Synthesis E. Voutyritsa et al. Special Topic

Photoorganocatalytic Atom Transfer Radical Addition of Bromoacetonitrile to Aliphatic Olefins

Errika Voutyritsa
Nikolaos F. Nikitas
Mary K. Apostolopoulou
Anna Dimitra D. Gerogiannopoulou
Christoforos G. Kokotos*

Department of Chemistry, National and Kapodistrian University of Athens, Panepistimiopolis, Athens 15771, Greece
ckokotos@chem.uoa.gr

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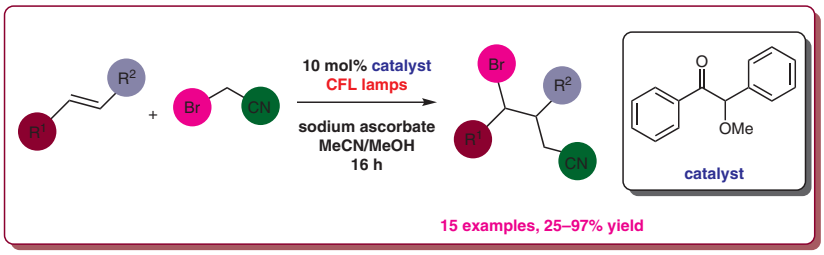

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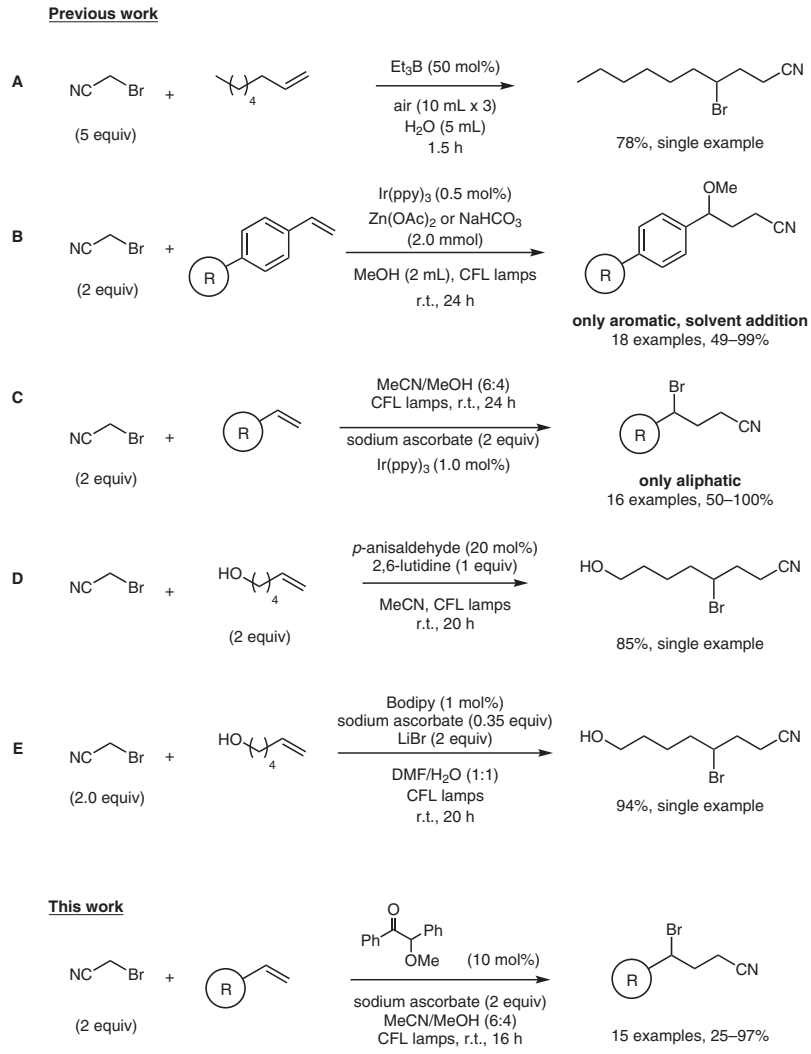
Abstract A green and cheap protocol for the photocatalytic atom transfer radical addition (ATRA) of bromoacetonitrile to aliphatic alkenes is presented. The use of benzoin methyl ehter as the photocatalyst and irradiation using a household lightbulb leads to a highly useful synthetic method for the conversion of a wide range of substituted aliphatic olefins into the corresponding bromonitriles.

Key words photoorganocatalysis, photochemistry, ATRA reaction, alkenes, bromoacetonitrile, nitriles

The successful interconversion of functional groups is one of the main targets and challenges of synthetic organic chemistry. A common challenge faced by researchers is successful functionalization via the use of radical species. A standard technique for the formation of radical species is photocatalysis, which allows the formation of different radicals under mild conditions. Molecules that are especially useful in this sense are alkyl halides that can undergo homolytic cleavage. The successful addition of the generated radicals to olefins can lead to the formation of new C–X and C–C bonds, and subsequently to augmented carbon chains.[1] Reactions of haloalkanes and halocarbonyls with unsaturated compounds, via atom transfer radical additions (ATRA) or atom transfer radical cyclizations (ATRC), are widely reported with the use of metal catalysts. Successful examples include the use of iron,[2] ruthenium,[3] copper,[4] nickel,[5] palladium[6] and iridium.[7] A revolution in the field was introduced by photoredox catalysis, with MacMillan,[8] Yoon[9] and Stephenson[10] highlighting the ability of photoredox catalysts to introduce novel organic transformations.[11] Contributions by Bach,[12] Nicewicz[13] and Melchiorre[14] have further demonstrated the ease in controlling photoinduced radical reactions.

Among synthetically versatile organic compounds, bromonitriles occupy a special place.[15,16] Recently, the photochemical atom transfer radical addition (ATRA) of bromoacetonitrile to olefins has started to play a dominant role among the methods reported for their synthesis. There are numerous examples of the addition of haloalkanes to olefins; however, the addition of bromoacetonitrile to olefins is rather less investigated (Scheme 1, **A**–**E**). In 2001, Oshima and co-workers utilized triethylborane in water for the addition of bromoacetonitrile to 1-octene (Scheme 1, **A**).[17] A drawback of this method could be considered the stoichiometric amount of the promoter that was required. More recently, two methods were developed for the addition of bromoacetonitrile to styrene derivatives under photoredox catalysis (Scheme 1, **B**).[18,19] In both cases, the olefin was limited to styrene derivatives and the intermediate radical was trapped by the alcoholic solvent, providing evidence that this method proceeds via a carbocation intermediate and that the more versatile bromide intermediates could not be isolated. We recently contributed to the literature on this area of metal-catalyzed photoredox catalysis by introducing a complementary method targeting aliphatic olefins utilizing an iridium photocatalyst and sodium ascorbate as the stoichiometric reagent to alter the mechanistic pathway (Scheme 1, **C**).[20] In 2014, the group of Melchiorre developed a photoorganocatalytic atom transfer radical addition of haloalkanes to olefins (Scheme 1, **D**). In this case, only one example using bromoacetonitrile was reported, while a stoichiometric amount of base was required.[21] Another recent photoorganocatalytic example, demonstrating a single example with bromoacetonitrile, was reported by Cozzi and co-workers (Scheme 1, **E**).[22]

We have recently turned our attention to photocatalysis,[23] including photoorganocatalysis and photoredox catalysis.



Scheme 1 Synthetic pathways for the addition of bromoacetonitrile to olefins

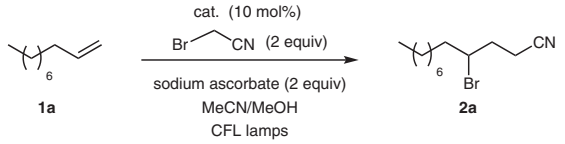
Herein, we describe an expansion of current knowledge toward a synthetic protocol for the ATRA addition of bromoacetonitrile to a wide range of aliphatic olefins bearing various functional groups utilizing benzoin methyl ether as the photoorganocatalyst (Scheme 1, bottom).

We began our investigations with the reaction between 1-decene (**1a**) and bromoacetonitrile using several different catalysts. This reaction was chosen in order to provide a complementary methodology to literature knowledge, where mostly styrene derivatives are employed. Utilizing various photoorganocatalysts, moderate to high yields of product **2a** were obtained (Table 1). Benzoin methyl ether proved to be the best photoorganocatalyst (Table 1, entry 3). Unlike previous literature precedent, no alcohol addition was observed. We believe that the nature of the substituent on the double bond (aryl vs aliphatic), which can stabilize the intermediate radical formed, is crucial for the reaction outcome.

Next, we turned our attention to screening the effect of the solvent (Table 2). A range of organic solvents was tested; however, the expected product **2a** was obtained in a lower yield in each case (Table 2, entries 1–9).

After identifying benzoin methyl ether as the optimum photocatalyst, we proceeded with optimizing the reaction conditions further by studying the performance of the reaction with and without the catalyst or sodium ascorbate, and without light (Table 3). In the absence of the photocatalyst, no reaction took place (Table 3, entry 2 vs entry 1). When the reaction was kept in the dark, 1-decene was not converted into the corresponding product (Table 3, entry 3).

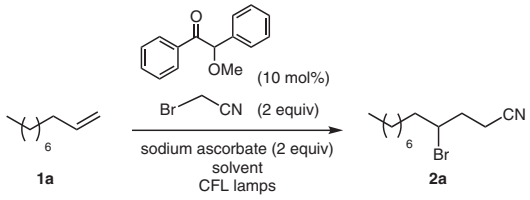
Table 1 Photoorganocatalyst Screening for the Photocatalytic Atom Transfer Radical Addition of Bromoacetonitrile to **1a**



Entry	Catalyst	Yield (%)[a]
1	phenylglyoxylic acid	33
2	thioxanthone	43
3	benzoin metyl ether	90
4	eosin	32
5	benzoin	26
6	benzophenone	0
7	2,2-dimethoxy-2-phenyl-acetophenone	27

[a] Yield of isolated product. The reaction was performed with 1-decene (0.50 mmol), catalyst (0.05 mol, 10 mol%), bromoacetonitrile (1.00 mmol) and sodium ascorbate (1.00 mmol) in MeCN (2 mL) and MeOH (1.5 mL) under irradiation with a household lightbulb for 16 h.

Table 2 Solvent Screening for the Photocatalytic Atom Transfer Radical Addition of Bromoacetonitrile to **1a**

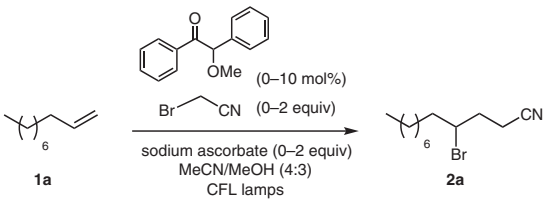


Entry	Solvent	Yield (%)[a]
1	MeCN/MeOH (2:1.5)	90
2	MeOH	18
3	MeCN	87
4	petroleum ether	21
5	EtOAc	0
6	CH_2Cl_2	37
7	$CHCl_3$	40
8	DMSO	0
9	DMF	0

[a] Yield of isolated product. The reaction was performed with 1-decene (0.5 mmol), benzoin methyl ether (0.05 mol, 10 mol%), bromoacetonitrile (1.00 mmol) and sodium ascorbate (1.00 mmol) in the solvent under irradiation with a household lightbulb for 16 h.

Moreover, when no sodium ascorbate was employed, no product could be identified (Table 3, entry 4). Lowering the amount of the catalyst resulted in lower yields of **2a** (Table 3, entries 5 and 6 vs entry 1). Reducing the amount of bromoacetonitrile or the amount of sodium ascorbate also led to diminished yields of the product (Table 3, entries 7–10 vs entry 1).

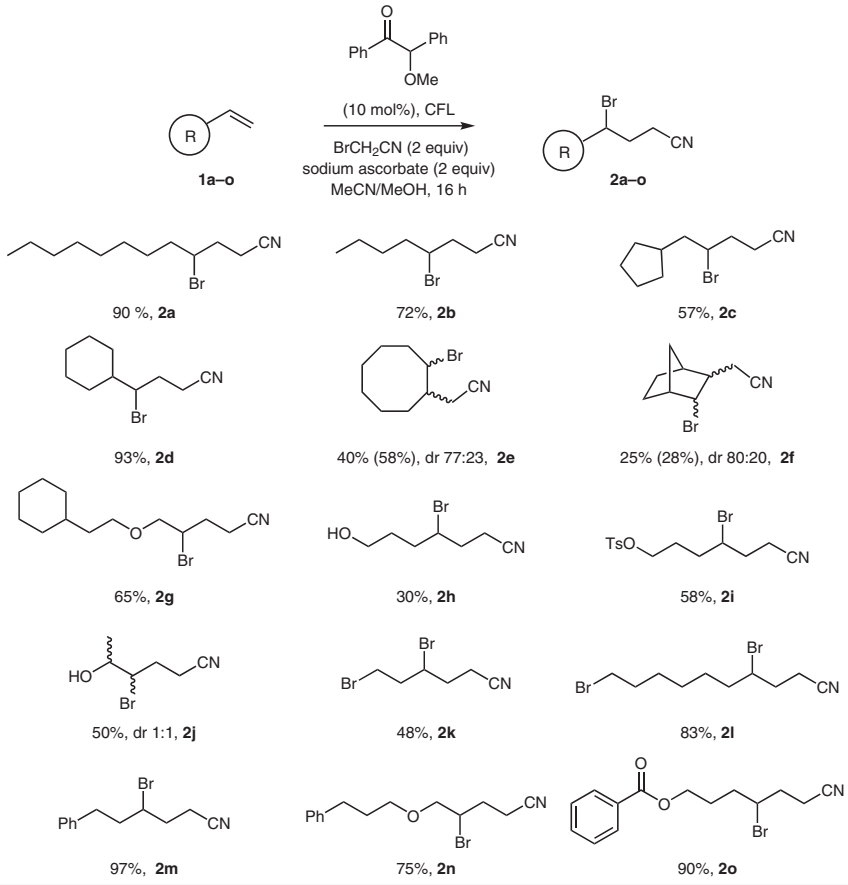
Table 3 Optimization of the Reaction Conditions for the Photocatalytic Atom Transfer Radical Addition of Bromoacetonitrile to **1a**



Entry	Catalyst (mol%)	$BrCH_2CN$ (equiv)	Sodium ascorbate (equiv)	Yield (%)[a]
1	10	2	2	90
2	–	2	2	n.d.
3[b]	10	2	2	n.d.
4	10	2	–	n.d.
5	5	2	2	27
6	2	2	2	n.d.
7	10	1.5	2	5
8	10	1.1	2	n.d.
9	10	2	1.5	48
10	10	2	1.1	n.d.

[a] Yield of isolated product; n.d. = not detected. The reaction was performed with 1-decene (0.5 mmol), benzoin methyl ether, bromoacetonitrile, and sodium ascorbate in MeCN (2 mL) and MeOH (1.5 mL) under irradiation with a household lightbulb for 16 h.
[b] The reaction was performed in the dark.

The next step was to explore the scope of the olefin partner (Scheme 2). All the tested olefins were converted into the corresponding products in moderate to excellent yields. It is necessary to highlight the fact that no special precautions were taken in order to perform the reactions. Initially, the atom transfer radical addition was performed with aliphatic olefins, leading to the corresponding products **2a–d** in good to high yields. The less reactive internal cyclic alkenes cyclooctene (**1e**) and 2-norbornene (**1f**) were also tested in these ATRA reactions. These proved to be more problematic substrates, and the catalyst loading had to be increased to 20 mol% in order to obtain low to moderate yields of the corresponding products **2e** and **2f**. Since the yields of these two examples were low, we decided to repeat the reactions employing dry and degassed solvents, but there was no improvement. In addition, when the reactions were performed under Ar, a slight increase in the yield was observed. Allyl ethers proved to be very efficient substrates, affording the expected products **2g** and **2n** in high yields. Terminal olefins bearing a wide array of functionalities were transformed into the corresponding products **2h–m** and **2o** in moderate to good yields.



Scheme 2 Substrate scope for the photoorganocatalytic atom transfer radical addition of bromoacetonitrile to different olefins; yields in parentheses are those of the products when the reaction was performed under Ar

In order to gain more insight into the reaction mechanism, the quantum yield of the reaction was measured (Φ = 144). This finding suggests that the catalyst operates as a photoinitiator, and once the first radical from bromoacetonitrile is formed, a radical propagation mechanism follows.

In conclusion, an efficient atom transfer radical addition of bromoacetonitrile to aliphatic alkenes has been developed. The reaction takes place under mild conditions involving an organic molecule as the photocatalyst and irradiation with a household lightbulb. A range of aliphatic and cyclic aliphatic olefins were tested successfully, leading to the desired products in moderate to excellent yields.

Chromatographic purification of products was accomplished using forced-flow chromatography on Merck® Kieselgel 60 F_{254} 230–400 mesh. Thin-layer chromatography (TLC) was performed on aluminum-backed silica plates (0.2 mm, 60 F_{254}). Visualization of the developed chromatogram was performed by fluorescence quenching using phosphomolybdic acid, anisaldehyde or potassium permanganate stains. Reactions were irradiated with OSRAM 80 W compact fluorescent household lightbulbs. ^{1}H and ^{13}C NMR spectra were recorded on a Varian® Mercury spectrometer at 200 MHz and 50 MHz, respectively, and are internally referenced to residual solvent signals. Data for ^{1}H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br s = broad singlet), coupling constant (*J*), integration and assignment. Data for ^{13}C are reported in terms of chemical shift (δ ppm). Mass spectra (ESI) were recorded on a Finnigan® Surveyor MSQ LC-MS spectrometer. HRMS spectra were recorded on a Bruker® Maxis Impact QTOF spectrometer. Mass spectra and conversions of the reactions were recorded on a Shimadzu® GCMS-QP2010 Plus gas chromatograph mass spectrometer utilizing a MEGA® column (MEGA-5, F.T.: 0.25 µm, I.D.: 0.25 mm, L: 30 m, T_{max}: 350 °C, column ID# 11475).

Photoorganocatalytic Atom Transfer Radical Addition; General Procedure

To a screw-cap glass vial containing benzoin methyl ether (12 mg, 0.05 mmol) in MeCN (2 mL) and MeOH (1.5 mL) were added consecutively alkene **1** (0.50 mmol), $BrCH_2CN$ (120 mg, 1.00 mmol) and sodium ascorbate (198 mg, 1.00 mmol). The vial was sealed with a screw cap and the contents stirred under irradiation with two household lightbulbs (2 × 80 W) for 16 h. The desired product was isolated after purification by column chromatography.

4-Bromododecanenitrile (2a)

Yield: 211 mg (90%); yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.13–3.95 (m, 1 H, CHBr), 2.60 (t, *J* = 6.9 Hz, 2 H, $NCCH_2$), 2.22–1.98 (m, 2 H, CH_2), 1.90–1.73 (m, 2 H, CH_2), 1.61–1.39 (m, 2 H, CH_2), 1.37–1.12 (m, 10 H, 5 × CH_2), 0.87 (t, *J* = 6.2 Hz, 3 H, CH_3).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.8, 55.0, 38.8, 34.5, 31.7, 29.3, 29.1, 28.8, 27.4, 22.6, 16.0, 14.0.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{12}H_{23}BrN$: 260.1008; found: 260.1013.

4-Bromooctanenitrile (2b)

Yield: 74 mg (72% yield); yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.15–3.96 (m, 1 H, CHBr), 2.61 (t, *J* = 6.7 Hz, 2 H, $NCCH_2$), 2.23–1.99 (m, 2 H, CH_2), 1.93–1.75 (m, 2 H, CH_2), 1.60–1.22 (m, 4 H, 2 × CH_2), 0.92 (t, *J* = 7.0 Hz, 3 H, CH_3).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.8, 55.0, 38.6, 34.5, 29.5, 22.0, 16.0, 13.9.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_8H_{15}BrN$: 204.0382; found: 204.0389.

4-Bromo-5-cyclopentylpentanenitrile (2c)

Yield: 67 mg (57%); brown oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.15–3.96 (m, 1 H, CHBr), 2.62 (t, *J* = 6.7 Hz, 2 H, $NCCH_2$), 2.22–1.95 (m, 3 H, CH_2 and CH), 1.92–1.70 (m, 3 H, 3 × CH*H*), 1.68–1.41 (m, 5 H, 5 × CH*H*), 1.19–0.95 (m, 2 H, 2 × CH*H*).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.8, 54.4, 45.2, 38.1, 34.7, 32.5, 31.8, 24.9, 24.8, 15.9.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{10}H_{17}BrN$: 230.0539; found: 230.0542.

4-Bromo-4-cyclohexylbutanenitrile (2d)

Yield: 107 mg (93%); yellow oil.

^{1}H NMR (200 MHz, CD_3OD): δ = 4.09–3.92 (m, 1 H, CHBr), 2.72–2.52 (m, 2 H, $NCCH_2$), 2.19–2.02 (m, 2 H, CH_2), 1.88–1.47 (m, 6 H, CH and 5 × CH*H*), 1.36–1.04 (m, 5 H, 5 × CH*H*).

^{13}C NMR (50 MHz, CD_3OD): δ = 118.8, 62.0, 44.4, 31.8, 30.6, 29.3, 26.0, 25.9, 25.8, 16.4.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{10}H_{17}BrN$: 230.0539; found: 230.0546.

2-(2-Bromocyclooctyl)acetonitrile (2e)

Reaction with 20 mol% of the catalyst.

Yield: 46 mg (58%) (under an Ar atmosphere); pale yellow oil; 77:23 mixture of diastereomers.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.51–4.26 (m, 0.77 H, CHBr), 4.22–4.08 (m, 0.23 H, CHBr), 2.40–2.17 (m, 3 H, $CNCH_2$ and CH), 2.15–1.19 (m, 12 H, 6 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.93, 118.87, 56.2, 55.8, 35.6, 35.5, 35.1, 34.3, 33.7, 32.8, 30.3, 30.2, 30.1, 29.4, 25.8, 25.5, 25.4, 24.9, 24.6, 24.2.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{10}H_{17}BrN$: 230.0539; found: 230.0544.

***trans*-2-(3-Bromobicyclo[2.2.1]heptan-2-yl)acetonitrile (2f)**

Reaction with 20 mol% of the catalyst.

Yield: 27 mg (28%) (under an Ar atmosphere); yellow oil; 80:20 mixture of diastereomers.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.18 (dd, *J* = 7.3, 1.8 Hz, 0.80 H, CHBr), 3.81–3.73 (m, 0.20 H, CHBr), 2.61–2.26 (m, 3 H, $CNCH_2$ and CH), 2.19–2.05 (m, 1 H, CH), 1.89–1.77 (m, 1 H, CH), 1.70–1.43 (m, 3 H, 3 × CH*H*), 1.39–1.17 (m, 3 H, 3 × CH*H*).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 119.6, 58.6, 57.3, 49.7, 48.1, 44.5, 44.2, 42.1, 41.2, 34.7, 33.1, 29.6, 29.1, 27.2, 23.8, 23.1, 21.3.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_9H_{13}BrN$: 214.0226; found: 214.0231.

4-Bromo-5-(2-cyclohexylethoxy)pentanenitrile (2g)

Yield: 94 mg (65%); orange oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.20–4.05 (m, 1 H, CHBr), 3.72 (dd, *J* = 10.5, 5.0 Hz, 1 H, OCH*H*), 3.64–3.36 (m, 3 H, OCH_2 and OCH*H*), 2.68–2.51 (m, 2 H, $NCCH_2$), 2.45–2.27 (m, 1 H, CH*H*), 2.16–1.95 (m, 1 H, CH*H*), 1.77–1.57 (m, 4 H, CH and 3 × CH*H*), 1.51–1.34 (m, 3 H, 3 × CH*H*), 1.27–1.10 (m, 3 H, 3 × CH*H*), 1.03–0.75 (m, 3 H, 3 × CH*H*).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.7, 74.1, 69.5, 49.9, 36.9, 34.5, 33.3, 31.2, 26.5, 26.2, 15.7.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{13}H_{23}BrNO$: 288.0958; found: 288.0964.

4-Bromo-7-hydroxyheptanenitrile (2h)

Reaction with 20 mol% of the catalyst.

Yield: 31 mg (30%); yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.20–4.05 (m, 1 H, CHBr), 3.70 (t, *J* = 6.0 Hz, 2 H, OCH_2), 2.62 (t, *J* = 6.0 Hz, 2 H, $NCCH_2$), 2.20–1.60 (m, 6 H, 3 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 119.1, 62.1, 55.0, 35.5, 34.9, 30.7, 16.3.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_7H_{12}BrNONa$: 227.9994; found: 227.9994.

4-Bromo-6-cyanohexyl 4-Methylbenzenesulfonate (2i)

Reaction with 20 mol% of the catalyst.

Yield: 105 mg (58%); orange oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.79 (d, *J* = 8.8 Hz, 2 H, ArH), 7.36 (d, *J* = 8.8 Hz, 2 H, ArH), 4.06 (t, *J* = 6.0 Hz, 2 H, OCH_2), 4.00–3.90 (m, 1 H, CHBr), 2.59 (t, *J* = 7.0 Hz, 2 H, $NCCH_2$), 2.45 (s, 3 H, CH_3), 2.15–1.78 (m, 6 H, 3 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 145.3, 132.9, 130.2, 128.1, 118.8, 69.6, 53.9, 35.0, 34.8, 27.3, 22.0, 16.3.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{18}BrNO_3SNa$: 382.0083; found: 382.0086.

4-Bromo-5-hydroxyhexanenitrile (2j)

Reaction with 20 mol% of the catalyst.

Yield: 48 mg (50%); brown oil; 1:1 mixture of diastereomers.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.17–4.02 (m, 1 H, CHBr), 4.00–3.89 (m, 1 H, OCH), 3.77 (br s, 1 H, OH), 2.70–2.53 (m, 2 H, $NCCH_2$), 2.29–2.13 (m, 2 H, CH_2), 1.34 (d, *J* = 6.3 Hz, 1.5 H, CH_3), 1.31 (d, *J* = 6.3 Hz, 1.5 H, CH_3).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.7, 70.3, 69.8, 61.9, 61.0, 31.0, 29.2, 21.3, 19.8, 16.1, 16.0.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_6H_{11}BrNO$: 192.0019; found: 192.0020.

4,6-Dibromohexanenitrile (2k)

Yield: 61 mg (48%); colorless oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.33–4.17 (m, 1 H, CHBr), 3.66–3.50 (m, 2 H, CH_2Br), 2.71–2.55 (m, 2 H, $NCCH_2$), 2.39–2.25 (m, 2 H, CH_2), 2.23–2.05 (m, 2 H, CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.4, 52.0, 41.0, 34.3, 30.4, 16.0.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_6H_{10}Br_2N$: 253.9175; found: 253.9182.

4,10-Dibromodecanenitrile (2l)

Yield: 129 mg (83%); colorless oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.13–3.96 (m, 1 H, CHBr), 3.39 (t, *J* = 6.7 Hz, 2 H, CH_2Br), 2.60 (t, *J* = 6.8 Hz, 2 H, $NCCH_2$), 2.25–1.97 (m, 2 H, CH_2), 1.94–1.75 (m, 4 H, 2 × CH_2), 1.60–1.22 (m, 6 H, 3 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 118.7, 54.8, 38.6, 34.5, 33.8, 32.5, 27.9, 27.8, 27.2, 16.0.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{10}H_{18}Br_2N$: 309.9801; found: 309.9809.

4-Bromo-6-phenylhexanenitrile (2m)

Yield: 122 mg (97%); pale yellow oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.40–7.12 (m, 5 H, ArH), 4.09–3.90 (m, 1 H, CHBr), 3.00–2.71 (m, 2 H, $NCCH_2$), 2.67–2.54 (m, 2 H, CH_2), 2.22–2.07 (m, 4 H, 2 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 140.1, 128.6, 128.4, 126.3, 118.7, 54.1, 40.4, 34.6, 33.5, 15.9.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{12}H_{15}BrN$: 252.0382; found: 252.0388.

4-Bromo-5-(3-phenylpropoxy)pentanenitrile (2n)

Yield: 111 mg (75%); colorless oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.38–7.28 (m, 5 H, ArH), 4.20–4.12 (m, 1 H, CHBr), 3.77–3.62 (m, 2 H, OCH_2), 3.49 (t, *J* = 6.0 Hz, 2 H, OCH_2), 2.70 (t, *J* = 8.0 Hz, 2 H, $CNCH_2$), 2.65–2.28 (m, 3 H, 3 × C*H*H), 2.15–1.75 (m, 3 H, 3 × C*H*H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 141.8, 128.5, 126.1, 119.0, 74.4, 70.7, 50.2, 32.4, 31.3, 31.2, 15.9.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{18}BrNONa$: 318.0464; found: 318.0457.

4-Bromo-6-cyanohexyl Benzoate (2o)

Yield: 140 mg (90% yield); colorless oil.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 8.02 (d, *J* = 8.8 Hz, 2 H, ArH), 7.60–7.40 (m, 3 H, ArH), 4.34 (t, *J* = 4.0 Hz, 2 H, OCH_2), 4.16–4.04 (m, 1 H, CHBr), 2.61 (t, *J* = 7.0 Hz, 2 H, $CNCH_2$), 2.31–1.89 (m, 6 H, 3 × CH_2).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 166.8, 133.3, 130.2, 129.8, 128.7, 118.9, 64.2, 54.5, 35.8, 34.9, 27.2, 16.4.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{14}H_{17}NO_2Br$: 310.0437; found: 310.0432.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0037-1610138.

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