0.36 g, 2.0 mmol) was added in the 10 mL MeOH with $NaBH_4$ (0.11 g, 3.0 mmol) and stirred at room temperature for 10 hours. After quenching the reaction with water, **3g** was afforded as a viscous light yellow oil by extraction with EtOAc (3 × 20 mL, which was then dried over Na_2SO_4 and concentrated in vacuo) and purification with silica gel flash chromatography (0.34 g, 94 % yield). ^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.23 (d, *J* = 8.6 Hz, 2H), 6.77 (t, *J* = 14.2 Hz, 2H), 4.56 (s, 2H), 3.80 (t, *J* = 11.3 Hz, 2H), 3.46 (t, *J* = 11.4 Hz, 2H), 2.96 (s, 3H), 1.86 (s, br, 2H). ^{13}C-NMR (100 MHz, $CDCl_3$): δ 150.28, 130.03, 129.27, 114.18, 113.54, 65.76, 60.59, 55.94, 39.41. Calculated for $C_{10}H_{15}NO_2$: C, 66.27; H, 8.34; N, 7.73. Found: C, 66.25; H, 8.29; N, 7.79.

Procedure for the alcohol oxidations

$FeCl_3{\cdot}6H_2O$ (5.4 mg, 20 μmol, 2.0 mol %) and **L2** (7.0 mg, 20 μmol, 2.0 mol %) were mixed in 1 mL H_2O and stirred at room temperature to give a yellow clear solution in 20 minutes. After addition of the substrate (1 mmol) into the above solution, the mixture was vigorously stirred and then H_2O_2 (30 wt% in water, 2 mmol, 0.2 mL) was added dropwise continuously with a syringe pump in 10 minutes at room temperature. When the reaction was complete, the aldehyde layer was separated and rapidly purified with silica gel flash chromatography to get the desired aldehyde product; the water layer was recovered by extraction with EtOAc (2 × 10 mL) for reuse.

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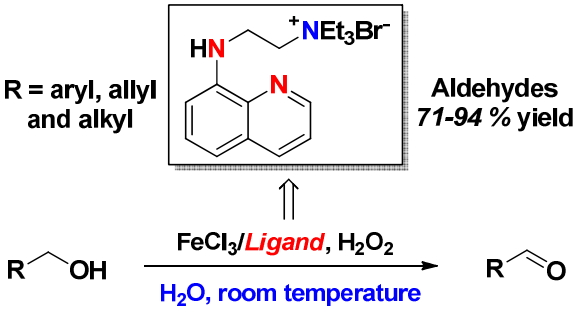
Graphic Abstract



A novel, water-soluble and reusable $FeCl_3$ catalyst showed high catalytic activity and chemoselectivity in the H_2O_2-oxidation of primary alcohols into aldehydes.