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Conversion of aldoximes into nitriles catalyzed by simple transition metal salt of the fourth period in acetonitrile

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ABSTRACT

Conversion of aldoximes into nitriles catalyzed by simple transition metal catalysts, such as copper salts, nickel salts, cobalt salts, zinc salts, iron salts, and manganese salts in acetonitrile was investigated. All the metal salts display catalytic property in the conversion of aldoximes into nitriles and cupric acetate exhibits much higher activity than other catalysts. The corresponding amide was detected in almost all cases and acetonitrile was found to be involved in the conversion of aldoximes into nitriles.

1. Introduction

Dehydration of aldoximes is a useful method for the synthesis of nitriles, which are important synthetic intermediates for pharmaceuticals, agricultural chemicals, dyes, and material sciences.[1] In the past 40 years, a variety of reagents, such as acid anhydrides,[2] acids,[3] bases,[4] acid chlorides,[5] *N*-triflylimidazole,[6] bromodimethylsulfonium bromide,[7] phosphorus-containing compounds,[8] etc. have been introduced for the dehydration of aldoximes to nitriles. However, the approach suffers from some disadvantages, such as the use of stoichiometric amounts of reagents and limitations arising from the sensitivity of some functional groups to the reaction conditions. Thus, the development of metal-catalyzed dehydration of aldoxime has received much attention. A number of metal catalysts, such as nickel catalysts,[9] metal triflates,[10] $[RuCl_2(pcymene)]$,[11] $[(CH_3CH_2CN)_2PtCl_4]$,[12] copper salts,[13] zinc salts,[14] $Pd(OAc)_2$,[15] $[(Ipr)AuCl]/AgBF_4$,[16] iron porphyrin,[17] and tungsten-tin mixed hydroxide[18] have been reported. In addition, supported catalyst[19] and ionic liquid[20] were employed in the conversion of aldoximes into nitriles.

In our previous study,[21] we disclosed an efficient method for the conversion of nitriles into the corresponding amides by employing acetaldoxime and simple transition metal catalysts of the fourth period. In the continuation of the study on simple transition metal catalysts for the chemical transformation, we found that aldoximes were converted into the corresponding nitriles catalyzed by simple transition metal catalysts, such as copper salts, nickel salts, cobalt salts, zinc salts, iron salts, and manganese salts in acetonitrile. The corresponding amide was detected as a by-product in almost all cases and the yield of amide depends on the hydration of the nitrile product.

At the same time, we have noticed that the conversion of aldoximes into nitriles catalyzed by cupric acetate ($Cu(OAc)_2$),[13a] $CuCl_2$ under ultrasound conditions[13b] and nickel salts[9b] in acetonitrile have been reported. In these literature, catalytic dehydration of aldoximes were performed efficiently with catalyst in acetonitrile. However, they did not mention the formation of amide except *p*-nitrobenzamide.[9b] Moreover, they did not found that acetonitrile plays an important role in the reaction. In the course of our study, we are certain that the corresponding amide was obtained as a by-product in almost all cases and acetonitrile play dual roles as solvent and reagent in the reaction.

2. Results and discussion

In this paper, *p*-methoxybenzaldoxime was selected as a model substrate to investigate the catalytic activity of various metal salts of the fourth period. As shown in Table 1, we found that all the metal salts displayed catalytic properties in the conversion of *p*-methoxybenzaldoxime into *p*-methoxybenzonitrile (Table 1, entries 2–14) and cupric acetate showed the highest catalytic activity (Table 1, entry 4). Both the cation and anion of the metal salt had an

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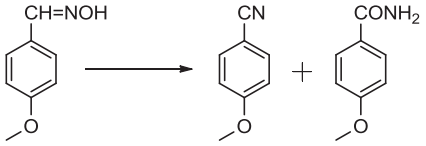
Table 1
Screen of reaction conditions[a]



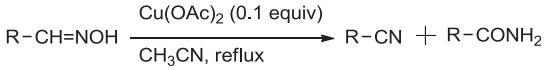
Entry	Conditions	(Yield) (%)[b]	
		Nitrile	Amide
1	CH_3CN, reflux, 24 h.	—	—
2	CuO (0.1 equiv), CH_3CN, reflux, 24 h.	85	6
3	$CuCl_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 3 h	91	9
4	$Cu(OAc)_2$ (0.1 equiv), CH_3CN, reflux, 0.25 h	96 (90)	4
5	$Cu(OAc)_2$ (0.05 equiv), CH_3CN, reflux, 1.5 h	96	4
6	$Ni(OAc)_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 4 h	92	8
7	$NiCl_2·6H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	86	13
8	$CoCl_2·6H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	91	8
9	$Co(OAc)_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 12 h	93	7
10	$ZnCl_2$ (0.1 equiv), CH_3CN, reflux, 24 h	92	7
11	$Zn(OAc)_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	93	6
12	$FeCl_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	13	Trace
13	$MnCl_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	12	Trace
14	$Mn(OAc)_2·4H_2O$ (0.1 equiv), CH_3CN, reflux, 24 h	16	Trace
15	$Cu(OAc)_2$ (0.1 equiv), CH_3CN, rt, 24 h	91	Trace
16	$Cu(OAc)_2$ (0.1 equiv), CH_3OH, rt, 24 h	—	—
17	$Cu(OAc)_2$ (0.1 equiv), $(CH_3)_2CHOH$, rt, 24 h	—	—
18	$Cu(OAc)_2$ (0.1 equiv), toluene, rt, 24 h	—	—
19	$Cu(OAc)_2$ (0.1 equiv), dioxane, rt, 24 h	—	—

[a] Reaction conditions: *p*-methoxybenzaldoxime (2 mmol), solvent (5 mL).
[b] Determined by GC. In brackets the isolated yield is stated.

effect on the catalytic property. Treatment of *p*-methoxybenzaldoxime with cupric acetate ($Cu(OAc)_2$), copper(II) chloride dihydrate ($CuCl_2·2H_2O$), nickel(II) acetate tetrahydrate ($Ni(OAc)_2·4H_2O$) or cobalt(II) acetate ($Co(OAc)_2·4H_2O$) at refluxing temperature in anhydrous acetonitrile afforded 100% conversion (Table 1, entries 3–6 and 8). When we reduced the amounts of catalyst to 5 mol % (Table 1, entry 5), *p*-methoxybenzaldoxime was converted to the corresponding nitrile and amide with complete conversion after a relatively long reaction time of 1.5 h. *p*-Methoxybenzamide was detected in each case and the yield of *p*-methoxybenzamide depends on the catalyst. When nickel(II) chloride hexahydrate ($NiCl_2·6H_2O$) was used as a catalyst, *p*-methoxybenzamide was obtained in relatively high yield (Table 1, entry 7). When iron salt or manganese salt was used as a catalyst, a trace amount of *p*-methoxybenzamide was detected (Table 1, entries 12–14). In addition, we found that the conversion of *p*-methoxybenzaldoxime into *p*-methoxybenzonitrile can proceed at ambient temperature when $Cu(OAc)_2$ was used as a catalyst (Table 1, entry 15). However, use of other solvent in place of acetonitrile resulted in no product when the reaction was carried out at room temperature (Table 1, entries 16–19). Therefore, we thought that acetonitrile may be involved in the reaction.

On the basis of the above results, we can conclude that using cupric acetate ($Cu(OAc)_2$) in acetonitrile at refluxing temperature is the optimal conditions for the conversion of aldoximes into nitriles. This protocol was subsequently applied to various aromatic aldoximes, aliphatic aldoxime and heterocyclic aldoximes. As shown in Table 2, various aldoximes including aromatic aldoximes (Table 2, entries 1–8), aliphatic aldoxime (Table 2, entry 9) and heterocyclic aldoximes (Table 2, entries 10–12) were converted into the corresponding nitriles and amides with complete conversion. Substrates bearing an electron-donating group proceed more effectively than aldoximes with an electron-withdrawing group (Table 2, entries 3 and 7), the sterically unhindered aldoximes were easier to convert into the corresponding nitriles than the sterically hindered aldoximes (Table 2, entries 2–4). Heterocyclic aldoximes with a heteroatom lone pair positioned *ortho* to the oximido group

Table 2
Conversion of various aldoximes using cupric acetate and acetonitrile[a]



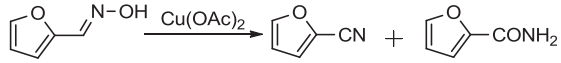
Entry	Substrate (R)	Time (h)	Yield (%)[b]	
			Nitrile	Amide
1	Ph	1	99 (91)	1
2	2-Cl–C_6H_4	1.5	100 (95)	—
3	4-Cl–C_6H_4	1	90 (83)	10
4	2-Cl-4-Cl–C_6H_3	2	99 (93)	Trace
5	4-NO_2–C_6H_4	1	88 (80)	12
6	3-MeO-4-MeO-5-MeO–C_6H_2	0.75	95 (87)	5
7	4-OH–C_6H_4	0.25	96 (89)	4
8	4-$N(CH_3)_2$–C_6H_4	0.25	99 (92)	Trace
9	n-$C_{11}H_{23}$	1	99 (86)	Trace
10	4-Pyridyl	1.5	85 (77)	15
11	2-Furyl	0.25	57 (50)	43
12	2-Thienyl	0.25	69 (61)	31

[a] Reaction conditions: aldoxime (2 mmol), $Cu(OAc)_2$ (0.2 mmol), anhydrous acetonitrile (5 mL), reflux.
[b] Determined by GC. In brackets the isolated yield is stated.

show high reactivity and these aldoximes were converted to the corresponding nitriles and amides with complete conversion after a short reaction time of 15 min (Table 2, entries 11–12). From Table 2, it can be seen that the corresponding amide was obtained as a by-product in all cases except 2-chlorobenzaldehydeoxime. More amide was obtained in the case of aldoxime having electron-withdrawing group and aldoximes without steric hindrance. In the case of heterocyclic aldoxime with a heteroatom lone pair positioned *ortho* to the oximido group, the yield of the corresponding amide was reached over 30% (Table 2, entries 11–12). To our surprise, the above phenomenon of formation of amide is similar to the hydration of nitriles catalyzed by transition metal salt with the aid of acetaldoxime.[21] Therefore, we guessed that the conversion of aldoximes to nitriles may not proceed via the routes reported in the literature[9b,13a] and acetonitrile may be involved in the reaction.

To prove our guess, we selected (*E*)-furan-2-carbaldehyde oxime as a model substrate to investigate the reaction pathway. As can be seen from Table 2, furan-2-carbaldehyde oxime showed high reactivity and a complete conversion of furan-2-carbaldehyde oxime took place within 15 min at refluxing temperature. In fact, this reaction can proceed at ambient temperature and 100% of (*E*)-furan-2-carbaldehyde oxime was transformed into furan-2-carbonitrile and furan-2-carboxamide. As show in Table 3, we found that (*E*)-furan-2-carbaldehyde oxime was not converted to furan-2-carbonitrile by the action of cupric acetate ($Cu(OAc)_2$) alone (Table 3, entry 1). When 0.1 equiv of acetonitrile was added, 100% of (*E*)-furan-2-carbaldehyde oxime was transformed into furan-2-carboxamide at room temperature (Table 3, entry 2). Therefore, we can conclude that acetonitrile was not only involved in the reaction but that it also regenerated in this reaction. To our surprise, a mixture of furan-2-carbonitrile and furan-2-carboxamide was obtained when we increased the amounts of acetonitrile (Table 3, entry 3) and the furan-2-carbonitrile was completely converted to furan-2-carboxamide when an additional acetaldoxime was added. Based on the above results, we proposed a possible reaction pathway as follows: (*E*)-furan-2-carbaldehyde oxime reacted with acetonitrile in the presence of transition metal catalyst to give furan-2-carbonitrile and acetaldoxime, and then furan-2-carbonitrile reacted with acetaldoxime in the presence of transition metal catalyst to afford furan-2-carboxamide and acetonitrile.[21,22] According to the proposed reaction pathway, we know that the existence of massive acetonitrile impedes the hydration of nitrile on the basis of the principles of chemical equilibrium. Moreover, acetonitrile can also be hydrated in presence of

Table 3
Conversion of (*E*)-furan-2-carbaldehyde oxime[a]



Entry	Conditions	Yield (%)[b]	
		Nitrile	Amide
1	$Cu(OAc)_2$ (10 mol %), H_2O (3 mL), rt, 12 h	—	—
2	$Cu(OAc)_2$ (10 mol %), H_2O (3 mL), acetonitrile (0.1 equiv) rt, 12 h	Trace	99
3	Cu(OAc)2 (10 mol %), H2O (3 mL), acetonitrile (3 mL) rt, 8 h	42	58
4	$Cu(OAc)_2$ (10 mol %), H_2O (3 mL), acetonitrile (0.1 equiv) 80 °C, 3 h	—	78[c]

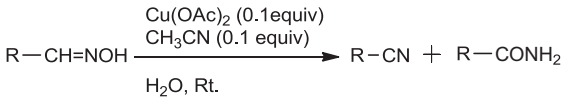
[a] Reaction conditions: aldoxime (2 mmol), $Cu(OAc)_2$ (0.2 mmol).
[b] Determined by GC.
[c] Furan-2-carbaldehyde was obtained in 21% yield.

catalyst and acetaldoxime. Therefore, a mixture of furan-2-carbonitrile and furan-2-carboxamide was obtained when an excess of acetonitrile was used. In contrast, the (*E*)-furan-2-carbaldehyde oxime was completely transformed to furan-2-carboxamide when a catalytic amount of acetonitrile was used.

In addition, the effect of water on the reaction was studied. The presence of water in the reaction system did not affect the reaction at room temperature (Table 3, entries 2–3). When we increased the reaction temperature, furan-2-carbaldehyde was detected (Table 3, entry 4). No aldehyde was obtained when anhydrous acetonitrile was used as solvent (Table 2, entry 11). Therefore, the presence of water can result in the formation of the corresponding aldehyde under the condition of heating. This is the reason why we used anhydrous acetonitrile as solvent in the above study.

It is worth pointing out that this efficient chemical transformation did not occur in the case of ordinary aldoximes. As shown in Table 4, no product was obtained in the cases of substrates bearing an electron-withdrawing group (Table 4, entries 2–3). Actually, these reactions also did not proceed at room temperature when an excess of acetonitrile was used. In the case of substrate having an electron-donating group, the corresponding nitrile was obtained in low yield (Table 4, entry 4). Although the aldoximes bearing an electron-donating group can be transformed to the corresponding nitrile, the product nitrile with electron-donating group can not be hydrated by catalyst and acetaldoxime at room temperature according to our previous study.[21] Thiophene-2-carbaldehyde oxime with a heteroatom lone pair positioned *ortho* to the oximido group show relatively high reactivity and it can be converted to thiophene-2-carbonitrile at room temperature. In addition, the product thiophene-2-carbonitrile can be hydrated by catalyst and acetaldoxime at room temperature according to our previous study.[21] Therefore, thiophene-2-carboxamide was obtained in 46% yield (Table 4, entry 4).

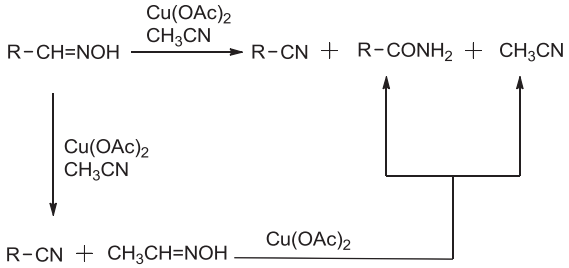
Table 4
Conversion of various aldoximes to the corresponding amide[a]



Entry	Substrate (R)	Time (h)	Yield (%)[b]	
			Nitrile	Amide
1	Ph	24	Trace	—
2	4-Cl–C_6H_4	24	—	—
3	4-Pyridyl	24	—	—
4	4-MeO–C_6H_4	24	8	Trace
5	2-thienyl	24	13	46

[a] Reaction conditions: aldoxime (2 mmol), $Cu(OAc)_2$ (0.2 mmol), CH_3CN (0.2 mmol), H_2O (3 mL).
[b] Determined by GC.

Furan-2-carbaldehyde oxime and furan-2-carbonitrile show high reactivities in the conversion of them to furan-2-carbonitrile and furan-2-carboxamide, respectively and these reactions can be carried out at room temperature. So, furan-2-carbaldehyde oxime was completely converted to furan-2-carboxamide catalyzed by metal salt and acetonitrile. Although this efficient chemical transformation did not occur in the case of ordinary aldoximes, we thought that the same reaction process occurred in the conversion of all the aldoximes into the corresponding nitriles. A possible reaction pathway was presented in Scheme 1. Initially, aldoxime reacts with acetonitrile in the presence of transition metal catalyst to give the corresponding nitrile and acetaldoxime, and then the nitrile product reacts with acetaldoxime in the presence of transition metal catalyst to give the corresponding amide.



Scheme 1. Proposed reaction pathway of aldoximes conversion via $Cu(OAc)_2$ and acetonitrile.

3. Conclusion

In summary, we investigated the catalytic activity of various metal salts, such as copper salts, nickel salts, zinc salts, cobalt salts, iron salts, and manganese salts in the conversion of aldoximes into nitriles. All the metal salts displayed catalytic properties and cupric acetate ($Cu(OAc)_2$) showed the highest catalytic activity. The corresponding amide was often obtained as a by-product and the yield of amide depends on the hydration of the nitrile product. Acetonitrile was found to be involved in the conversion of aldoximes into nitriles and a possible reaction pathway was proposed to explain the formation of amide.

4. Experimental section

4.1. General methods

NMR spectra were obtained from a Bruker DPX 500 spectrometer. GC analyses of organic compounds were performed on an Agilent Technologies 1790 GC. Analytical thin layer chromatography (TLC) was performed on precoated silica gel 60 F254 plates. Yields refer to the isolated yields of the products after purification by silica-gel column chromatography (300 mesh). Aldoximes were synthesized according to the method reported in the literature.[16]

4.2. General procedure for the synthesis of amides

To a 25 mL round-bottom flask equipped with magnetic stirrer were added aldoximes (2 mmol), $Cu(OAc)_2$ (0.2 mmol), acetonitrile (5 mL). The mixture was heated to reflux for 0.25–1.5 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane) to give the corresponding nitriles. All the nitriles are commercially available and they were characterised by melting point or ^1H NMR spectra. Their physical and spectroscopic data was compared with those of pure examples.

4.2.1. 4-Methoxybenzonitrile (Table 1, entry 4). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 4-methoxybenzaldehyde oxime 302 mg (2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.25 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:4) to give 4-methoxybenzonitrile as a white solid (239 mg, 90%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.86 (s, 1H), 6.97 (d, J=8.8 Hz, 2H), 7.61 (d, J=8.8 Hz, 2H). Data are in good agreement with the literature.[19]

4.2.2. Benzonitrile (Table 2, entry 1). To a 25 mL round-bottom flask equipped with magnetic stirrer were added benzaldehyde oxime (241 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give benzonitrile as a colourless liquid (187 mg, 91%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.49 (m, 2H), 7.63 (m, 1H), 7.67 (d, J=1.0 Hz, 2H) Data are in good agreement with the literature.[23]

4.2.3. 2-Chlorobenzonitrile (Table 2, entry 2). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 2-chlorobenzaldehyde oxime (311 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1.5 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:10) to give 2-chlorobenzonitrile as a white solid (261 mg, 95%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.39 (m, 1H), 7.56 (m, 2H), 7.69 (m, 1H) Data are in good agreement with the literature.[24]

4.2.4. 4-Chlorobenzonitrile (Table 2, entry 3). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 4-chlorobenzaldehyde oxime (311 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give 4-chlorobenzonitrile as a white solid (228 mg, 83%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.48 (d, J=8.4 Hz, 2H), 7.62 (d, J=8.4 Hz, 2H). Data are in good agreement with the literature.[24]

4.2.5. 2,4-Dichlorobenzonitrile (Table 2, entry 4). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 2,4-dichlorobenzaldehyde oxime (380 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 2 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give 2,4-dichlorobenzonitrile as a white solid (320 mg, 93%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.39 (m, 1H), 7.55 (m, 1H), 7.62 (m, 1H). Data are in good agreement with the literature.[25]

4.2.6. 4-Nitrobenzonitrile (Table 2, entry 5). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 4-nitrobenzaldehyde oxime (332 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:5) to give 4-nitrobenzonitrile as a white solid (237 mg, 80%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.90 (m, 2H), 8.37 (m, 2H). Data are in good agreement with the literature.[23]

4.2.7. 3,4,5-Trimethoxylbenzonitrile (Table 2, entry 6). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 3,4,5-trimethoxybenzaldehyde oxime (422 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.75 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:3) to give 3,4,5-trimethoxybenzonitrile as a white solid (336 mg, 87%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.87 (s, 6H), 3.89 (s, 3H), 6.86 (s, 2H). Data are in good agreement with the literature.[26]

4.2.8. 4-Hydroxybenzonitrile (Table 2, entry 7). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 4-hydroxybenzaldehyde oxime (274 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.25 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:3) to give 4-hydroxybenzonitrile as a white solid (212 mg, 89%). ^{1}H NMR (500 MHz, DMSO-d_6): δ 6.89 (m 2H), 7.63 (m, 2H). Data are in good agreement with the literature.[27]

4.2.9. 4-(Dimethylamino)benzonitrile (Table 2, entry 8). To a 25 mL round-bottom flask equipped with magnetic stirrer were added 4-(dimethylamino)benzaldehyde oxime (328 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.25 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:10) to give 4-(dimethylamino)benzonitrile as a white solid (269 mg, 92%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.04 (s, 6H), 6.63 (m, 2H), 7.47 (m, 2H). Data are in good agreement with the literature.[25]

4.2.10. Dodecanenitrile (Table 2, entry 9). To a 25 mL round-bottom flask equipped with magnetic stirrer were added dodecanal oxime (398 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give dodecanenitrile as a colourless liquid (311 mg, 86%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.89 (t, J=7.0 Hz, 3H), 1.27–1.33 (m, 14H), 1.45 (m, 2H), 1.66 (m, 2H), 2.34 (t, J=7.2 Hz, 2H). Data are in good agreement with the literature.[28]

4.2.11. Isonicotinonitrile (Table 2, entry 10). To a 25 mL round-bottom flask equipped with magnetic stirrer were added isonicotinaldehyde oxime (244 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 1.5 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:1) to give isonicotinonitrile as a white solid (160 mg, 77%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.54 (m, 2H), 8.82 (m, 2H). Data are in good agreement with the literature.[26]

4.2.12. Furan-2-carbonitrile (Table 2, entry 11). To a 25 mL round-bottom flask equipped with magnetic stirrer were added furan-2-carbaldehyde oxime (222 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.25 h. After cooling to room temperature, the solution

was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give furan-2-carbonitrile as a colourless liquid (93 mg, 50%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.55 (m, 1H), 7.12 (m, 1H), 7.60 (m, 1H). Data are in good agreement with the literature.[29]

4.2.13. Thiophene-2-carbonitrile (Table 2, entry 12). To a 25 mL round-bottom flask equipped with magnetic stirrer were added thiophene-2-carbaldehyde oxime (254 mg, 2 mmol), cupric acetate ($Cu(OAc)_2$) 36 mg (0.2 mmol) and acetonitrile (5 mL). The mixture was heated to reflux for 0.25 h. After cooling to room temperature, the solution was directly evaporated to dryness and the residue was purified by column chromatography on silica gel (ethyl acetate/*n*-hexane=1:15) to give thiophene-2-carbonitrile as a colourless liquid (143 mg, 61%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.14 (m, 1H), 7.62 (m, 1H), 7.65 (m, 1H). Data are in good agreement with the literature.[23]

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Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2013.01.059. These data include MOL files and InChiKeys of the most important compounds described in this article.

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