

α -Alkylation of Nitriles with Primary Alcohols by a Well-Defined Molecular Cobalt Catalyst

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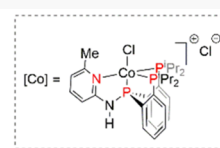


Supporting Information

ABSTRACT: The α -alkylation of nitriles with primary alcohols to selectively synthesize nitriles by a well-defined molecular homogeneous cobalt catalyst is presented. Thirty-two examples with up to 95% yield are reported. Remarkably, this transformation is environmentally friendly and atom economical with water as the only byproduct.



- By a well-defined molecular cobalt catalyst
- Environmentally benign and atom efficient with water as the only byproduct
- 32 examples with up to 95% yield



INTRODUCTION

With the unique $\text{C}\equiv\text{N}$ functional group, nitriles are a class of organic compounds that have found ubiquitous applications in chemical and pharmaceutical industries.¹ α -Alkylated nitriles are key building blocks for the synthesis of various compounds such as carboxylic acids, amides, amines, ketones, etc.¹ Homogeneous transition-metal-mediated construction of the carbon–carbon bond belongs to one of the most imperative synthetic strategies for the products of added values.² Traditional alkylation requires toxic alkyl halides and stoichiometric amounts of bases, generating the copious amount of wastes.³ An attractive alternative is to utilize alcohol as the alkylating agent via a borrowing hydrogen (BH) process.^{4,5} In a typical BH process to α -alkylated nitriles, a primary alcohol is first dehydrogenated to an aldehyde with the catalyst “borrowing” a hydride and a proton. The aldehyde undergoes a nucleophilic attack by the nitrile in the presence of a base to generate an α,β -unsaturated nitrile, which is subsequently hydrogenated to the α -alkylated nitrile product by the catalyst “returning” the hydride and the proton. The BH strategy is more sustainable, environmentally friendly, and atom-efficient, with water as the only byproduct.^{4,5}

In this regard, catalysts based on precious transition metals, such as Rh,^{6a,b} Ir,^{6c,d} Os,^{6e} Ru,^{6f} and Pd,^{6g} have significantly promoted this field. With increasing concerns on sustainability and economy, base transition-metal surrogates like Fe, Co, Mn, Ni, and Cu are becoming more appealing.⁷ It is just recently that such base transition-metal-catalyzed transformations are revealed.⁸ A transition-metal-free method was recently reported using 80 mol % KO^tBu under aerobic conditions.⁹ As part of the study on methylation of $\text{C}(\text{sp}^3)\text{--H}/\text{C}(\text{sp}^2)\text{--H}$ bonds, Liu and co-workers reported their seminal work on the nitrile alkylation by a cobalt salt $\text{Co}(\text{BF}_4)_2\cdot 6\text{H}_2\text{O}$, $\text{P}(\text{CH}_2\text{CH}_2\text{PPh}_2)_3$ (PP_3) ligand, and a stoichiometric amount of base, which is the only known cobalt example in literature.^{8a} However, the reported substrates were very limited, and methanol was the only alcohol used.^{8a} In addition, no mechanistic study on the α -alkylation of nitrile was disclosed.^{8a} Herein, we present a systematic study on the selective nitrile

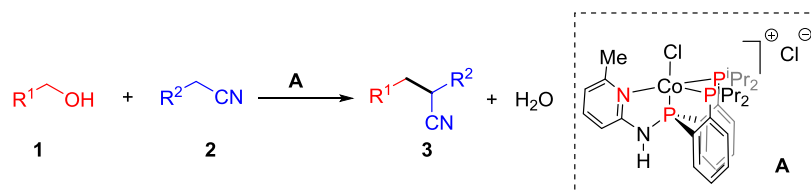
alkylation with primary alcohols mediated by a well-defined molecular cobalt catalyst (Scheme 1).

We have recently developed a new tetradentate mixed P/N donor ligand $i^{\text{Pr}}\text{PPPN}^{\text{H}}\text{Py}^{\text{Me}}$.^{10a} The air-stable cobalt complex **A** is an efficient precatalyst for dehydrogenation of secondary alcohols to ketones,^{10a} dehydrogenative self-coupling of primary alcohols to esters,^{10b} and β -alkylation of secondary alcohols with primary alcohols to ketones.^{10c} We envision that the **A**-based catalytic system has a potential for the selective nitrile alkylation with primary alcohols to α -alkylated nitriles.

RESULTS AND DISCUSSION

We initiated the work to explore the reaction of the model substrates benzyl alcohol (0.5 mmol) and phenylacetonitrile (0.25 mmol) under various conditions. A temperature of 140 °C was required to obtain an optimized yield (Table 1, entries 1–3). After investigating various bases for the reaction, KOH turned out to be the most suitable base (Table 1, entries 3–6). It was shown that **A**, base, and KHBet_3 were essential for this reaction (Table 1, entries 7–9). Twenty mole percent KOH was needed to optimize the yield (Table 1, entries 5 and 10). Interestingly, doubling **A** and KHBet_3 loading gave a comparable yield (Table 1, entry 11). Solvents were also screened, and toluene was found to be the most suitable one (Table 1, entries 5, 12–14). Notably, a good 83% yield was observed in only 6 h, demonstrating the great reactivity of the catalytic system (Table 1, entry 16). Thus, the optimized conditions were obtained (Table 1 entry 5). Mercury test suggested a homogeneous catalytic process (Table 1, entry 17).

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Scheme 1. Well-Defined Molecular Cobalt Catalyst-Mediated α -Alkylation of Nitriles with Primary AlcoholsTable 1. Optimization of the Reaction Conditions^a

entry	cat.	base	solvent	temp (°C)	yield ^b (%)
1	A	KO ^t Bu	toluene	105	15
2	A	KO ^t Bu	toluene	125	65
3	A	KO ^t Bu	toluene	140	68
4	A	NaO ^t Bu	toluene	140	74
5	A	KOH	toluene	140	88 (85)
6	A	K ₂ CO ₃	toluene	140	13
7 ^c	A	KOH	toluene	140	65
8	A		toluene	140	16
9		KOH	toluene	140	11
10 ^d	A	KOH	toluene	140	68
11 ^e	A	KOH	toluene	140	85
12	A	KOH	benzene	140	74
13	A	KOH	THF	140	66
14	A	KOH	<i>t</i> -AmOH	140	50
15 ^f	A	KOH	toluene	140	82 (80)
16 ^g	A	KOH	toluene	140	83
17 ^h	A	KOH	toluene	140	83

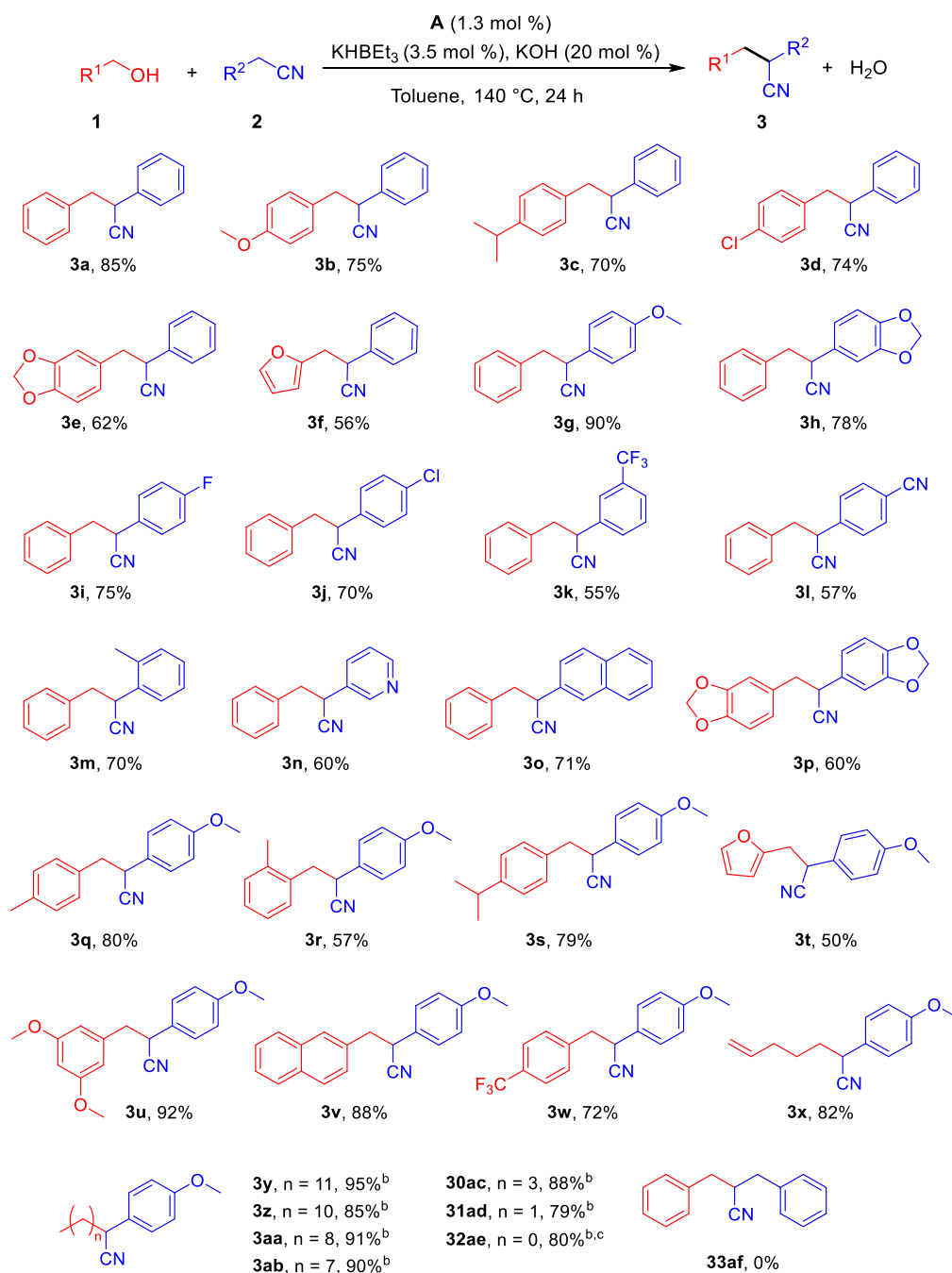
^aReaction conditions: A (1.3 mol %), KHBET₃ (3.5 mol %), base (20 mol %), 1a (0.5 mmol), 2a (0.25 mmol), and solvent (1.25 mL) were heated in a sealed 15 mL reaction tube for 24 h. ^bYields were determined by ¹H NMR analysis of the crude reaction mixture with 1,3,5-trimethoxybenzene as an internal standard. Isolated yield is in parenthesis. ^cReaction was carried out in the absence of KHBET₃. ^dKOH (10 mol %) was used. ^eA (2.6 mol %) and KHBET₃ (7 mol %) were used. ^f1a (2.0 mmol) and 2a (1.0 mmol) were used. ^g6 h. ^hMercury (125 mg) was added to the reaction.

With the optimized conditions in hand, we then probed the scope of the reaction by examining a wide range of primary alcohols and nitriles. First, we explored the scope of primary alcohols. Aromatic primary alcohols bearing electron-donating groups such as -OMe, -Pr, and -Me at the para position afforded the desired nitriles in good 70–80% yields (Table 2, entries 3b, 3c, and 3q). Aromatic primary alcohols with electron-withdrawing groups like -Cl and -CF₃ at the para position also transformed smoothly (Table 2, entries 3d and 3w). 2-Methyl benzyl alcohol showed a diminished activity in a 57% yield probably due to the steric hindrance (Table 2, entry 3r). Notably, 2-naphthyl methanol proceeds successfully in a very good 88% yield (Table 2, entry 3v). Heteroaryl alcohols, such as piperonyl alcohol and 2-furfuryl methanol, furnished the corresponding nitriles in moderate yields (Table 2, entries 3e, 3f, 3p, and 3t). Moreover, aliphatic primary alcohols could also be applied to give the desired nitrile products in good to excellent yields (80–95%) using 2.6 mol % A and 15 mol % KO^tBu (Table 2, entries 3x–3ae). It is worth noting that the alkene functional group is intact (Table 2, entries 3x). A methanol/4-methoxybenzonitrile ratio of 10 was required to reach an 80% yield of 2-(4-methoxyphenyl)propanenitrile (Table 2, entry 3ae). Next, we investigated the scope of nitriles. Similarly, a variety of aromatic nitriles with electron-

donating or -withdrawing groups at different positions could be utilized for the alkylation reactions with 50–90% yields (Table 2, entries 3g–3ae). Importantly, nitriles bearing pyridyl and naphthyl ring delivered the corresponding products in 60 and 71% yields, respectively (Table 2, entries 3n and 3o). Unfortunately, benzenepropanenitrile and aliphatic nitriles did not work under these conditions (Table 2, entry 3af).

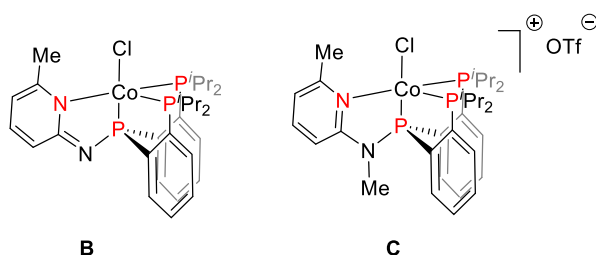
Next, we performed a mechanistic study to understand the nitrile alkylation reaction. We first explored the reactivity of A derivatives B and C using the model substrates^{10a} (Figure 1). B is air-sensitive, but C is air-stable. B, with a dearomatized pyridine arm, demonstrated a slightly diminished activity compared to A (73% yield), indicating B is also a precatalyst. C that bears a N-Me linker on the pyridine arm efficiently mediated the reaction leading to an 82% yield, suggesting metal–ligand cooperativity (MLC) that might originate from the N–H linker on A did not play an essential role.

We have shown that A can mediate the self-coupling of primary alcohols to esters.^{10b} Mechanistic study suggests a pathway that involves dehydrogenation of primary alcohols to aldehydes followed by the Tishchenko reaction to esters. We also reported dehydrogenation of secondary alcohols to ketones catalyzed by A.^{10a} Thus, aldehyde is likely an intermediate in the α -alkylation of nitriles with primary

Table 2. α -Alkylation of Nitriles with Primary Alcohols^{a,b,c}

^aReaction conditions: **A** (1.3 mol %), KHBET₃ (3.5 mol %), KOH (20 mol %), alcohol (0.5 mmol), nitrile (0.25 mmol), and toluene (1.25 mL) were heated in a 15 mL reaction tube for 24 h. Isolated yields are given. ^bReaction was carried out using **A** (2.6 mol %) and KO^tBu (15 mol %).

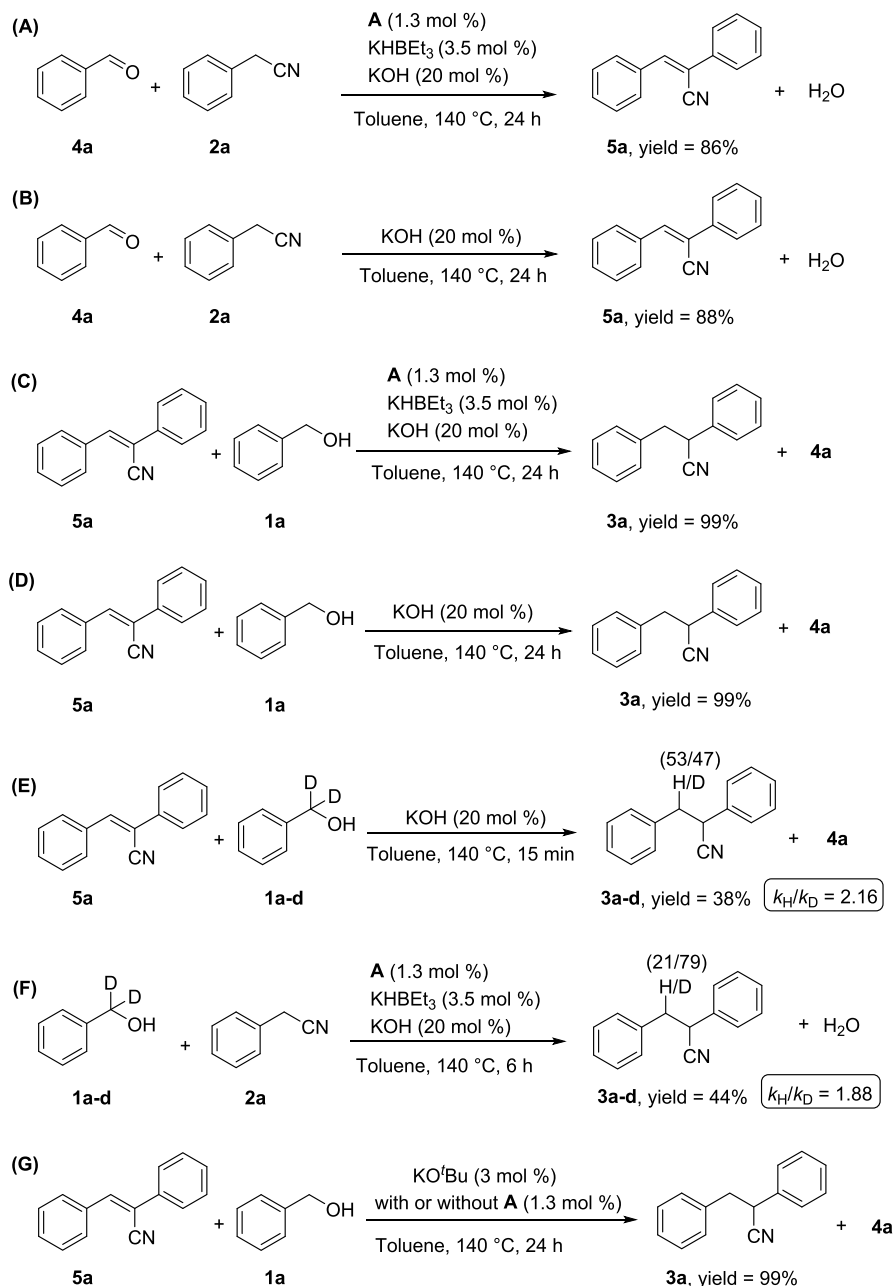
^cReaction was carried out using MeOH (2.5 mmol) for 60 h.

Figure 1. **A** derivatives **B** and **C** examined.

alcohols. The condensation of benzaldehyde and phenylacetonitrile under the optimal conditions afforded 2,3-diphenylacrylonitrile in an 86% yield (Scheme 2A).

Without **A** and KHBET₃, a comparable yield of 88% was also obtained (Scheme 2B). These results suggest that α,β -unsaturated nitrile is a possible intermediate,¹¹ and its formation can be mediated by base alone. Interestingly, the transfer hydrogenation of 2,3-diphenylacrylonitrile with benzyl alcohol (2 equiv) proceeded to completion by 20 mol % KOH in the standard conditions, with or without **A**/KHBET₃ (Scheme 2C,D). This unexpected result supports a base-

Scheme 2. Control Experiments



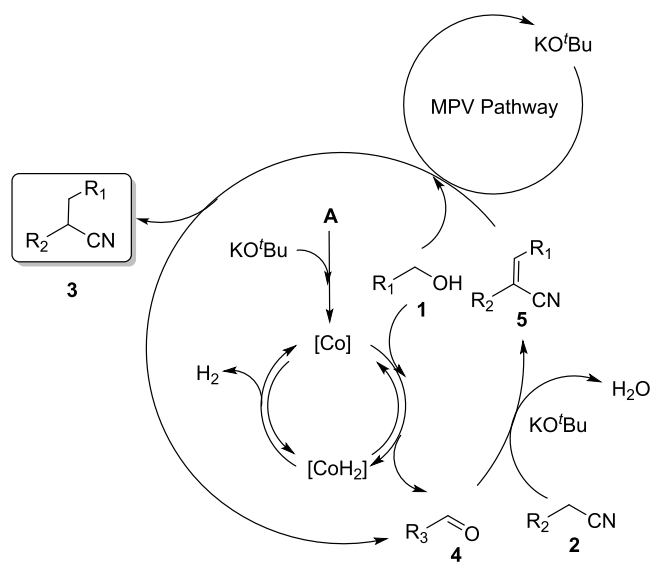
mediated Meerwein–Ponndorf–Verley (MPV) hydrogenation pathway.¹²

Further investigations showed that the transfer hydrogenation can be finished in an hour by 20 mol % KOH. The deuterium labeling experiment utilizing benzyl alcohol- α,α - d_2 in the 2,3-diphenylacrylonitrile transfer hydrogenation resulted in a k_H/k_D ratio of 2.16 (Scheme 2E), indicating that the cleavage of the α -C–H bond of benzyl alcohol is a slow step. The H/D ratio is close to unit, which suggests that the deuterium at the benzyl position transfers to the β position of the nitrile group in the MPV process. However, a H/D ratio close to 1:4 was obtained in the α -alkylation of phenylacetonitrile with benzyl alcohol- α,α - d_2 (Scheme 2F). The incorporation of hydrogen infers that A-mediated dehydrogenation of primary alcohol may be reversible. A k_H/k_D ratio of 1.88 was acquired, which is in line with the result from the 2,3-

diphenylacrylonitrile transfer hydrogenation. Different bases were also examined. Employing only 3 mol % KOtBu with or without A both gave a full conversion of 2,3-diphenylacrylonitrile in 24 h (Scheme 2G), suggesting that A might not play a crucial role in the α,β -unsaturated nitrile hydrogenation step.

Based on the mechanistic study, a plausible catalytic cycle is proposed as depicted in Scheme 3. Initial A-mediated primary alcohol dehydrogenation leads to aldehyde, which undergoes a nucleophilic attack by the nitrile substrate affording α,β -unsaturated nitrile in the presence of base. Finally, the α,β -unsaturated nitrile is reduced to the nitrile product via a base-mediated MPV pathway. To the best of our knowledge, such a mechanism has yet been revealed for the α -alkylation of nitriles. A more in-depth mechanistic investigation is ongoing in our laboratory.

Scheme 3. Proposed Reaction Mechanism



CONCLUSIONS

In summary, we disclosed a well-defined molecular cobalt catalyst for the selective nitrile alkylation with primary alcohols to α -alkylated nitriles. Notably, this method is atom-efficient and environmentally friendly with water as the only byproduct. We expect this work will contribute to the development of base transition-metal catalysts in green synthesis.

EXPERIMENTAL SECTION

General Method. Unless otherwise is stated, all reactions were set up in an MBraun glovebox under an atmosphere of N_2 . Anhydrous solvents were deoxygenated by sparging with N_2 and dried by passing through activated alumina columns of a Pure Solv solvent purification system. $CDCl_3$ was purchased from Cambridge Isotope Lab and dried over molecular sieves (4 Å). Cobalt complexes (A–C) were prepared according to our published procedures.^{10a} Chemicals used in this paper were purchased from Sigma-Aldrich, Oakwood Chemical, or Fisher Scientific and used as received. NMR spectra were recorded on a JEOL Unity 500 or 300 MHz spectrometer. 1H NMR spectra were referenced to tetramethyl silane (0.00 ppm) using $CDCl_3$ as a solvent. ^{13}C NMR were referenced to solvent carbons at 77.0 ppm for $CDCl_3$. ^{19}F NMR spectra were referenced to fluorobenzene at –113.15 ppm. HRMS were acquired from the Mass Spectrometry and Proteomics Facility at University of Notre Dame.

General Procedure for the α -Alkylation of Nitriles with Aryl Primary Alcohols Using A. Inside a N_2 -filled glovebox, a mixture of A (1.3 mol %), $KHBET_3$ (3.5 mol %), KOH (20 mol %), nitrile (0.25 mmol), primary alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

General Procedure for the α -Alkylation of Nitriles with Aliphatic Primary Alcohols Using A. Inside a N_2 -filled glovebox, a mixture of A (2.6 mol %), KOtBu (15 mol %), nitrile (0.25 mmol), primary alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel

plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

Procedure for the α -Alkylation of 4-Methoxybenzonitrile with Methanol Using A. Inside a N_2 -filled glovebox, a mixture of A (2.6 mol %), KOtBu (15 mol %), 4-methoxybenzonitrile (0.25 mmol), methanol (2.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 60 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

Procedure for the α -Alkylation of Phenylacetoneitrile with Benzyl Alcohols Using B. Inside a N_2 -filled glovebox, a mixture of B (1.3 mol %), $KHBET_3$ (3.5 mol %), KOH (20 mol %), phenylacetoneitrile (0.25 mmol), benzyl alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

Procedure for the α -Alkylation of Phenylacetoneitrile with Benzyl Alcohols Using C. Inside a N_2 -filled glovebox, a mixture of C (1.3 mol %), $KHBET_3$ (3.5 mol %), KOH (20 mol %), phenylacetoneitrile (0.25 mmol), benzyl alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

Procedure for the α -Alkylation of Phenylacetoneitrile with Benzyl Alcohols Using A in 1.0 mmol Scale. Inside a N_2 -filled glovebox, a mixture of A (1.3 mol %), $KHBET_3$ (3.5 mol %), KOH (20 mol %), phenylacetoneitrile (1.0 mmol), benzyl alcohol (2.0 mmol), and toluene (2.0 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product: 166 mg (80%).

Procedure for Homogeneity Test. Inside a N_2 -filled glovebox, a mixture of A (1.3 mol %), $KHBET_3$ (3.5 mol %), KOH (20 mol %), phenylacetoneitrile (0.25 mmol), benzyl alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel and stirred at room temperature for 10 min. Mercury (125 mg, 0.625 mmol) was added to the vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, the reaction mixture was filtered through a silica gel plug and the collected filtrate was concentrated by a rotavap. The obtained residue was purified by a silica gel column using ethyl acetate/hexane (1:20, v/v) as an eluent, giving the pure alkylated nitrile product.

Procedure for Condensation of Benzaldehyde and Phenylacetoneitrile by KOH or A/ $KHBET_3$ /KOH. Inside a N_2 -filled glovebox, a mixture of A (0 or 1.3 mol %), $KHBET_3$ (0 or 3.5 mol %), KOH (20 mol %), phenylacetoneitrile (0.25 mmol), benzaldehyde (0.25 mmol), and toluene (1.25 mL) was loaded into a 15 mL

reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, 1,3,5-trimethoxybenzene (8.4 mg, 0.05 mmol) dissolved in diethyl ether was added to the reaction mixture, stirred, and filtered through a silica gel plug. The plug was washed with diethyl ether, and the collected filtrate was concentrated under vacuum using a rotavapor. The obtained residue was dissolved in CDCl_3 and subjected to NMR analysis.

Procedure for Transfer Hydrogenation of 2,3-Diphenylacrylonitrile with Benzyl Alcohol by A/KO^tBu or KO^tBu. Inside a N_2 -filled glovebox, a mixture of A (1.3 mol %), KO^tBu (3 mol %), 2,3-diphenylacrylonitrile (0.25 mmol), benzyl alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, 1,3,5-trimethoxybenzene (8.4 mg, 0.05 mmol) dissolved in diethyl ether was added to the reaction mixture, stirred, and filtered through a silica gel plug. The plug was washed with diethyl ether, and the collected filtrate was concentrated under vacuum using a rotavapor. The obtained residue was dissolved in CDCl_3 and subjected to NMR analysis.

Procedure for Transfer Hydrogenation of 2,3-Diphenylacrylonitrile with Benzyl Alcohol by KOH or A/KHBET₃/KOH. Inside a N_2 -filled glovebox, a mixture of A (0 or 1.3 mol %), KHBET₃ (0 or 3.5 mol %), KOH (20 mol %), 2,3-diphenylacrylonitrile (0.25 mmol), benzyl alcohol (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 24 h. After the reaction was finished and cooled down, 1,3,5-trimethoxybenzene (8.4 mg, 0.05 mmol) dissolved in diethyl ether was added to the reaction mixture, stirred, and filtered through a silica gel plug. The plug was washed with diethyl ether, and the collected filtrate was concentrated under vacuum using a rotavapor. The obtained residue was dissolved in CDCl_3 and subjected to NMR analysis.

Deuterium Labeling Experiment for the Transfer Hydrogenation of 2,3-Diphenylacrylonitrile with Benzyl Alcohol or Benzyl Alcohol- α,α -d₂ by KOH. Inside a N_2 -filled glovebox, a mixture of KOH (20 mol %), 2,3-diphenylacrylonitrile (0.25 mmol), benzyl alcohol or benzyl alcohol- α,α -d₂ (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 15 min. After the reaction was finished and cooled down, 1,3,5-trimethoxybenzene (8.4 mg, 0.05 mmol) dissolved in diethyl ether was added to the reaction mixture, stirred, and filtered through a silica gel plug. The plug was washed with diethyl ether, and the collected filtrate was concentrated under vacuum using a rotavapor. The obtained residue was dissolved in CDCl_3 and subjected to NMR analysis.

Deuterium Labeling Experiment for the α -Alkylation of Phenylacetone with Benzyl Alcohols or Benzyl Alcohol- α,α -d₂ by A/KHBET₃/KOH. Inside a N_2 -filled glovebox, a mixture of A (1.3 mol %), KHBET₃ (3.5 mol %), KOH (20 mol %), phenylacetone (0.25 mmol), benzyl alcohol or benzyl alcohol- α,α -d₂ (0.5 mmol), and toluene (1.25 mL) was loaded into a 15 mL reaction vessel. The reaction vessel was sealed by a screw cap and brought out of the glovebox. The reaction tube was placed in a preheated oil bath at 140 °C for 6 h. After the reaction was finished and cooled down, 1,3,5-trimethoxybenzene (8.4 mg, 0.05 mmol) dissolved in diethyl ether was added to the reaction mixture, stirred, and filtered through a silica gel plug. The plug was washed with diethyl ether, and the collected filtrate was concentrated under vacuum using a rotavapor. The obtained residue was dissolved in CDCl_3 and subjected to NMR analysis.

2,3-Diphenylpropanenitrile^{8d} (3a). White solid; 44 mg (85%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.37–7.25 (m, 8H), 7.14–7.13 (m, 2H), 3.99 (dd, 1H, J = 8.4, 6.4 Hz), and 3.21–3.11 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 136.3, 135.3, 129.2, 129.1, 128.7, 128.2, 127.5, 127.4, 120.4, 42.2, and 39.8.

3-(4-Methoxyphenyl)-2-phenylpropanenitrile^{8d} (3b). White solid; 45 mg (75%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.37–7.31 (m, 3H), 7.26–7.25 (m, 2H), 7.04 (d, 2H, J = 10.5 Hz), 6.82 (d, 2H, J = 10.9 Hz), 3.96 (t, 1H, J = 7.7 Hz), 3.79 (s, 3H), and 3.16–3.07 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 158.9, 135.3, 130.3, 129.0, 128.4, 128.2, 127.5, 120.5, 114.0, 55.3, 41.5, and 40.1.

3-(4-Isopropylphenyl)-2-phenylpropanenitrile^{8f} (3c). White solid; 44 mg (70%); m.p. 65–67 °C; ¹H NMR (CDCl_3 , 500 MHz): δ 7.38–7.33 (m, 3H), 7.30–7.28 (m, 2H), 7.16 (d, 2H, J = 8.1 Hz), 7.09 (d, 2H, J = 8.1 Hz), 3.97 (dd, 1H, J = 8.7, 6.2 Hz), 3.18–3.07 (m, 2H), 2.93–2.84 (m, 1H), and 1.24 (d, 6H, J = 6.9 Hz); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 148.1, 135.5, 133.7, 129.1, 129.0, 128.2, 127.5, 126.7, 120.5, 41.9, 40.0, 33.8, and 24.0.

3-(4-Chlorophenyl)-2-phenylpropanenitrile^{8b} (3d). White solid; 45 mg (74%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.38–7.33 (m, 3H), 7.27–7.23 (m, 4H), 7.04 (d, 2H, J = 8.4 Hz), 3.99 (dd, 1H, J = 7.9, 6.5 Hz), and 3.18–3.10 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 134.8, 134.6, 133.4, 130.6, 129.1, 128.8, 128.4, 127.5, 120.1, 41.5, and 39.6.

3-(Benzo[d][1,3]dioxol-5-yl)-2-phenylpropanenitrile^{8f} (3e). Colorless oil; 39 mg (62%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.37–7.33 (m, 3H), 7.27–7.26 (m, 2H), 6.73 (d, 1H, J = 7.9 Hz), 6.62–6.60 (m, 2H), 5.94 (s, 2H), 3.95 (dd, 1H, J = 8.3, 6.5 Hz), and 3.13–3.03 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 147.8, 146.9, 135.2, 130.0, 129.1, 128.3, 127.5, 122.5, 120.4, 109.5, 108.4, 101.1, 42.0, and 40.1.

3-(Furan-2-yl)-phenylpropanenitrile^{8b} (3f). Pale yellow oil; 28 mg (56%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.40–7.31 (m, 4H), 7.30–7.27 (m, 2H), 6.29 (dd, 1H, J = 3.1, 2.0 Hz), 6.11 (d, 1H, J = 3.4 Hz), 4.15 (dd, 1H, J = 8.5, 6.6 Hz), and 3.30–3.13 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 150.0, 142.2, 134.9, 129.1, 128.4, 127.3, 120.1, 110.5, 108.2, 37.1, and 34.7.

2-(4-Methoxyphenyl)-3-phenylpropanenitrile^{8d} (3g). White Solid; 53 mg (90%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.29–7.25 (m, 3H), 7.17–7.12 (m, 4H), 6.87 (d, 2H, J = 8.6 Hz), 3.95 (dd, 1H, J = 8.2, 6.6 Hz), 3.80 (s, 3H), and 3.19–3.08 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 159.5, 136.4, 129.3, 128.7, 128.6, 127.3, 127.3, 120.6, 114.4, 55.4, 42.3, and 39.0.

2-(Benzo[d][1,3]dioxol-5-yl)-3-phenylpropanenitrile^{8f} (3h). Colorless oil; 49 mg (78%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.32–7.26 (m, 3H), 7.15–7.13 (m, 2H), 6.76–6.75 (m, 2H), 6.69 (dd, 1H, J = 8.1, 1.7 Hz), 5.98 (s, 2H), 3.90 (dd, 1H, J = 8.2, 6.5 Hz), and 3.19–3.07 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 148.2, 147.6, 136.3, 129.2, 128.9, 128.7, 127.4, 121.0, 120.4, 108.6, 107.9, 101.4, 42.3, and 39.5.

2-(4-Fluorophenyl)-3-phenylpropanenitrile^{8f} (3i). White solid; 42 mg (75%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.31–7.26 (m, 3H), 7.21–7.19 (m, 2H), 7.10 (dd, 2H, J = 7.6, 1.5 Hz), 7.03 (t, 2H, J = 8.6 Hz), 3.99 (dd, 1H, J = 7.8, 6.9 Hz), and 3.21–3.09 (m, 2H); ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 162.5 (d, $J_{\text{C-F}}$ = 247.5 Hz), 135.9, 131.0 (d, $J_{\text{C-F}}$ = 6.0 Hz), 129.3 (d, $J_{\text{C-F}}$ = 6.0 Hz), 129.2, 128.7, 127.5, 120.2, 116.0 (d, $J_{\text{C-F}}$ = 21.8 Hz), 42.2, and 39.0; and ¹⁹F NMR (283 MHz, CDCl_3): δ –113.4.

2-(4-Chlorophenyl)-3-phenylpropanenitrile^{8d} (3j). White Solid; 42 mg (70%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.33–7.25 (m, 5H), 7.16 (d, 2H, J = 8.5 Hz), 7.10 (dd, 2H, J = 7.6, 1.7 Hz), 3.99 (dd, 1H, J = 7.8, 6.8 Hz), and 3.21–3.08 (m, 2H); and ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 134.7, 133.2, 132.5, 128.1, 128.1, 127.8, 127.6, 126.4, 118.8, 40.9, and 38.1.

3-Phenyl-2-(3-(trifluoromethyl)phenyl)propanenitrile (3k). Colorless oil; 38 mg (55%); ¹H NMR (CDCl_3 , 500 MHz): δ 7.60 (d, 1H, J = 7.7 Hz), 7.49 (t, 1H, J = 8.0 Hz), 7.46–7.44 (m, 2H), 7.32–7.28 (m, 3H), 7.11 (dd, 2H, J = 7.4, 1.8 Hz), 4.08 (dd, 1H, J = 8.1, 6.5 Hz), and 3.25–3.13 (m, 2H); ¹³C{¹H} NMR (CDCl_3 , 125 MHz): δ 136.2, 135.5, 131.5 (q, $J_{\text{C-F}}$ = 33.1 Hz), 130.9, 129.6, 129.2, 128.8, 127.7, 125.9 (q, $J_{\text{C-F}}$ = 272.0 Hz), 125.2 (d, $J_{\text{C-F}}$ = 3.7 Hz), 124.5 (d, $J_{\text{C-F}}$ = 3.7 Hz), 119.6, 42.0, and 39.6; ¹⁹F NMR (283 MHz, CDCl_3): δ –113.4.

δ –62.6; HRMS (ESI+): m/z $[M]^+$ calcd for $C_{16}H_{12}NF_3$, 275.0922; found 275.0912.

4-(Benzyl-cyano-methyl)-benzonitrile (3l). White solid; 33 mg (57%); m.p. 84 °C; 1H NMR ($CDCl_3$, 500 MHz): δ 7.65 (d, 2H, J = 8.4 Hz), 7.34 (d, 2H, J = 8.4 Hz), 7.30–7.27 (m, 3H), 7.07 (dd, 2H, J = 7.0, 2.3 Hz), 4.08 (t, 1H, J = 7.2 Hz), and 3.19 (ddd, 2H, J = 20.3, 13.6, 7.2 Hz); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): 140.2, 135.2, 132.8, 129.2, 128.8, 128.5, 127.8, 119.2, 118.1, 112.6, 41.8, and 39.7; HRMS (ESI+): m/z $[M]^+$ calcd for $C_{16}H_{13}N_2$, 233.1073; found 233.1077.

3-Phenyl-2-(o-tolyl)propanenitrile^{6l} (3m). Colorless oil; 39 mg (70%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.44–7.42 (m, 1H), 7.33–7.27 (m, 3H), 7.25–7.22 (m, 2H), 7.18–7.16 (m, 3H), 4.15 (dd, 1H, J = 8.9, 6.0 Hz), 3.18–3.06 (m, 2H), and 2.26 (s, 3H); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 136.6, 135.1, 133.7, 131.0, 129.1, 128.7, 128.3, 127.7, 127.4, 126.9, 120.7, 41.0, 36.6, and 19.0.

3-Phenyl-2-(pyridin-3-yl)propanenitrile^{6c} (3n). Colorless solid; 31 mg (60%); 1H NMR ($CDCl_3$, 500 MHz): δ 8.59 (dd, 1H, J = 4.9, 1.5 Hz), 8.46 (d, 1H, J = 2.4 Hz), 7.61–7.55 (m, 1H), 7.35–7.27 (m, 4H), 7.11 (dd, 2H, J = 7.4, 1.8 Hz), 4.06 (t, 1H, J = 7.2 Hz), and 3.26–3.13 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 149.7, 148.9, 135.4, 135.0, 131.0, 129.3, 128.8, 127.8, 123.7, 119.4, 41.9, and 37.3.

2-(Naphthalen-2-yl)-3-phenylpropanenitrile (3o). White solid; 46 mg (71%); m.p. 95–96 °C; 1H NMR ($CDCl_3$, 500 MHz): δ 7.86–7.83 (m, 2H), 7.81–7.79 (m, 1H), 7.73 (d, 1H, J = 1.3 Hz), 7.51 (dd, 2H, J = 6.1, 3.2 Hz), 7.35 (dd, 1H, J = 8.5, 1.8 Hz), 7.31–7.26 (m, 3H), 7.16 (dd, 2H, J = 7.6, 1.8 Hz), 4.17 (dd, 1H, J = 8.2, 6.5 Hz), and 3.30–3.21 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 136.3, 133.3, 132.9, 132.5, 129.3, 129.0, 128.7, 127.9, 127.8, 127.5, 126.7, 126.7, 126.6, 125.0, 120.4, 42.2, and 40.0; HRMS (ESI+): m/z $[M]^+$ calcd for $C_{19}H_{15}N$, 257.1204; found 257.1212.

2,3-bis(Benzo[d][1,3]dioxol-5-yl)propanenitrile (3p). Colorless oil; 44 mg (60%); m.p. 64–66 °C; 1H NMR ($CDCl_3$, 500 MHz): δ 6.69 (dd, 3H), 6.62–6.58 (m, 2H), 5.98 (s, 2H), 5.95 (s, 2H), 3.85 (dd, 1H, J = 8.2, 6.6 Hz), and 3.09–2.99 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 148.2, 147.8, 147.6, 146.9, 129.9, 128.8, 122.5, 121.0, 120.4, 109.5, 108.6, 108.4, 107.9, 101.4, 101.1, 42.0, and 39.7; HRMS (ESI+): m/z $[M + Na]^+$ calcd for $C_{17}H_{13}NNaO_4$, 318.0737; found 318.0735.

2-(4-Methoxyphenyl)-3-(p-tolyl)propanenitrile^{8d} (3q). Colorless oil; 50 mg (80%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.17 (d, 2H, J = 8.7 Hz), 7.10 (d, 2H, J = 7.9 Hz), 7.02 (d, 2H, J = 8.0 Hz), 6.87 (d, 2H, J = 8.6 Hz), 3.92 (dd, 1H, J = 8.3, 6.5 Hz), 3.81 (s, 3H), 3.15–3.04 (m, 2H), and 2.32 (s, 3H); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.4, 137.0, 133.4, 129.3, 129.1, 128.7, 127.4, 120.7, 114.4, 55.4, 41.9, 39.2, and 21.1.

2-(4-Methoxyphenyl)-3-(o-tolyl)propanenitrile (3r). Colorless oil; 36 mg (57%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.22–7.08 (m, 6H), 6.87 (d, 2H, J = 8.6 Hz), 3.91 (dd, 1H, J = 8.5, 6.6 Hz), 3.81 (s, 3H), 3.23–3.07 (m, 2H), and 2.22 (s, 3H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.5, 136.3, 134.8, 130.6, 130.1, 128.6, 127.5, 126.3, 120.8, 114.4, 55.4, 39.6, 38.0, and 19.3; HRMS (ESI+): m/z $[M + H]^+$ calcd for $C_{17}H_{18}NO$, 252.1382; found 252.1374.

3-(4-Isopropylphenyl)-2-(4-methoxyphenyl)-phenylpropanenitrile^{8d} (3s). White solid; 55 mg (79%); m.p. 67–69 °C; 1H NMR ($CDCl_3$, 500 MHz): δ 7.19 (d, 2H, J = 8.7 Hz), 7.16 (d, 2H, J = 8.1 Hz), 7.08 (d, 2H, J = 8.1 Hz), 6.88 (d, 2H, J = 8.7 Hz), 3.92 (dd, 1H, J = 8.7, 6.2 Hz), 3.81 (s, 3H), 3.15–3.04 (m, 2H), 2.93–2.84 (m, 1H), and 1.24 (d, 6H, J = 6.9 Hz); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.4, 148.0, 133.8, 129.1, 128.6, 127.5, 126.7, 120.8, 114.4, 55.4, 42.0, 39.2, 33.8, and 24.0.

3-(Furan-2-yl)-2-(4-methoxyphenyl)propanenitrile (3t). Colorless oil; 28 mg (50%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.38–7.32 (m, 1H), 7.19 (d, 2H, J = 8.7 Hz), 6.88 (d, 2H, J = 8.6 Hz), 6.29 (dd, 1H, J = 3.1, 1.9 Hz), 6.11 (d, 1H, J = 3.7 Hz), 4.09 (dd, 1H, J = 8.3, 6.7 Hz), 3.81 (s, 3H), and 3.27–3.10 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.6, 150.1, 142.1, 128.4, 126.9, 120.4, 114.5, 110.5, 108.2, 55.4, 36.3, and 34.8; HRMS (ESI+): m/z $[M + Na]^+$ calcd for $C_{14}H_{13}NNaO_2$, 250.0838; found 250.0840.

3-(3,5-Dimethoxyphenyl)-2-(4-methoxyphenyl)propanenitrile (3u). Pale yellow oil; 68 mg (92%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.18 (d, 2H, J = 8.7 Hz), 6.88 (d, 2H, J = 8.6 Hz), 6.36 (t, 2H, J = 2.2 Hz), 6.28 (d, 2H, J = 2.3 Hz), 3.94 (dd, 1H, J = 8.3, 6.5 Hz), 3.81 (s, 3H), 3.74 (s, 6H), and 3.13–3.01 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 160.9, 159.5, 138.7, 128.7, 127.3, 120.7, 114.4, 107.3, 99.49, 55.4, 55.3, 42.6, and 38.8; HRMS (ESI+): m/z $[M + Na]^+$ calcd for $C_{18}H_{19}NNaO_3$, 320.1257; found 320.1256.

2-(4-Methoxyphenyl)-3-(naphthalen-2-yl)propanenitrile^{8d} (3v). Pale yellow oil; 63 mg (88%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.84–7.80 (m, 1H), 7.77 (d, 2H, J = 8.0 Hz), 7.60 (s, 1H), 7.49–7.43 (m, 2H), 7.23 (dd, 1H, J = 8.3, 1.8 Hz), 7.18 (d, 2H, J = 8.7 Hz), 6.86 (d, 2H, J = 8.6 Hz), 4.05 (dd, 1H, J = 8.1, 6.7 Hz), 3.80 (s, 3H), and 3.36–3.24 (m, 2H); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.5, 133.9, 133.4, 132.6, 128.7, 128.3, 128.2, 127.8, 127.7, 127.2, 126.2, 125.9, 120.7, 114.4, 55.4, 42.5, and 39.0.

2-(4-Methoxyphenyl)-3-(4-(trifluoromethyl)phenyl)propanenitrile^{8d} (3w). Colorless oil; 55 mg (72%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.55 (d, 2H, J = 8.1 Hz), 7.23 (d, 2H, J = 8.1 Hz), 7.15 (d, 2H, J = 8.7 Hz), 6.88 (d, 2H, J = 8.6 Hz), 3.9 (t, 1H, J = 7.5 Hz), 3.81 (s, 3H), and 3.24–3.15 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.6, 140.2, 129.7, 128.6, 126.5, 125.6 (q, J_{C-F} = 3.7 Hz), 124.1 (q, J_{C-F} = 270.0 Hz), 120.2, 114.5, 55.4, 41.9, and 38.6; and ^{19}F NMR (283 MHz, $CDCl_3$): δ –62.4.

2-(4-Methoxyphenyl)hept-6-enenitrile (3x). Colorless oil; 44 mg (82%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.23 (d, 2H, J = 8.6 Hz), 6.90 (d, 2H, J = 8.6 Hz), 5.75 (ddt, 1H, J = 16.9, 10.1, 6.7 Hz), 5.07–4.89 (m, 2H), 3.81 (s, 3H), 3.73 (dd, 1H, J = 8.2, 6.5 Hz), 2.09 (q, 2H, J = 7.1 Hz), 1.96–1.76 (m, 2H), and 1.63–1.45 (m, 2H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): 159.4, 137.6, 128.4, 127.9, 121.1, 115.4, 114.5, 55.4, 36.5, 35.3, 33.0, and 26.1; HRMS (ESI+): m/z $[M]^+$ calcd for $C_{14}H_{18}NO$, 216.1383; found 216.1388.

2-(4-Methoxyphenyl)tetradecanenitrile (3y). Colorless oil; 75 mg (95%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.23 (d, 2H, J = 8.7 Hz), 6.90 (d, 2H, J = 8.6 Hz), 3.81 (s, 3H), 3.71 (dd, 1H, J = 8.5, 6.3 Hz), 1.93–1.78 (m, 2H), 1.50–1.37 (m, 2H), 1.30–1.25 (m, 18H), and 0.88 (t, 3H, J = 6.9 Hz); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 158.4, 127.5, 127.3, 120.3, 113.5, 54.5, 35.7, 35.1, 30.1, 28.8, 28.7, 28.6, 28.5, 28.5, 28.1, 26.1, 21.8, and 13.2; HRMS (ESI+): m/z $[M + H]^+$ calcd for $C_{21}H_{34}NO$, 316.2635; found 316.2631.

2-(4-Methoxyphenyl)tridecanenitrile (3z). Colorless oil; 64 mg (85%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.23 (d, 2H, J = 8.7 Hz), 6.90 (d, 2H, J = 8.8 Hz), 3.81 (s, 3H), 3.71 (dd, 1H, J = 8.5, 6.4 Hz), 1.93–1.78 (m, 2H), 1.50–1.37 (m, 2H), 1.31–1.25 (m, 16H), and 0.88 (t, 3H, J = 6.9 Hz); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.4, 128.4, 128.2, 121.3, 114.5, 55.4, 36.7, 36.0, 32.0, 29.7, 29.7, 29.6, 29.4, 29.0, 29.0, 27.1, 22.8, and 14.2; HRMS (ESI+): m/z $[M + Na]^+$ calcd for $C_{20}H_{31}NNaO$, 324.2297; found 324.2289.

2-(4-Methoxyphenyl)undecanenitrile^{8d} (3aa). Colorless oil; 62 mg (91%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.23 (d, 2H, J = 8.7 Hz), 6.90 (d, 2H, J = 8.8 Hz), 3.81 (s, 3H), 3.71 (dd, 1H, J = 8.5, 6.3 Hz), 1.93–1.78 (m, 2H), 1.50–1.37 (m, 2H), 1.30–1.25 (m, 12H), and 0.88 (t, 3H, J = 6.9 Hz); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.3, 128.4, 128.1, 121.2, 114.4, 55.4, 36.6, 36.0, 31.9, 29.5, 29.3, 29.3, 29.0, 27.0, 22.7, and 14.1.

2-(4-Methoxyphenyl)decanenitrile (3ab). Colorless oil; 58 mg (90%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.23 (d, 2H, J = 8.7 Hz), 6.90 (d, 2H, J = 8.7 Hz), 3.81 (s, 3H), 3.71 (dd, 1H, J = 8.3, 6.5 Hz), 1.93–1.78 (m, 2H), 1.51–1.38 (m, 2H), 1.30–1.25 (m, 10H), and 0.87 (t, 3H, J = 6.8 Hz); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 159.3, 128.4, 128.1, 121.2, 114.4, 55.4, 36.6, 36.0, 31.8, 29.3, 29.2, 29.0, 27.0, 22.6, and 14.1; HRMS (ESI+): m/z $[M + Na]^+$ calcd for $C_{17}H_{25}NNaO$, 282.1828; found 282.1824.

2-(4-Methoxyphenyl)hexanenitrile^{8d} (3ac). Colorless oil; 45 mg (88%); 1H NMR ($CDCl_3$, 500 MHz): δ 7.24 (d, 2H, J = 8.7 Hz), 6.90 (d, 2H, J = 8.8 Hz), 3.81 (s, 3H), 3.71 (dd, 1H, J = 8.5, 6.4 Hz), 1.94–1.79 (m, 2H), 1.47–1.31 (m, 4H), and 0.90 (t, 3H, J = 7.2 Hz); and $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz): δ 158.2, 127.3, 127.0, 120.1, 113.3, 54.3, 35.5, 34.6, 28.0, 21.0, and 12.7.

2-(4-Methoxyphenyl)butanenitrile^{8d} (**3ad**). Colorless oil; 35 mg (79%); ¹H NMR (CDCl₃, 500 MHz): δ 7.24 (d, 2H, *J* = 8.5 Hz), 6.90 (d, 2H, *J* = 8.8 Hz), 3.81 (s, 3H), 3.68 (dd, 1H, *J* = 7.8, 6.6 Hz), 1.95–1.87 (m, 2H), and 1.06 (t, 3H, *J* = 7.4 Hz); and ¹³C{¹H} NMR (CDCl₃, 125 MHz): δ 159.3, 128.4, 127.8, 121.0, 114.4, 55.4, 38.2, 29.3, and 11.5.

2-(4-Methoxyphenyl)propanenitrile^{8a} (**3ae**). Yellowish oil; 33 mg (80%); ¹H NMR (CDCl₃, 500 MHz): δ 7.28–7.25 (m, 2H), 6.93–6.88 (m, 2H), 3.85 (q, 1H, *J* = 7.3 Hz), 3.81 (s, 3H), and 1.62 (d, 3H, *J* = 7.1 Hz); and ¹³C{¹H} NMR (CDCl₃, 125 MHz): δ 159.4, 129.1, 127.9, 121.8, 114.5, 55.4, 30.5, and 21.5.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.joc.0c01822>.

Copies of the ¹H, ¹³C{¹H}, and ¹⁹F NMR spectra for all product copies of the ¹H NMR spectra for the deuterium labeling experiments (PDF)

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Notes

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