JOC The Journal of Organic Chemistry

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Tetrabutylammonium Fluoride (TBAF)-Catalyzed Addition of Substituted Trialkylsilylalkynes to Aldehydes, Ketones, and Trifluoromethyl Ketones

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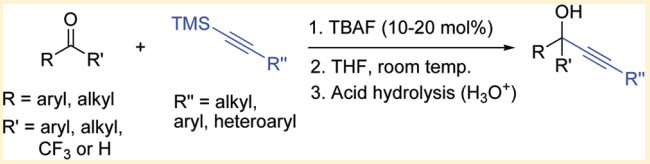
Supporting Information

ABSTRACT: Herein we report that tetrabutylammonium fluoride (TBAF) is a very efficient catalyst for the addition of trialkylsilylalkynes to aldehydes, ketones, and trifluoromethyl ketones in THF solvent at room temperature. The reaction conditions are mild and operationally simple, and a variety of aryl functional groups, such as chloro, trifluoromethyl, bromo, and fluoro groups, are tolerated. Impressively, using our protocol, useful CF_3-bearing tertiary propargylic alcohols can be synthesized. Product yields are generally better than or comparable to those in the literature. 1-Phenyl-2-trimethylsilyl acetylene, trimethyl ((4-(trifluoromethyl)phenyl)ethynyl)silane, 1-trimethylsilyl-1-hexyne, and trimethyl(thiophen-3-ylethynyl)silane underwent clean conversion to their corresponding propargylic alcohols as products under our conditions. Heterocyclic carbonyl compounds, such as furan-3-carboxaldehyde, thiophene-3-carboxaldehyde, and 2-pyridyl ketone, gave good yields of propargylic alcohols.



INTRODUCTION

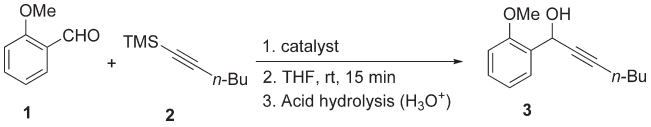
Development of simple and efficient methodologies for C−C bond formation is important to the advancement of synthetic organic chemistry, and the formation of such bonds to multiple carbon−carbon bonds is an important route to the creation of complex structures. Propargylic alcohols are key building blocks for the synthesis of many natural products and biologically important molecules,[1,2] and not surprisingly, many methods have been developed for the efficient synthesis of such species. A common approach to propargylic alcohol synthesis involves the use of an equivalent of a strong metal-base (e.g., *n*-BuLi) to generate acetylide ions from terminal alkynes for nucleophilic addition to carbonyl groups.[3] Other methods for synthesizing propargylic alcohols employ heavy metal catalysts such as zinc or indium in the presence of bulky ligands.[4−8] However, the latter method suffers from the drawback that enolizable aldehydes and ketones do not function in these reactions.

In 1976, Kuwajima et al. reported the first use of tetrabutylammonium fluoride (TBAF) for the reaction of 1-phenyl-2-trimethylsilyl acetylene with aldehydes and ketones, providing products in yields ranging from 5 to 87% using a 3−5 mol % loading of catalyst. However, they screened only an acetylene substrate with a phenyl substituent.[9a,b] Lerebours et al. reported that TBAF is an efficient catalyst for the arylation of aldehydes,[9c] and Yoshizawa et al. reported reactions aimed at the synthesis of Morita−Baylis−Hillman type adducts using quaternary ammonium fluorides derived from cinchonine as the catalyst.[10a] In these reactions, propargylic alcohols were formed as byproduct. In fact, when TBAF was used as the catalyst, the proportion of side product surpassed that of the expected product. The use of 10 mol % KOEt in THF as solvent at 0 °C was reported by Scheidt et al. to provide good yields of alkynylated product when triethoxysilylacetylenes bearing alkyl substituents on the acetylene were used as reagents with aldehydes, ketones and imines.[10b] In 2006, Mukaiyama et al. disclosed that 10 mol % of $[Bu_4N][OPh]$ at −78 °C in THF solvent gave 39−100% isolated alkynylated product yields with aldehydes and four ketone substrates, but unfortunately, alkyl-substituted acetylenes did not work well in their methodology.[10c] Using trimethylsilylethers and aldehydes as reaction partners, Shioiri et al. reported the use of KO*t*Bu as a catalyst for the formation of *Z*-selective β-branched Morita−Baylis−Hillman-type adducts.[10d] Recently we reported the use of the proazaphosphatrane, $P(PhCH_2NCH_2CH_2)_3N$, as a catalyst for the synthesis of propargylic alcohols at room temperature with aldehydes, although this method did not work for ketones.[11,12] Most importantly, β-branched Morita−Baylis−Hillman (MBH) type adducts were isolated when electron-deficient aromatic aldehydes were employed.[12] This result prompted us to broaden our investigation of TBAF in an effort to generalize its use as an efficient catalyst for aldehyde and ketone alkynylation using alkyl-substituted terminal silylated acetylenes.

Here we report a mild method for alkynylating aldehydes with trialkylsilylalkynes using TBAF as the catalyst (see scheme in the abstract). TBAF is a well-known desilylating agent and its use as a catalyst for Michael reactions, intramolecular aldolizations, alcohol silylations and aldehyde arylations has been described in the literature.[9c,13] The uniqueness of TBAF stems from its bulky *n*-butyl

Received: February 13, 2011
Published: April 25, 2011

Table 1. Screening of Fluoride Salts as Catalysts for Aldehyde Alkynylation



1 2 3

entry	catalyst	2 (equiv.)	catalyst (mol %)	yield (%)
1	TBAF	1.1	1	50
2	TBAF	1.1	2	57
3	TBAF	1.1	5	63
4	TBAF	1.1	10	65
5	TBAF	1.5	10	71
6	TBAF	2.0	10	75
7	MF (M = Na, K or Cs)	2.0	10	—[a]
8	Me_4NF	2.0	10	—[a]
9	Bu_3SnF	2.0	10	—[a]
10[b]	Bu_3SnF	2.0	10	—[a]

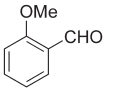
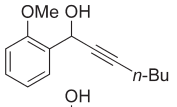
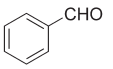
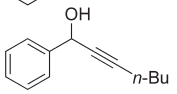
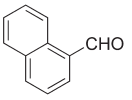
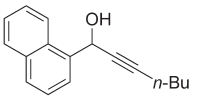
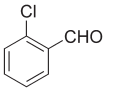
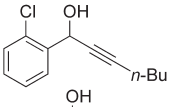
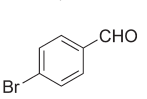
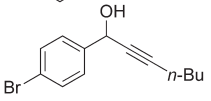
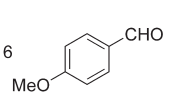
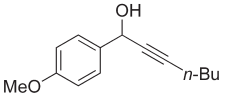
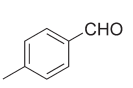
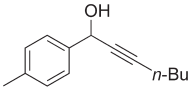
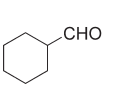
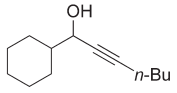
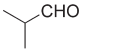
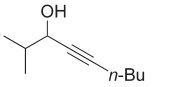
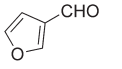
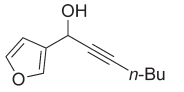
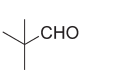
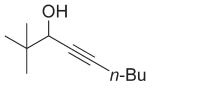
[a] No detectable yield. [b] Toluene as solvent at 80 °C.

groups which render this catalyst highly soluble in polar organic solvents to function simultaneously as a nucleophilic fluoride source and also as a possible source of electrophilic bulky quaternary ammonium cations that act as a Lewis acid for activating carbonyl groups via oxygen coordination.[8] These notions are supported by the superior performance of TBAF over alkali fluoride salts in the arylation of aldehydes[8] and by our results in entry 7 of Table 1 in which alkali fluorides were ineffective in facilitating formation of the desired product.

Initially, the reaction of *o*-methoxybenzaldehyde (**1**) with 1-trimethylsilyl-1-hexyne (**2**) was screened with various fluoride salts for the synthesis of **3** (Table 1). Because of the good solubility of TBAF in THF, this solvent was chosen for further study. As anticipated, only TBAF efficiently catalyzed the screening reaction, thus corroborating previously reported results.[10] Other fluoride salts produced no significant conversions (Table 1, entries 7−10). The use of tetramethylammonium fluoride (Table 1, entry 8) was not beneficial, apparently because of its poor solubility in THF. Tributyltin fluoride was tested to determine if its greater Lewis acidity promoted carbonyl group activation in THF or toluene as solvent. However, no product was detected by ^{1}H NMR spectroscopy in either case. As shown in Table 1, entries 1−6, 10 mol % of TBAF in the presence of 2 equiv of 1-trimethylsilyl-1-hexyne (**2**) at room temperature gave the best results.

We then examined various aldehydes under the conditions given in Table 1, entry 6. From the data in Table 2, it is seen that our method has advantages over existing methods which include good efficiency at ambient temperature and significantly shorter reaction times (15 min). Thus, literature references report temperatures of −50−100 °C and reaction times of 30 min to 48 h. Moreover, the addition of strong bases and metal/ligand combinations[4−8] is avoided with our approach. A variety of functional groups were tolerated under our conditions, providing good to excellent yields as shown in Table 2. Electron donating groups such as methoxy and methyl resulted in good isolated yields (Table 2, entries 1, 6 and 7) and as expected, halogen-containing aldehydes, such as *o*-chlorobenzaldehyde and *p*-bromobenzaldehyde, also afforded good product yields (entries 4 and 5). Since our

Table 2. Reactions of Aldehydes with 1-Trimethylsilyl-1-hexyne (2) using TBAF as the Catalyst[a]

entry	aldehyde	product	yield (%)	lit. yield (%)
1			75	82[b]
2			78	60-96[b,g,h,j,k]
3			72	66-76[b,k]
4			99	72[e]
5			83	76[b]
6			79	81-84[b,e]
7			75	80[b]
8			91	56-91[b,c,d]
9			91	58[b]
10			72	85[b]
11			84	56-93[b,d,f]

[a] TBAF (10 mol %), THF (4 mL), room temperature for 15 min. Isolated yields after column chromatography. [b] Reference 4. [c] Reference 5c. [d] Reference 6c. [e] Reference 5d. [f] Reference 7c. [g] Reference 5e. [h] Reference 5f. [i] Reference 5g. [j] Reference 6g. [k] Reference 8e.

procedure does not involve the use of strong bases to generate acetylide ions, enolizable aldehydes also gave excellent product yields (Table 2, entries 8 and 9). Although quantitative conversion was observed in the case of heterocyclic 3-furaldehyde (entry 10), the yield was only 72%. Even bulky 1-naphthaldehyde (Table 2, entry 3) gave a good product yield, and the sterically hindered alkyl aldehyde in Table 2, entry 11 provided a better yield of product than that obtained using a quaternary ammonium hydroxide as a catalyst (10 mol %).[7c] Higher yields for this alkyl aldehyde were also reported with the use of potassium ethoxide (10 mol %) and cesium hydroxide (10 mol %) as bases, respectively.[6c,10b]

Since Kuwajima et al. screened only 1-phenyl-2-trimethylsilyl acetylene,[9a,b] we broadened our protocol by screening three different terminally silylated alkynes (Table 3). The electron-rich

dx.doi.org/10.1021/jo200314g |*J. Org. Chem.* 2011, 76, 4482–4488

Table 3. Screening of Trimethylsilyl Aryl Alkynes with Aromatic and Aliphatic Aldehydes[a]

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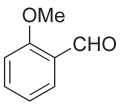
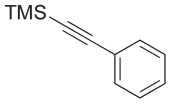
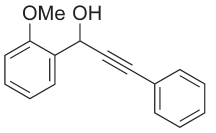
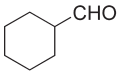
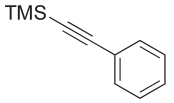
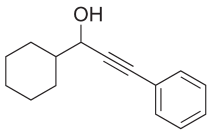
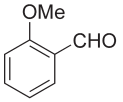
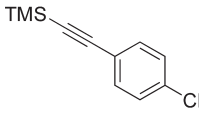
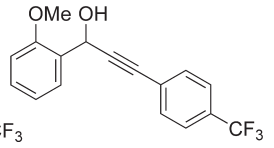
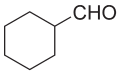
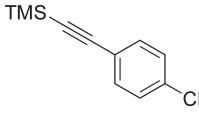
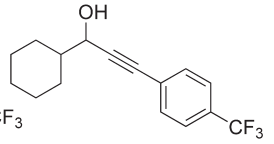
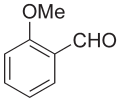
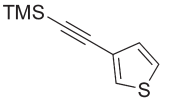
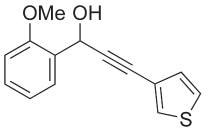
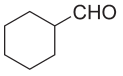
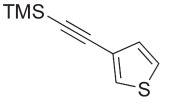
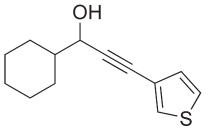
1				76	64-87[b,c,d]
2				75	70-99[e,f,g,h]
3				69	-
4				79	-
5				77	-
6				73	-

[a] TBAF (10 mol %), THF (4.0 mL), room temperature, 15 min. Isolated yields after column chromatography. [b] Reference 6d. [c] Reference 6e. [d] Reference 6f. [e] Reference 5c. [f] Reference 6c. [g] Reference 7c. [h] Reference 7e.

alkyne 1-phenyl-2-trimethylsilyl acetylene, afforded a good product yield with both an aromatic and an enolizable aldehyde (entries 1 and 2, respectively). Electron deficient trimethyl ((4-(trifluoromethyl)phenyl)ethynyl)silane (entries 3 and 4) and the functionalized alkyne trimethyl(thiophen-3-ylethynyl)silane (entries 5 and 6) were also screened with the aforementioned aromatic and enolizable aldehyde, providing generally good yields of product.

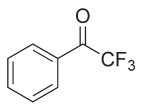
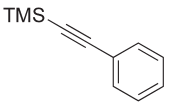
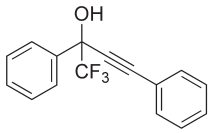
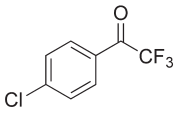
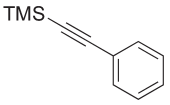
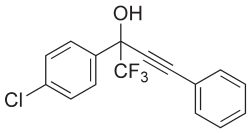
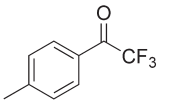
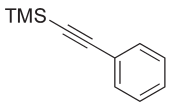
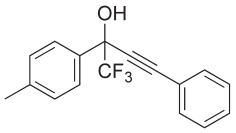
There are many literature examples of trifluoromethyl-containing analogs of biologically active molecules[14] featuring an alkyne motif, for example, the anti-HIV drug Efavirenz,[14] in which the trifluoromethyl substituent substantially changes the electronic properties, leading to a different drug candidate. In this context, Shibasaki, and Kanai et al. developed an elegant method for the synthesis of CF_3-functionalized propargylic alcohols using CuO^{t}Bu-xantphos or phenanthroline with alkyne substrates at 60−100 °C.[15] Thus, we focused our attention on achieving a gratifying synthesis of CF_3-containing alkynes using commercially available materials in a simple metal-free protocol. From our results in Table 4, it is seen that electron-neutral (entries 1, and 2) and electron-donating (entry 3) CF_3-containing acetophenones with aromatic alkyne, 1-phenyl-2-trimethylsilyl acetylene give rise to excellent isolated yields affording CF_3-substituted tertiary propargyl alcohols at room temperature.

We then turned our attention to screening various heterocyclic, aromatic and aliphatic ketones with 1-phenyl-2-trimethylsilyl acetylene (Table 5). Nitrogen-containing 2-pyridyl ketone afforded an excellent isolated product yield (Table 5, entry 1) in the TMS as well as in the alcohol form. Long chain aliphatic ketone (entry 4) also provided good yields of the corresponding TMS-protected propargylic alcohols. However, 4-bromobenzophenone gave an excellent isolated product yield (entry 2) in TMS form. Nonetheless, the syntheses of these molecules have not been reported previously in the literature. A heterocyclic ketone did not participate in alkyne addition reaction under our reaction conditions (entry 5).

The mechanism we suggest in Scheme 1 parallels that proposed by Scheidt et al. in 2005 for aldehyde and ketone alkynylation using triethoxysilylalkynes in the presence of 10% KOEt.[10b] Activation of the silyl group of the alkyne by TBAF forms the activated pentacoordinated silicon species **A** which is followed by silicon coordination of the aldehyde leading to **B**. The subsequent dissociative equilibrium which gives rise to **C** provides an acetylide ion which nucleophilically attacks the carbonyl carbon of the coordinated aldehyde in **C** to create **D** which in turn liberates trimethylsilated **E**. Acid hydrolysis of **E** then provides product **F**.[10b]

dx.doi.org/10.1021/jo200314g |*J. Org. Chem.* 2011, 76, 4482–4488

Table 4. Screening of 1-Phenyl-2-trimethylsilyl Acetylene with Trifluoromethyl Ketones[a]

entry	ketone	alkyne	product	time (h)	yield (%)	lit. yield (%)
1				12	98[b]	83[c], 95[d], 99[e]
2				12	98[b]	91[d]
3				16	90[b]	94[d]

[a] TBAF (10 mol %), ketone (2.0 mmol), alkyne (4.0 mmol), THF (4 mL), room temperature. Isolated yields after column chromatography. [b] No acid workup. Product hydrolyzed during column chromatography. [c] See ref 14b using $(AgF/C_6H_{11})_3P$, 1 day, 100 °C. [d] See ref 15 CuO*t*Bu-xantphos or phenanthroline complex. [e] See ref 14c using CuF as the catalyst (5−10 mol %).

CONCLUSIONS

We have extended and broadened the alkynylation of aldehydes using TBAF as a catalyst in a mild and efficient protocol. Our reactions are faster than those observed with published methods and no organometallic reagents or metal/ligand combinations are required. Enolizable aldehydes participate well in our method, with no use of strong bases (e.g., BuLi). Facile participation of simple, heterocyclic, and trifluoromethyl ketones in alkynylation was observed at room temperature. Our approach is efficient for both aromatic and aliphatic aldehydes and tolerates a wide variety of functional groups. The low catalyst loading (ca. 10 mol %), high isolated product yields, broad scope, room temperature reaction conditions and the use of a relatively inexpensive commercially available nonmetallic base as catalyst are attractive features of our protocol which can serve as an eco-friendly alternative for the synthesis of propargylic alcohols in industrial and academic facilities.

EXPERIMENTAL SECTION

General Experimental Procedure. To a solution of TBAF (10 mol % in dry THF) was added trimethylsilyl alkyne (2.0 mmol) at room temperature. To this was added an aldehyde or ketone (1 mmol) and then the reaction mixture was stirred at room temperature for 15 min. This was followed by the addition of 1 M aqueous HCl (1.0 mL) and further stirring for 15 min at room temperature, unless otherwise stated in the foot notes of corresponding tables. The reaction mixture was neutralized with aqueous $NaHCO_3$ and then it was extracted with ethyl acetate. The organic layers were collected and dried with anhydrous Na_2SO_4 followed by solvent removal under reduced pressure. The crude product was purified by flash chromatography (hexane/ethyl acetate = 90:10) on silica gel to give the desired alkynylation product.

1-(2-Methoxyphenyl)-3-(4-trifluoromethylphenyl)prop-2-yn-1-ol (Table 3, entry 3). This product was purified via flash column chromatography with 10% ethyl acetate/hexane, yielding 69% as a yellow oil. ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.613 (dd, J = 7.2 Hz, J = 1.2 Hz, 1H), 7.57 (s, 4H), 7.351 (dt, J = 8 Hz, J = 1.6 Hz, 1H), (bs, 1H), 7.019 (t, J = 8.4 Hz, 1H), 7.954 (d, J = 8.4 Hz, 1H), 5.936 (d, J = 6.4 Hz, 1H), 3.931 (s, 3H), 3.161 (d, J = 6.4 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 157.0, 132.2, 130.2, 128.5, 128.2, 125.4 (q, J = 3.6 Hz), 121.18, 111.2, 91.1, 84.8, 61.9, 55.9 ppm; HRMS m/z Calcd for $C_{17}H_{13}F3O_2$: 306.08676. Found: 306.08724.

1-Cyclohexyl-3-(4-trifluoromethylphenyl)prop-2-yn-1-ol (Table 3, entry 4). This product was purified via flash column chromatography with 10% ethyl acetate/hexane, yielding 79% as a yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.49−7.56 (m, 4H), 4.39 (d, J = 6 Hz, 1H), 2.33 (s, 1H), 1.938−1.623 (m, 6H), 1.303−1.067 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ 132.1, 130.2 (q, J = 32.55 Hz), 126.8, 125.9, 125.4, 125.3, 122.3, 92.1, 84.5, 67.8, 44.4, 28.9, 28.5, 26.56, 26.08; HRMS m/z Calcd for $C_{16}H_{17}F_3O$: 244.05580. Found: 244.05630.

1-(2-Methoxyphenyl)-3-thiophen-3-yl-prop-2-yn-1-ol (Table 3, entry 5). This product was purified via flash column chromatography with 10% ethyl acetate/hexane, yielding 77% as a yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.643 (dd, J = 1.8 Hz, J = 7.5 Hz, 1 H) 7.485−7.461.(m, 1H) 7.330 (t, J = 7.5 Hz, 1H) 7.266−7.239 (m, 1 H) 7.145 (dd, J = 0.9 Hz, J = 5 Hz, 1 H) 7.008 (dt, J = 0.9 Hz, J = 7.5 Hz, 1 H) 6.785 (d, J = 9 Hz, 1 H) 5.918 (s, 1H) 3.904 (s, 3H) 3.171 (d, J = 5 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ 157.0, 130.2, 129.9, 129.3, 128.9, 128.2, 125.5, 121.9, 121.1, 111.1, 88.2, 81.5, 61.8, 55.9 ppm; HRMS m/z Calcd for $C_{14}H_{12}O_2S$: 282.12315 Found: 282.12361.

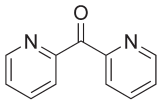
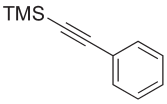
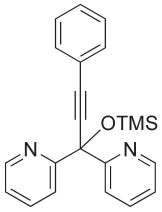
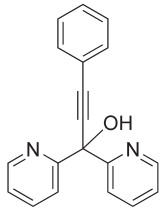
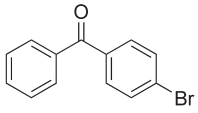
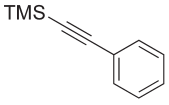
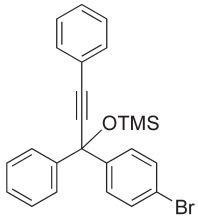
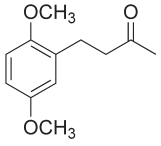
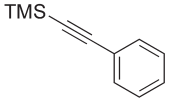
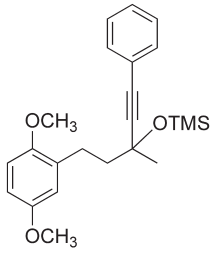
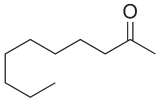
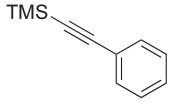
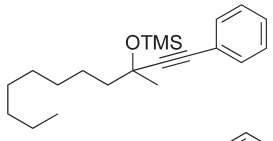
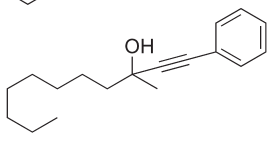
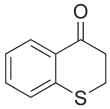
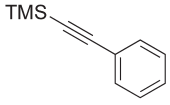
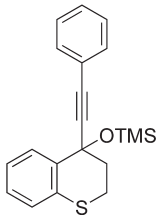
1-Cyclohexyl-3-thiophen-3-yl-prop-2-yn-1-ol (Table 3, entry 6). This product was purified via flash column chromatography with 10% ethyl acetate/hexane, yielding 73% as a yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.419 (dd, J = 0.9 Hz, J = 3 Hz, 1H), 7.092 (dd, J = 1.2 Hz, J = 4.8 Hz, 1H) 4.349 (d, J = 6 Hz, 1H) 2.326 (bs, 1H) 1.921−1.586 (m, 6H) 1.287−1.078 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz): δ 130.1, 129.0, 125.5, 122.0, 89.2, 80.9, 67.8, 44.5, 28.9, 28.5, 26.6, 26.1 ppm; HRMS m/z Calcd for $C_{13}H_{16}OS$: 220.09219. Found: 220.09246.

1,1,1-Trifluoro-2,4-diphenylbut-3-yn-2-ol (Table 4, entry 1). Purified via flash column chromatography with 5% ethyl acetate/hexane, yielding 98% as yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.22 (s, 1H), 7.35−7.47 (m, 6H), 7.47−7.57 (m, 2H), 7.84−7.87 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 73.4 (q, J = 32.2 Hz), 84.5, 88.2, 121.0, 123.5 (*q*, J = 283.2 Hz), 127.3, 128.3, 128.6, 129.4, 129.6, 129.7, 132.2, 135.4 ppm; HRMS m/z Calcd for $C_{16}H_{11}F_3O$: 276.07620. Found: 276.07667.

2,2′-(3-Phenyl-1-((trimethylsilyl)oxy)prop-2-yne-1,1-diyl)dipyridine (Table 5, entry 1). Purified via flash column chromatography with 5% ethyl acetate/hexane, yielding 98% as a light yellow oil. ^{1}H NMR

dx.doi.org/10.1021/jo200314g |*J. Org. Chem.* 2011, 76, 4482–4488

Table 5. Screening of 1-Phenyl-2-trimethylsilyl Acetylene with Ketones[a]

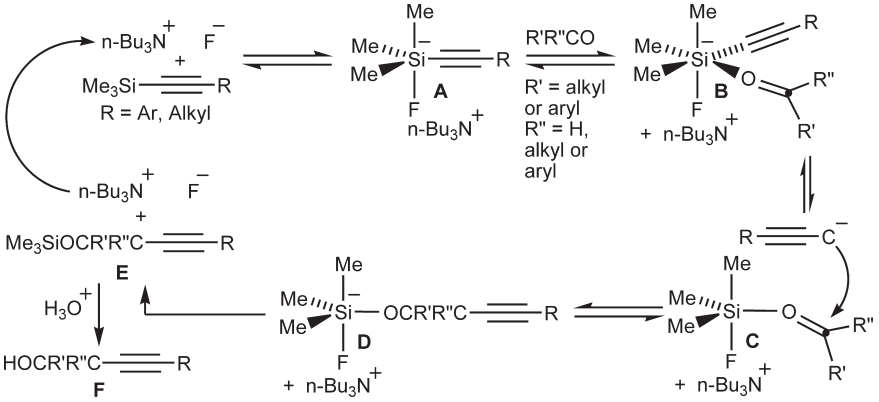
entry	ketone	alkyne	product	time (h)	yield (%)
1				18	98[b,c]
				13	93
2				18	98
3				18	44
4				18	76[b]
					22[b]
5				24	n.r[d]

[a] 10 mol % TBAF, ketone (2.0 mmol), alkyne (4.0 mmol), THF (4 mL), room temperature. Isolated yields after column chromatography. None of these products have been reported in the literature. [b] No acid workup. Product hydrolyzed during column chromatography. [c] Catalyst (20 mol %) was used. [d] No product detected.

($CDCl_3$, 300 MHz): δ 0.22 (s, 9H), 7.08−7.11 (m, 1H), 7.23−7.26 (m, 1H), 7.31−7.35 (m, 4H), 7.54−7.56 (m, 2H), 7.66−7.70 (m, 1H), 7.74−7.76 (m, 2H), 7.90−7.92 (m, 1H), 8.54−7.86 (m, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 1.7, 77.3, 87.9, 91.7, 119.4, 122.1, 122.8, 126.5, 127.5, 128.1, 128.3, 128.6, 131.8, 136.7, 145.5, 149.1, 164.4 ppm; HRMS m/z Calcd for $C_{22}H_{22}N_2OSi$: 358.15013. Found: 358.15108.

dx.doi.org/10.1021/jo200314g |J. Org. Chem. 2011, 76, 4482–4488

Scheme 1. Mechanism Proposed for TBAF-Catalyzed Alkynylation of Aldehydes and Ketones



((1-(4-Bromophenyl)-1,3-diphenylprop-2-yn-1-yl)oxy)trimethylsilane (Table 5, entry 2). Purified via flash column chromatography using hexanes yielding 98% as a light-yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.23 (s, 9H), 7.28−7.30 (m, 1H), 7.35−7.40 (m, 5H), 7.47−7.49 (m, 2H), 7.56−7.58 (m, 4H), 7.67 (d, J = 6.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 1.9, 75.8, 88.7, 91.7, 121.5, 122.7, 126.2, 127.7, 128.1, 128.4, 128.7, 129.0, 131.4, 131.8, 146.3, 146.4 ppm; HRMS m/z Calcd for $C_{24}H_{23}BrOSi$: 434.07014. Found: 434.07124.

((5-(2,5-Dimethoxyphenyl)-3-methyl-1-phenylpent-1-yn-3-yl)oxy)-trimethylsilane (Table 5, entry 3). Purified via flash column chromatography using 10% ethyl acetate in hexanes yielding 44% as a colorless oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.26 (s, 9H), 1.60 (m, 3H), 1.96−2.01 (m, 2H), 2.82−2.86 (m, 2H), 3.75 (s, 3H), 3.77 (s, 3H), 6.67−6.70 (m, 2H), 6.75−6.78 (m, 1H), 6.75−6.78 (m, 2H), 7.30−7.32 (m, 3H), 7.43−7.44) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 2.0, 26.0, 31.1, 45.2, 55.7, 56.0, 69.8, 84.5, 93.5, 110.8, 111.3, 116.2, 123.2, 128.2, 131.5, 132.3, 152.0, 153.6 ppm; HRMS m/z Calcd for $C_{23}H_{30}O_3Si$: 382.1957. Found: 382.1964.

Trimethyl((3-methyl-1-phenylundec-1-yn-3-yl)oxy)silane (Table 5, entry 4). Purified via flash column chromatography using hexanes yielding 76% as colorless oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.21 (s, 9H), 0.85−0.88 (m, 3H), 1.26−1.29 (m, 10H), 1.51 (m, 5H), 1.64−1.70 (m, 2H), 7.28−7.30 (m, 3H), 7.39−7.40 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 2.2, 14.4, 23.0, 25.0, 29.6, 29.8, 30.0, 31.5, 32.1, 45.5, 70.1, 84.4, 94.0, 123.4, 128.3, 128.5, 131.6 ppm; HRMS m/z Calcd for $C_{21}H_{34}OSi$: 330.2379. Found: 330.2379.

3-Methyl-1-phenylundec-1-yn-3-ol (Table 5, entry 4). Purified via flash column chromatography using 10% ethyl acetate in hexanes yielding 22% as a colorless oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.87−0.90 (s, 3H), 1.28−1.33 (m, 10H), 1.55−1.57 (m, 10H), 1.72−1.77 (m, 2H), 2.13 (s, 1H), 7.29−7.30 (m, 3H), 7.40−7.43 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 14.4, 22.9, 25.0, 29.5, 29.8, 30.0, 30.1, 32.1, 44.0, 68.9, 83.5, 93.25, 123.0, 128.4, 131.9 ppm; HRMS m/z Calcd for $C_{18}H_{26}O$: 258.1984. Found: 258.1981.

■ ASSOCIATED CONTENT

Supporting Information. References to the known compounds and copies of ^{1}H and ^{13}C NMR spectra for all alkynylation products, and HRMS reports for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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■ ACKNOWLEDGMENT

The National Science Foundation is gratefully acknowledged for financial support of this research in the form of grant 0750463.

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