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Triflic Acid Promoted Direct α-Alkylation of Unactivated Ketones Using Benzylic Alcohols via in Situ Formed Acetals

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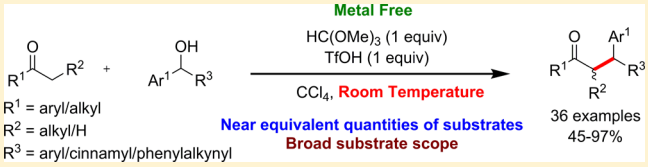
Supporting Information

ABSTRACT: Direct α-alkylation of unactivated ketones using benzylic alcohols as electrophiles has been achieved at room temperature. This reaction takes place via in situ formed acetal using triflic acid and trimethyl orthoformate. It is believed that methyl vinyl ether formed from the in situ generated dimethyl acetal in the presence of triflic acid undergoes alkylation. Diverse ketones could be alkylated with diarylmethanols, cinnamyl alcohols, and phenyl propargyl alcohols having different electrophilicities.



INTRODUCTION

Alkylation at the α-carbon of carbonyl compounds is one of the fundamental reactions to form a C−C bond. In recent years there has been considerable interest in carrying out α-alkylation using unactivated carbonyl compounds directly without any prior activation, like converting them into enolates and attaching good leaving groups to the electrophile. By doing so, metal based byproducts are avoided, and at the same time the number of steps is also reduced. In this regard, alcohols are attractive electrophiles to make alkylated products.[1] The advantage of using alcohol is the formation of water as the byproduct. Primary alcohols have been employed in alkylation via transfer hydrogenation.[2] This strategy essentially involves oxidation of primary alcohol into aldehyde under transition metal catalysis, which undergoes aldol reaction with the ketone, and subsequent hydrogenation under the influence of metal catalyst present in the reaction results the product of α-alkylation ultimately. Another strategy that is being explored recently employs activation of alcohols by Lewis/Brønsted acid to generate electrophilic carbon center to facilitate the alkylation.[3−7] Alcohols used are generally diarylmethanols. Carbonyl compounds used in these reactions are in the form of activated systems like enol acetates,[3] silyl-enol ethers,[4] 1,3-dicarbonyls[5] and enamines[6,7] (generated using chiral amine organocatalysts). Baba and co-workers reported the reaction of enol acetate derivatives with different benzylic alcohols at 83 °C in DCE to make α-alkylated products.[3] Rubenbauer and Bach used silyl enol ether for the alkylation with benzylic alcohols catalyzed by $Bi(OTf)_3$.[4] Direct alkylation of 1,3-dicarbonyls is a favorable reaction because they exist mostly in enolic form.[5] Even then, it required heating on many instances. Enamines generated by secondary amine organocatalysts can only be applied in the alkylation of ketones and aldehydes with diarylmethanols such as bis(4-(dialkylamino)phenyl)methanol that can generate stable diarylmethyl carbocations.[6,7] Recently, Chi and co-workers have reported direct alkylation of aldehydes with diarylmethanols and aryl attached allyl alcohols under Brønsted acid catalysis.[8] They successfully overcome the problem of ether formation from alcohol by adding *t*-BuOH to the reaction. Because of differences in the reactivities of diarylmethanols having substituents with different electronic properties, reaction conditions and choice of Brønsted acid catalyst has to be optimized in each case. It is really a challenging task to make ketones to undergo such direct alkylation at the α-position because of the very reduced concentration of enol form of simple ketones at normal circumstances. It is known, on the basis of both experiments and computational calculations, that concentration of enols in keto−enol tautomerism of ketones is considerably less than that of aldehydes (other than acetaldehyde).[9] Experimental pK_E values of acetaldehyde, 2-methylpropanaldehyde, acetone, cyclohexanone, acetophenone and methyl 4-methylphenyl ketone are, respectively, 6.23, 3.86, 8.33, 6.39, 7.96, and 8.34. While preparing this manuscript, Gu and co-workers reported $Fe(OTf)_3$-catalyzed reaction of aryl methyl ketones using diarylmethanols by refluxing them in chlorobenzene at 130 °C to get the corresponding α-alkylated products in moderate yields.[10] However, the authors found that the reaction occurred only when one of the aryls in diarylmethanol had methoxy group in it. It is worth mentioning that in all the above α-alkylation reactions using diarylmethanols, carbonyl compounds were taken in 2−10 fold excess. More recently, Kalutharage and Yi have developed cationic ruthenium hydride complex catalyzed α-alkylation of ketones using amino acids under reflux in toluene.[11] Pd/C catalyzed direct α-alkylation of ketones with primary alcohols in water at 180 °C under microwave conditions has been reported by Mu and co-workers.[12] In a recent study, α-alkylation of ketones was achieved by catalyst free heating of ketones with alcohols in the presence of stoichiometric amount of NaOH at 110 °C.[13] This

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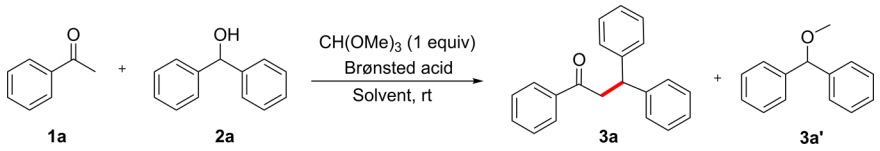
Table 1. Optimization of Acid Reagent and Solvent for the Direct Alkylation[a]



1a 2a 3a 3a'

entry	Brønsted acid	amount of Brønsted acid	solvent	time (h)	yield[b] (%) 3a	yield[b] (%) 3a′
1	*p*-TSA	1 equiv	CCl_4	12	–	85
2	CCl_3COOH	1 equiv	CCl_4	12	–	63
3	CSA	1 equiv	CCl_4	12	–	84
4	$HClO_4$	1 equiv	CCl_4	12	trace	80
5[c]	TfOH	1 equiv	CCl_4	16	9	–
6	TfOH	20 mol %	CCl_4	24	–	71
7[c,d]	TfOH	20 mol %	CCl_4	16	4	–
8	**TfOH**	**1 equiv**	**CCl_4**	**1**	**60**	**9**
9	TfOH	1 equiv	dioxane	12	0	91
10	TfOH	1 equiv	hexane	12	37	58
11[d]	TfOH	20 mol %	CCl_4	16	–	85

[a]Reactions were carried out with ketone (1 equiv), benzhydrol (1.2 equiv), and trimethyl orthoformate (1 equiv). [b]Isolated yields. [c]Without trimethyl orthoformate. [d]Reaction was heated to 60 °C.

reaction involving interesting redox pathway is however limited to aryl ketones and benzylic primary alcohols.

Herein we report a facile method for the direct α-alkylation of ketones under mild condition using near equivalent amounts of ketones and diarylmethanols. Our protocol involves in situ formation of dimethylacetal of ketone using trimethyl orthoformate, which generates methyl vinyl ether under acidic condition. This reacts with the carbocation generated from benzylic alcohol under the influence of the same acid. Hence the role of acid in this reaction is of three folds. Acetals are known to form vinyl ethers under different conditions.[14] Such a transformation can happen by the influence of Brønsted acid under heating conditions. Ghatak and co-workers have observed intramolecular cyclization of methyl ketone on a double bond.[15] It was believed that the reaction occurred by the C-alkylation of enol ether generated by heating the methyl ketone containing substrate with excess of trimethyl orthoformate and perchloric acid. Further this intramolecular cyclization occurred only when the double bond is attached to *p*-methoxyphenyl group. However, with TfOH, we have found that such vinyl ether could be generated at room temperature itself from different ketones and made to react intermolecularly with electrophile.

RESULTS AND DISCUSSION

To explore the optimum reaction condition for the direct alkylation via in situ generated acetals, acetophenone was reacted with benzhydrol in the presence of 1 equiv of trimethyl orthoformate and different Brønsted acids separately at room temperature (Table 1). Of the different Brønsted acids screened, strong Brønsted acid TfOH was found to be promising (entry 8, Table 1). Among the other Brønsted acids, *p*-TSA, trichloroacetic acid and camphorsulfonic acid did not promote the reaction (entries 1−3, Table 1). In these reactions methyl ether of benzhydrol was only obtained. Moreover, the alkylation reaction using TfOH is favored in nonpolar solvents and CCl_4 was found to be the best. Without trimethyl orthoformate, very low amount of the product (9%) was obtained (entry 5, Table 1). When the reaction was carried out using 20 mol % of TfOH no reaction was observed at room temperature. Upon heating the reaction mixture to 60 °C for 16 h, it resulted the desired product in 4% yield only (entry 7, Table 1). In a separate experiment, dimethyl acetal derived from acetophenone was treated with benzhydrol and TfOH in CCl_4. This reaction resulted in 33% yield of the desired product along with 43% of acetophenone. These observations are consistent with formation of an acetal and subsequent transformation into an enol ether as the key to effecting smooth alkylation. The advantage of generating the acetal in situ in the presence of trimethyl orthoformate is that good amount of acetal will be there for the reaction as whatever the ketone formed by deprotection under the reaction condition will be converted back into acetal.

Then the substrate scope of the present α-alkylation was explored with a range of carbonyl compounds and diarylmethanols using the condition mentioned in entry 8 of Table 1. Mayr's research group has made a seminal contribution to predict the reactivity of diversely substituted diarylmethanols with different nucleophiles under S_N1-type reaction conditions.[16] On the basis of several meticulous experiments they have established quantitative values for the nucleophilicity (N) and electrophilicity (E) of different nucleophiles and electrophiles, respectively. It is anticipated that methyl vinyl ether is the species responsible for the product formation. According to Mayr's scale, the N value of closely related ethyl vinyl ether is 3.92.[16,17] This value is much less than that of reactive enamines (N > 10), which reacts only with diarylmethanols having electron-donating substituents.[6,7] These diarylmethanols result in stabilized carbocations (E < −4).[16] In the present study, we have reacted a wide range of electrophiles (E = +5.47 to −2.64) such as electron-donating and electron-withdrawing groups substituted diarylmethanols, xanthydrol, cinnamyl alcohols and phenyl propargyl alcohols with ketones (nucleophiles) such as aryl methyl/aryl ethyl ketones, 4-phenylbut-3-en-2-one and cyclohexanone. To the best of our knowledge, none of the already reported protocols for direct α-alkylation of ketones using benzylic alcohols has this range of substrate scope.

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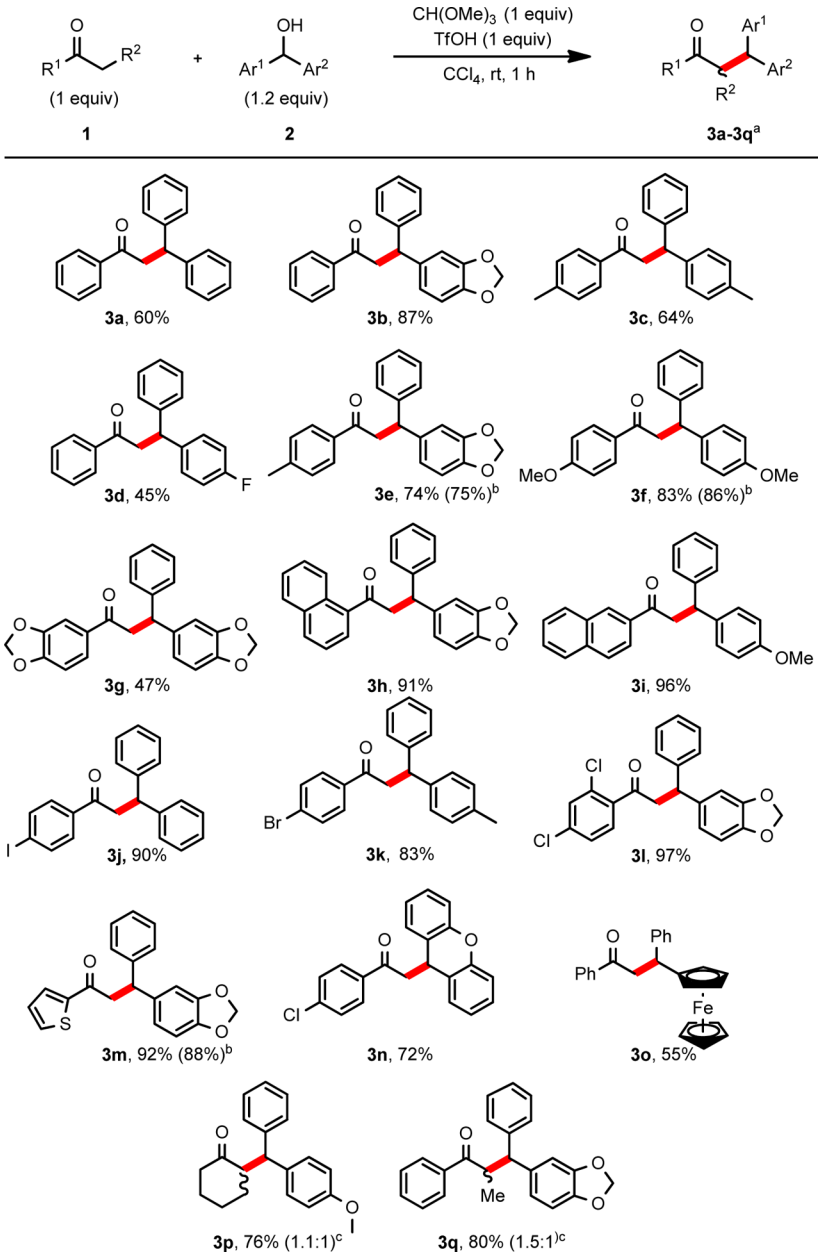
Scheme 1. TfOH Promoted α-Alkylation of Unactivated Ketones with Diarylmethanols



[a]Isolated yield. [b]Yield obtained in 2 mmol scale reaction. [c]Values in parentheses are diastereomeric ratios.

Scheme 1 presents the results of reaction of different ketones with diarylmethanol derivatives. Aryl ketones having electron-donating groups such as Me, OMe and 3,4-methylenedioxy and electron-withdrawing groups like halides were tested. Alkylation of acetophenone with simple benzhydrol (E = 5.47) resulted the α-alkylated product in moderate yield only (60%). Some amount of corresponding methyl ether of benzhydrol also formed in this reaction. The yields of the alkylation products were better when halide functionality is present in the aryl ring of the ketone (**3j**−**3l** and **3n**). Electron-donating groups on one of the aryl rings of diarylmethanol also improved the yield of the alkylated product (**3b**, **3e**, **3f**, **3h**, **3i**, **3l**, **3m and 3q**). On the other hand, electron-withdrawing group such as fluoro as in (4-fluorophenyl)(phenyl)methanol (E = 5.20) resulted in moderate yield of the desired product **3d**. In this case also some amount of corresponding methyl ether of the alcohol was obtained. Comparatively low yields of the alkylated products in this case (45%) and in the reaction with simple benzhydrol (60%) is not surprising as they have high E values and do not form the benzylic carbocations that readily. However, it is surprising that the α-alkylation did not work at both room and reflux temperatures when (4-(dimethylamino)phenyl)(phenyl)-methanol (with more negative E value) which is expected to generate more stable benzylic carbocation was used. Perhaps, protonation of the amine nitrogen with strong TfOH might have occurred which makes it less reactive. However, alcohol derived from benzoyl ferrocene (E = −2.64) underwent alkylation comfortably to yield **3o** in 55% yield. Heteroaryl ketone such as 2-acetylthiophene also reacted nicely and yielded the corresponding α-alkylated product **3m**. This methodology can be applied to ketones other than aryl methyl ketones as well. Dialkyl ketones such as cyclohexanone also

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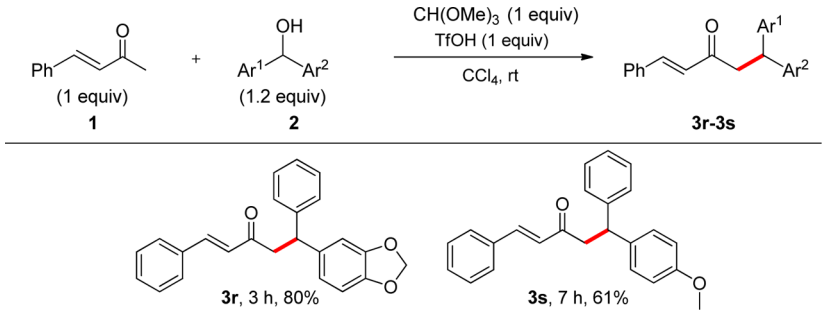
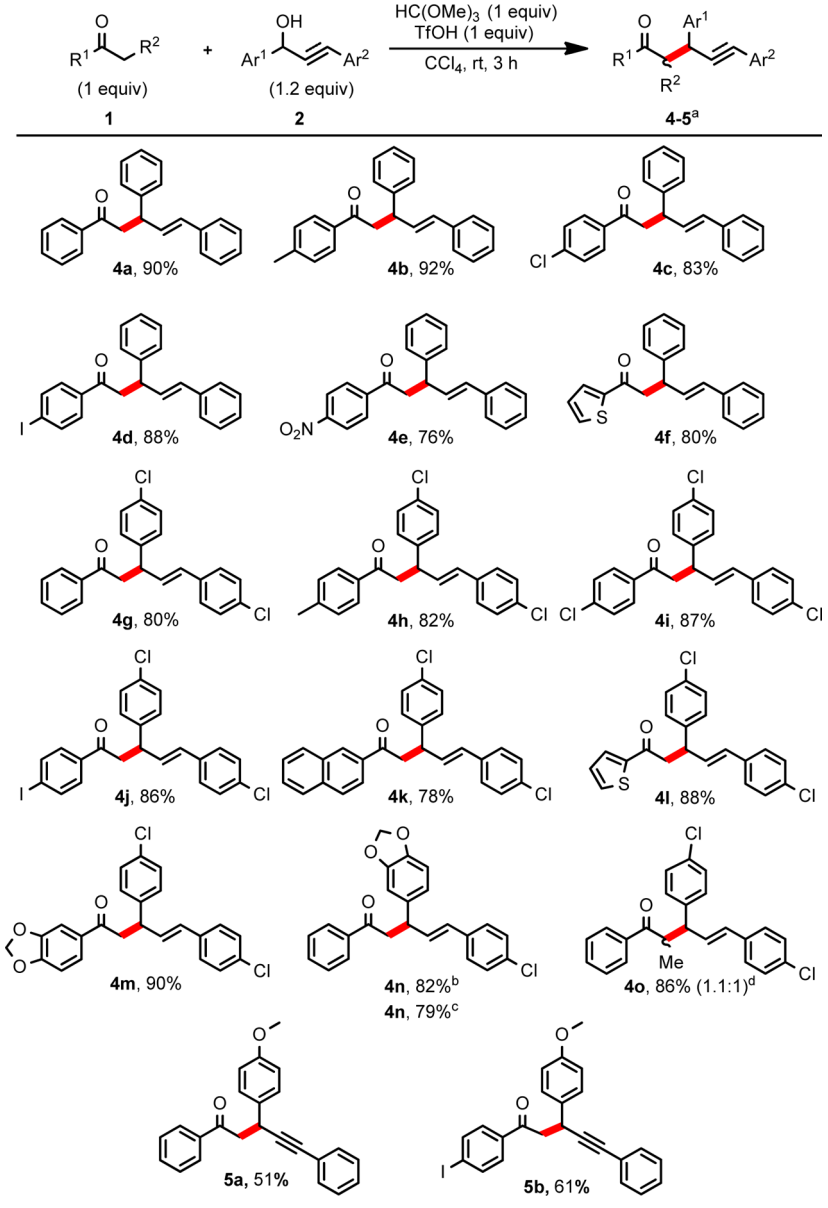
Scheme 2. TfOH Promoted α-Alkylation of (E)-4-Phenylbut-3-en-2-one with Diarylmethanols[a]



[a]Isolated yield.

Scheme 3. TfOH Promoted α-Alkylation of Unactivated Ketones with Cinnamyl and Phenyl Propargyl Alcohols



[a]Isolated yield. [b](E)-1-(Benzo[d][1,3]dioxol-5-yl)-3-(4-chlorophenyl)prop-2-en-1-ol (1.2 equiv) was used. [c](E)-3-(Benzo[d][1,3]dioxol-5-yl)-1-(4-chlorophenyl)prop-2-en-1-ol (1.2 equiv) was used. [d]Value in parenthesis is diastereomeric ratio.

underwent α-alkylation. Only mono alkylated product **3p** was obtained. Ethyl phenyl ketone resulted in a diastereomeric mixture of α-alkylated products **3q**. Three reactions were performed at 2 mmol scale (ketone) each to evaluate the

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applicability of this method in synthetic scale. The yields obtained were comparable to that obtained in 50 mg (ketone) scale. While **3e** and **3f** were obtained in slightly higher yields, **3m** was obtained in slightly lower yield in 2 mmol scale reactions (Scheme 1). Hence scaling up this reaction might not be a problem.

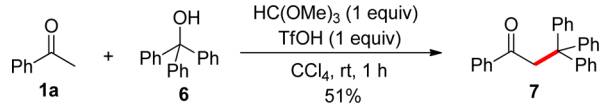
α,β-Unsaturated ketone such as (*E*)-4-phenylbut-3-en-2-one could also be employed to get the corresponding α-alkylated products (Scheme 2, **3r** and **3s**). It is worth mentioning that α,β-unsaturated carbonyl systems (in the form of aldehydes/ketones/enol acetates/silyl enol ethers) have not been studied so far in any of the reported alkylations involving diarylmethanols.

We then studied the α-alkylation of ketones with cinnamyl and phenyl propargyl alcohols. The results are compiled in Scheme 3. These reactions required slightly longer time but completed within 3 h. Allyl alcohols having aryl groups at both carbinol and olefinic carbons underwent smooth alkylation on a range of aryl methyl ketones. The reaction did not occur with substrates in which either carbinol carbon or olefinic carbon does not have an aryl group attached to it. Unlike the reactions involving diarylmethanols (Schemes 1 and 2), reactions with cinnamyl alcohols were smooth and high yielding irrespective of the substituents on the aryl group of the ketone. Even 4-nitro acetophenone underwent alkylation without much depreciation in the yield of the product **4e**. Cinnamyl alcohols provide unique opportunity to know the kind of intermediate involved because it will be reflected in the position of double bond in the product. Allyl alcohol having 3,4-methylenedioxyphenyl at carbinol carbon and 4-chlorophenyl at terminal carbon of double bond reacted with acetophenone under the reaction condition to form **4n** in 82% yield. The same product **4n** was obtained when the allyl alcohol having 4-chlorophenyl at the carbinol carbon and 3,4-methylenedioxyphenyl at terminal carbon of double bond was used. In the latter case, shift of allylic double bond is required to form **4n**. These experiments clearly indicate that the reaction takes place with stable benzyl carbocation (benzylic to 3,4-methylenedioxyphenyl). Reaction of acetophenone with (*E*)-4-phenylbut-3-en-2-ol was attempted under the reaction conditions to get more insight into the proposed carbocation intermediate. However, this reaction resulted in a complex mixture of products. Propargyl alcohols having aryl substituents at both carbinol and alkyne carbons could also be employed. The yields were moderate only (**5a** and **5b**) and possible formation of allenes was not detected. The products obtained in the reactions with propargyl alcohols are valuable starting materials for the synthesis of substituted furans.[18]

To compare the reactivities of diarylmethanols with cinnamyl alcohols a couple of reactions were conducted. In the first experiment, 0.5 equiv each of diphenylmethanol and (*E*)-1,3-diphenylprop-2-en-1-ol were mixed with 1 equiv each of acetophenone, trimethyl orthoformate and triflic acid and the reaction was carried out for 30 min. The crude product mixture was analyzed by ^{1}H NMR. It revealed 1:10 ratio of alkylated products due to diphenylmethanol and (*E*)-1,3-diphenylprop-2-en-1-ol. Good amount of methyl ether of diphenylmethanol was also there. Similar reaction of acetophenone with equimolar amounts of benzo[*d*][1,3]dioxol-5-yl(phenyl)-methanol and (*E*)-1,3-diphenylprop-2-en-1-ol resulted in nearly 1:1 ratio of the alkylated products as revealed by the ^{1}H NMR. It has to be mentioned that both benzo[*d*][1,3]dioxol-5-yl(phenyl)methanol and (*E*)-1,3-diphenylprop-2-en-1-ol resulted in almost equal isolated yields (87 and 90% respectively) whereas diphenylmethanol resulted 60% yield in the actual preparative reactions. The reactions with cinnamyl alcohols were done for 3 h as it ensured good yields. Otherwise the cinnamyl alcohols are more reactive. In the case of diarylmethanols, other than simple diphenylmethanol and (4-fluorophenyl)(phenyl)methanol, other diaryl methanols employed in this study had electron-donating groups which made them more reactive.

Further, one reaction was performed using triphenylmethanol, a tertiary alcohol as electrophile with acetophenone. Encouragingly, it resulted in 51% yield of the desired alkylated product **7**.

Scheme 4. TfOH Promoted α-Alkylation of Acetophenone with Triphenylmethanol



In mechanistic terms, it is believed that acetal[19] is formed first, which leads to the formation of the vinyl ether[20] under acidic condition. This vinyl ether might be in equilibrium with the acetal and undergoes alkylation with the benzylic carbocation formed from benzylic alcohol under the influence of acid (Scheme 5).

CONCLUSIONS

In summary, a TfOH mediated direct alkylation of unactivated ketone via in situ formed acetal has been developed. The reactions occur readily at room temperature. The protocol has good substrate scope. Although the reactions are carried out using 1 equiv of triflic acid, this methodology has overall advantages over the related protocols, like that reactants are used in near equivalent amounts, no metal or expensive reagents are involved, and most importantly, they are carried out at room temperature. Smooth generation of vinyl ethers under the reaction condition presented in the manuscript might find application in carrying out related reactions of unactivated ketones.

EXPERIMENTAL SECTION

General Information. All reagents were obtained commercially and used without further purification unless otherwise mentioned. Trimethyl orthoformate was distilled prior to use. HPLC grade CCl_4 was used as solvent for alkylation reactions. Thin-layer chromatography was performed by using silica gel F_{254} coated aluminum plates and the visualization of spots were done using UV illumination and charring the TLC plates sprayed with Seebach solution. Column chromatography was performed on silica gel 100−200 mesh, using ethyl acetate and hexanes mixture as eluent. ^{1}H and ^{13}C NMR spectra of the synthesized compounds were recorded in 400 NMR machine using their solutions in $CDCl_3$. The ^{1}H NMR and ^{13}C NMR were referred respectively to TMS used as an internal standard and the central line of $CDCl_3$ peaks. IR spectra were recorded using FT/IR spectrometer. High resolution mass spectra (HRMS) were recorded using ESI-Q-TOF technique. Melting points were determined by using visual melting range apparatus and are uncorrected. The synthesis and data of alcohol electrophiles employed in this work are already reported in the literature.[21−25]

Preparation of (*E*)-3-(benzo[*d*][1,3]dioxol-5-yl)-1-(4-chlorophenyl)prop-2-en-1-ol is described below.

(E)-3-(Benzo[d][1,3]dioxol-5-yl)-1-(4-chlorophenyl)prop-2-en-1-ol. It was prepared from corresponding ketone[25a] by $NaBH_4/CeCl_3$

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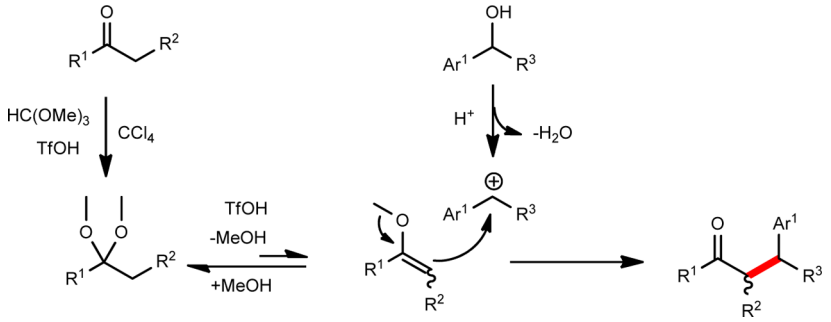
Scheme 5. Proposed Mechanism for α-Alkylation Reaction



reduction under standard Luche conditions. This compound is unstable and found to rearrange to the isomeric allyl alcohol in silica gel column. The crude product was fairly pure and was used in the alkylation reaction without purification. Data of the crude product: IR (KBr, cm^{-1}) 3358, 2892, 1648, 1593, 1489, 1445, 1248, 1034, 969, 870. ^1H NMR (400 MHz, $CDCl_3$) δ 7.29−7.28 (m, 4H), 6.85 (m, 1H), 6.77−6.70 (m, 2H), 6.49 (d, J = 16.0 Hz, 1H), 6.09 (dd, $J_{1,3}$ = 16.0 Hz, $J_{1,2}$ = 7.2 Hz, 1H), 5.90 (s, 2H), 5.25−5.23 (m, 1H), 2.73−2.71 (bs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.1, 147.5, 141.4, 133.4, 130.8, 130.7, 129.3, 128.7, 127.7, 121.5, 108.4, 105.8, 101.2, 74.5; HRMS (ESI-Q-TOF) m/z calcd for $C_{16}H_{13}ClO_3$ $[M + Na]^+$ 311.0451, found 311.0453.

General Procedure for α-Alkylation of Unactivated Ketones with Diarylmethanols. To a solution of unactivated ketone (50 mg, 1 equiv) and diarylmethanols (1.2 equiv) in CCl_4 (2 mL), trimethyl orthoformate (1 equiv) and triflic acid (1 equiv) were added. The reaction mixture was stirred at room temperature. After complete consumption of the ketone as revealed by TLC, solvent was evaporated, and the crude product was directly loaded on a silica gel column (usual water work-up in case of **3o**) and eluted with ethyl acetate/hexanes to get the pure alkylated product.

*1,3,3-Triphenylpropan-1-one (**3a**).*[26a] 71 mg, yield 60%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.93−7.89 (m, 2H), 7.51−7.49 (m, 1H), 7.42−7.39 (m, 2H), 7.26−7.23 (m, 8H), 7.19−7.13 (m, 2H), 4.82 (t, J = 7.3 Hz, 1H), 3.72 (d, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 144.1, 137.0, 133.0, 128.5, 128.4, 128.0, 127.8, 126.3, 45.9, 44.6.

*3-(Benzo[d][1,3]dioxol-5-yl)-1,3-diphenylpropan-1-one (**3b**).* 120 mg, yield 87%; cream colored solid; mp 96−98 °C; IR (KBr, cm^{-1}) 3413, 2882, 2783, 1671, 1594, 1490, 1446, 1238, 1035, 942, 745, 542; ^1H NMR (400 MHz, $CDCl_3$) δ 7.91−7.90 (m, 2H), 7.52−7.50 (m, 1H), 7.41 (t, J = 7.1 Hz, 2H), 7.28−7.21 (m, 4H), 7.17−7.16 (m, 1H), 6.74−6.72 (m, 2H), 6.68 (d, J = 8.4 Hz, 1H), 5.84 (s, 2H), 4.74 (t, J = 7.2 Hz, 1H), 3.67 (d, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 147.7, 145.9, 144.2, 138.0, 136.9, 133.0, 128.5, 128.0, 127.6, 126.3, 120.6, 108.3, 108.1, 100.8, 45.5, 44.7; HRMS (ESI-Q-TOF) m/z calcd for $C_{22}H_{18}O_3[M + H]^+$ 331.1334, found 331.1334.

*3-Phenyl-1,3-di-p-tolylpropan-1-one (**3c**).*[26b] 75 mg, yield 64%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, J = 8.3 Hz, 2H), 7.25−7.21 (m, 7H), 7.17−7.13 (m, 2H), 7.06 (d, J = 8.1 Hz, 2H), 4.78 (t, J = 7.3 Hz, 1H), 3.68 (d, J = 7.3 Hz, 2H), 2.39 (s, 3H), 2.27 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.7, 144.5, 143.8, 141.2, 141.2, 135.8, 134.6, 129.2, 128.5, 128.2, 127.8, 127.7, 126.2, 45.6, 44.6, 21.6, 21.0.

*3-(4-Fluorophenyl)-1,3-diphenylpropan-1-one (**3d**).*[26c] 57 mg, yield 45%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.92 (dd, J = 8.0, 0.8 Hz, 2H), 7.56−7.53 (m, 1H), 7.44 (t, J = 7.6 Hz, 2H), 7.29−7.16 (m, 7H), 6.94 (t, J = 8.8 Hz, 2H), 4.82 (t, J = 7.6 Hz, 1H), 3.71 (d, J = 6.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 161.4 (d, J = 242.9 Hz), 144.1, 139.9, 137.1, 133.3, 129.4, 129.3, 128.7, 128.2, 127.8, 126.6, 115.6 (d, J = 21.1 Hz), 45.3, 44.9; ^{19}F NMR (376.3 MHz, $CDCl_3$) −116.7 (s).

*3-(Benzo[d][1,3]dioxol-5-yl)-3-phenyl-1-p-tolylpropan-1-one (**3e**).* 95 mg, yield 74%; cream colored solid; mp 88−90 °C; IR (KBr, cm^{-1}) 3435, 2893, 1665, 1484, 1430, 1232, 1030, 931, 805; ^1H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, J = 8.2 Hz, 2H), 7.25−7.23 (m, 4H), 7.21−7.19 (m, 2H), 7.16−7.14 (m, 1H), 6.73−6.71 (m, 2H), 6.69−6.66 (m, 1H), 5.82 (s, 2H), 4.73 (t, J = 7.1 Hz, 1H), 3.63 (d, J = 7.1 Hz, 2H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.4, 147.6, 145.9, 144.3, 143.8, 138.1, 134.5, 129.2, 128.5, 128.1, 127.6, 126.3, 120.6, 108.3, 108.1, 100.8, 45.6, 44.5, 21.5; HRMS (ESI-Q-TOF) m/z calcd for $C_{23}H_{20}O_3[M + H]^+$ 345.1491, found 345.1490.

*1,3-Bis(4-methoxyphenyl)-3-phenylpropan-1-one (**3f**).*[26d] 96 mg, yield 83%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, J = 8.7 Hz, 2H), 7.26−7.22 (m, 4H), 7.17−7.12 (m, 3H), 6.88 (d, J = 8.7 Hz, 2H), 6.78 (d, J = 8.3 Hz, 2H), 4.76 (t, J = 7.2 Hz, 1H), 3.82 (s, 3H), 3.72 (s, 3H), 3.63 (d, J = 7.2 Hz, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$) δ 196.6, 163.4, 157.9, 144.6, 136.4, 130.3, 130.1, 128.7, 128.4, 127.7, 126.2, 113.8, 113.6, 55.4, 55.1, 45.2, 44.5.

*1,3-Di(benzo[d][1,3]dioxol-5-yl)-3-phenylpropan-1-one (**3g**).* 54 mg, yield 47%; yellow colored solid; mp 116−118 °C; IR (KBr, cm^{-1}) 3452, 3051, 1676, 1446, 1043, 931, 869, 734, 706; ^1H NMR (400 MHz, $CDCl_3$) δ 7.54 (m, 1H), 7.39−7.37 (m, 1H), 7.28−7.21 (m, 4H), 7.18−7.13 (m, 1H), 6.80 (d, J = 8.1 Hz, 1H), 6.73−6.66 (m, 3H), 6.00 (s, 2H), 5.86 (s, 2H), 4.71 (t, J = 7.3 Hz, 1H), 3.58 (d, J = 7.3 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.9, 151.7, 148.1, 147.7, 145.9, 144.2, 138.1, 131.8, 128.5, 127.6, 126.3, 124.2, 120.6, 108.3, 108.1, 107.9, 107.8, 101.8, 100.8, 45.7, 44.4; HRMS (ESI-Q-TOF) m/z calcd for $C_{23}H_{18}O_5[M + Na]^+$ 397.1052, found 397.1052.

*3-(Benzo[d][1,3]dioxol-5-yl)-1-(naphthalen-1-yl)-3-phenylpropan-1-one (**3h**).* 102 mg, yield 91%; gummy liquid; IR (KBr, cm^{-1}) 3447, 2924, 1682, 1487, 1440, 1240, 1039, 935, 700; ^1H NMR (400 MHz, $CDCl_3$) δ 8.18 (d, J = 8.3 Hz, 1H), 7.96 (d, J = 8.3 Hz, 1H), 7.85−7.83 (m, 1H), 7.75 (d, J = 7.6 Hz, 1H), 7.51−7.44 (m, 3H), 7.29−7.24 (m, 4H), 7.21−7.15 (m, 1H), 6.75−6.72 (m, 2H), 6.68 (d, J = 7.4 Hz, 1H), 5.88 (s, 2H), 4.77 (t, J = 7.6 Hz, 1H), 3.76 (d, J = 7.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.5, 147.8, 146.0, 143.9, 137.8, 136.5, 133.9, 132.4, 129.9, 128.6, 128.3, 127.7, 126.9, 126.5, 126.4, 125.7, 124.3, 120.7, 108.5, 108.2, 100.9, 48.4, 46.3; HRMS (ESI-Q-TOF) m/z calcd for $C_{26}H_{20}O_3[M + Na]^+$ 403.1310, found 403.1310.

*3-(4-Methoxyphenyl)-1-(naphthalen-2-yl)-3-phenylpropan-1-one (**3i**).* 103 mg, yield 96%; light yellow solid; mp 116−118 °C; IR (KBr, cm^{-1}) 3059, 2833, 1674, 1265, 1176, 1035, 812, 702, 557, 478; ^1H NMR (400 MHz, $CDCl_3$) δ 8.45 (s, 1H), 7.98 (m, 1H), 7.93 (d, J = 8.2 Hz, 1H), 7.86 (d, J = 8.2 Hz, 2H), 7.60−7.51 (m, 2H), 7.30−7.24 (m, 4H), 7.21−7.14 (m, 3H), 6.81 (m, 2H), 4.84 (t, J = 7.4 Hz, 1H), 3.83 (d, J = 7.4 Hz, 2H), 3.74 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 158.0, 144.5, 136.3, 135.5, 134.4, 132.5, 129.7, 129.5, 128.8, 128.5, 128.4, 127.7, 126.8, 126.3, 123.9, 113.9, 55.2, 45.3, 45.0; HRMS (ESI-Q-TOF) m/z calcd for $C_{26}H_{22}O_2[M + Na]^+$ 389.1517, found 389.1518.

*1-(4-Iodophenyl)-3-phenyl-3-p-tolylpropan-1-one (**3j**).* 75 mg, yield 90%; light yellow solid; mp 120−122 °C; IR (KBr, cm^{-1}) 3024, 1682, 1579, 981, 748, 700; ^1H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, J = 8.4 Hz, 2H), 7.61 (d, J = 8.4 Hz, 2H), 7.28−7.23 (m, 8H), 7.19−7.15 (m, 2H), 4.79 (t, J = 7.2 Hz, 1H), 3.67 (d, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.3, 143.9, 137.9, 136.3, 129.4, 128.6, 127.8, 126.5, 101.0, 45.9, 44.6; HRMS (ESI-Q-TOF) m/z calcd for $C_{21}H_{17}IO[M + Na]^+$ 435.0222, found 435.0222.

*1-(4-Bromophenyl)-3-phenyl-3-p-tolylpropan-1-one (**3k**).* 79 mg, yield 83%; light yellow colored solid; mp 128−130 °C; IR (KBr, cm^{-1})

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3022, 2916, 1680, 1583, 1259, 1205, 989, 817, 698, 557; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, J = 8.5 Hz, 2H), 7.56 (d, J = 8.5 Hz, 2H), 7.26−7.15 (m, 5H), 7.13 (d J = 7.1 Hz, 2H), 7.07 (d, J = 8.0 Hz, 2H), 4.75 (t, J = 7.4 Hz, 1H), 3.67 (d, J = 7.4 Hz, 2H), 2.26 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.1, 144.1, 140.9, 136.0, 135.8, 131.9, 129.6, 129.3, 128.6, 128.2, 127.7, 127.6, 126.4, 45.6, 44.7, 21.0; HRMS (ESI-Q-TOF) m/z calcd for $C_{22}H_{19}BrO[M + Na]^+$ 401.0517, found 401.0517.

*3-(Benzo[d][1,3]dioxol-5-yl)-1-(2,4-dichlorophenyl)-3-phenylpropan-1-one (**3l**).* 102 mg, yield 97%; light brown liquid; IR (neat, cm^{-1}) 3584, 2926, 1697, 1583, 1485, 1242, 933, 665; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, J = 1.9 Hz, 1H), 7.25−7.22 (m, 2H), 7.20−7.16 (m, 4H), 7.08 (d, J = 8.5 Hz, 1H), 6.68−6.67 (m, 3H), 5.87 (s, 2H), 4.60 (t, J = 7.8 Hz, 1H), 3.64 (d, J = 7.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.2, 147.7, 146.1, 143.4, 137.7, 137.3, 137.2, 131.7, 130.1, 128.6, 127.6, 127.2, 126.5, 120.6, 108.3, 108.1, 100.9, 49.1, 46.2; HRMS (ESI-Q-TOF) m/z calcd for $C_{22}H_{16}Cl_2O_3[M + Na]^+$ 421.0374, found 421.0374.

*3-(Benzo[d][1,3]dioxol-5-yl)-3-phenyl-1-(thiophen-2-yl)propan-1-one (**3m**).* 123 mg, yield 92%, cream colored solid; mp 134−136 °C; IR (KBr, cm^{-1}) 3084, 2872, 1639, 1487, 1415, 1244, 1039, 939, 729, 543; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, J = 3.5 Hz, 1H), 7.61 (d, J = 4.8 Hz, 1H), 7.29−7.24 (m, 4H), 7.19−7.15 (m, 1H), 7.10 (d, J = 4.3 Hz, 1H), 6.74 (d, J = 9.4 Hz, 2H), 6.70 (d, J = 7.8 Hz, 1H), 5.89 (s, 2H), 4.73 (t, J = 7.6 Hz, 1H), 3.60 (d, J = 7.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.8, 147.7, 146.0, 144.3, 143.9, 137.8, 133.7, 131.8, 128.6, 128.1, 127.6, 126.5, 120.7, 108.4, 108.2, 100.9, 45.8, 45.5; HRMS (ESI-Q-TOF) m/z calcd for $C_{20}H_{16}O_3S[M + H]^+$ 337.0898, found 337.0889.

*1-(4-Chlorophenyl)-2-(9H-xanthen-9-yl)ethanone (**3n**).* 78 mg, yield 72%; yellow colored solid; mp 92−94 °C; IR (KBr, cm^{-1}) 3038, 1682, 1477, 1456, 1257, 829, 760; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (d, J = 8.5 Hz, 2H), 7.32 (d, J = 8.5 Hz, 2H), 7.30−7.25 (m, 2H), 7.22−7.18 (m, 2H), 7.10 (d, J = 8.4 Hz, 2H), 7.03−6.99 (m, 2H) 4.81 (t, J = 6.6 Hz, 1H), 3.29 (d, J = 6.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9, 152.4, 139.7, 135.4, 129.6, 128.8, 128.8, 128.0, 125.4, 123.6, 116.7, 49.6, 35.0; HRMS (ESI-Q-TOF) m/z calcd for $C_{21}H_{15}ClO_2[M + Na]^+$ 357.0658, found 357.0659.

*3-Ferrocenyl-1,3-diphenylpropan-1-one (**3o**).*[26e] 90 mg, yield 55%; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88−7.90 (m, 2H), 7.53−7.51 (m, 1H), 7.42 (t, J = 7.6 Hz, 2H), 7.27−7.21 (m, 4H), 7.16−7.14 (m, 1H), 4.54 (dd, J = 8.0, 5.6 Hz 1H), 4.18 (s, 1H), 4.11 (s, 1H), 4.06 (s, 6H), 4.0 (s, 1H), 3.66−3.63 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.6, 144.9, 137.4, 133.1, 128.7, 128.4, 128.2, 127.9, 126.5, 93.5, 68.8, 68.1, 67.8, 67.4, 67.1, 46.4, 41.0.

*2-((4-Methoxyphenyl)(phenyl)methyl)cyclohexanone (**3p**).* 114 mg, 76%; Mixture of diastereomers; liquid; IR (neat, cm^{-1}) 2935, 1711, 1512, 1249, 1033, 700; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26−7.17 (m, 10H), 7.15−7.08 (m, 4H), 6.79−6.76 (m, 4H), 4.27 (d, J = 10.8 Hz, 2H), 3.71 (s, 3H), 3.70 (s, 2H), 3.29 (m, 2H), 2.43−2.29 (m, 4H), 2.03−1.96 (m, 2H), 1.84−1.70 (m, 6H), 1.67−1.58 (m, 2H), 1.44−1.34 (m, 2H); ^{13}C NMR(100 MHz, $CDCl_3$) δ 212.5, 212.4, 157.9, 157.7, 144.1, 143.2, 135.8, 135.0, 129.1, 128.5, 128.4, 128.3, 128.1, 127.4, 126.1, 125.9, 113.8, 113.7, 55.0, 55.0, 54.9, 50.0, 50.0, 42.3, 42.2, 33.3, 33.2, 29.1, 24.4, 24.2; HRMS (ESI-Q-TOF) m/z calcd for $C_{20}H_{22}O_2[M + Na]^+$ 317.1517, found 317.1526.

*3-(Benzo[d][1,3]dioxol-5-yl)-2-methyl-1,3-diphenylpropan-1-one (**3q**).* 103 mg, yield 80%; mixture of diastereomers; white solid; mp 108−110 °C; IR (KBr, cm^{-1}) 2874, 1674, 1502, 1487, 1440, 1232, 1037, 700; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (t, J = 8.5 Hz, 3.3H), 7.56−7.52 (m, 2H), 7.46−7.41 (m, 3.5 H), 7.34−7.29 (m, 2.9H), 7.21 (d, J = 7.1 Hz, 2.8H), 7.11 (t, J = 7.1 Hz, 2.2H), 7.04−7.00 (m, 1H), 6.83−6.81 (m, 2H), 6.74 (d, J = 7.8 Hz, 1H), 6.73−6.69 (m, 1.3H), 6.55 (dd, J = 7.8 Hz, 1H), 5.90 (d, J = 7.3 Hz, 2H), 5.77 (d, J = 4.9 Hz, 1.3H), 4.38−4.29 (m, 3.3H), 1.14 (d, J = 6.2 Hz, 3H), 1.10 (d, J = 6.2 Hz, 1.9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 203.3, 203.2, 147.8, 147.5, 146.1, 145.8, 143.6, 143.0, 137.6, 137.0, 136.7, 132.9, 128.6, 128.4, 128.3, 128.1, 128.1, 127.4, 126.5, 126.2, 121.6, 120.3, 108.5, 108.4, 108.2, 108.1, 100.9, 100.7, 53.9, 53.9, 44.9, 44.8, 18.0, 17.9; HRMS (ESI-Q-TOF) m/z calcd for $C_{23}H_{20}O_3[M + Na]^+$ 367.1310, found 367.1310.

*(E)-5-(Benzo[d][1,3]dioxol-5-yl)-1,5-diphenylpent-1-en-3-one (**3r**).* 98 mg, yield 80%; gummy solid; mp 106−108 °C; IR (KBr, cm^{-1}) 3022, 2920, 1651, 1487, 1234, 1176, 1037, 690; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53−7.49 (m, 3H), 7.37−7.36 (m, 3H), 7.29−7.21 (m, 4H), 7.18−7.15 (m, 1H), 6.74−6.67 (m, 4H), 5.89 (s, 2H), 4.65 (t, J = 7.4 Hz, 1H), 3.35 (d, J = 7.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 147.7, 145.9, 144.1, 142.8, 137.9, 134.3, 130.5, 128.9, 128.5, 128.2, 127.8, 126.4, 126.1, 120.8, 108.3, 108.1, 100.8, 46.9, 45.7; HRMS (ESI-Q-TOF) m/z calcd for $C_{24}H_{20}O_3[M + Na]^+$ 379.1310, found 379.1311.

*(E)-5-(4-Methoxyphenyl)-1,5-diphenylpent-1-en-3-one (**3s**).* 71 mg, yield 61%; white solid; mp 124−126 °C; IR (KBr, cm^{-1}) 3026, 2930, 1635, 1512, 1251, 1180, 1032, 692; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 16.2 Hz, 1H), 7.50−7.49 (m, 2H), 7.38−7.36 (m, 3H), 7.31−7.23 (m, 5H), 7.17 (d, J = 8.3 Hz, 2H), 6.81 (m, 2H), 6.69 (d, J = 16.2 Hz, 1H), 4.67 (t, J = 7.6 Hz, 1H), 3.75 (s, 3H), 3.38 (d, J = 7.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.2, 158.1, 144.4, 142.8, 136.2, 134.5, 130.5, 128.9, 128.8, 128.6, 128.3, 127.7, 126.3, 126.3, 113.9, 55.2, 47.2, 45.4; HRMS (ESI-Q-TOF) m/z calcd for $C_{24}H_{22}O_2[M + H]^+$ 343.1698, found 343.1700.

General Procedure for α-Alkylation of Unactivated Ketones with Cinnamyl Alcohols. To a solution of unactivated ketone (0.3 mmol (**4a**−**f**) or 0.224 mmol (**4g**−**n**), 1 equiv) and 1,3-diarylprop-2-en-1-ols (1.2 equiv) in CCl_4 (3 mL), trimethyl orthoformate (1 equiv) and triflic acid (1 equiv) were added. The reaction mixture was stirred at room temperature. After complete consumption of the ketone as revealed by TLC, solvent was evaporated, and the crude product was directly loaded on a silica gel column and eluted with ethyl acetate/hexanes to get the pure alkylated product.

*(E)-1,3,5-Triphenylpent-4-en-1-one (**4a**).*[27] 84 mg, yield 90%; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (d, J = 7.2 Hz, 2H), 7.53 (t, J = 7.6 Hz, 1H), 7.43 (t, J = 7.6 Hz, 2H), 7.32−7.18 (m, 10H), 6.40−6.39 (m, 2H), 4.33−4.28 (m, 1H), 3.54−3.47(m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.3, 143.4, 137.3, 137.2, 133.2, 132.7, 130.2, 128.8, 128.7, 128.6, 128.2, 127.9, 127.4, 126.7, 126.4, 44.6, 44.1.

*(E)-3,5-Diphenyl-1-(p-tolyl)pent-4-en-1-one (**4b**).* 90 mg, yield 92%; yellow gummy liquid; IR (neat, cm^{-1}) 3028, 1682, 1493, 1450, 1180, 966, 698; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, J = 8.4 Hz, 2H), 7.30−7.26 (m, 6H), 7.24−7.17 (m, 5H), 7.16−7.14 (m, 1H), 6.44−6.35 (m, 2H), 4.32−4.27 (m, 1H), 3.51−3.40 (m, 2H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.8, 143.9, 143.5, 137.3, 134.7, 132.8, 130.1, 129.4, 128.8, 128.5, 128.3, 127.9, 127.3, 126.7, 126.3, 44.4, 44.1, 21.7; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{22}O$ $[M + H]^+$ 327.1749, found 327.1749.

*(E)-1-(4-Chlorophenyl)-3,5-diphenylpent-4-en-1-one (**4c**).* 86 mg, 83%; yellow colored gummy liquid; IR (neat, cm^{-1}) 3026, 1685, 1493, 1452, 1240, 1091, 696; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88−7.86 (m, 2H), 7.42−7.40 (m, 2H), 7.32−7.29 (m, 6H), 7.26−7.24 (m, 3H), 7.23−7.18 (m, 1H), 6.39−6.38 (m, 2H), 4.30−4.25 (m, 1H), 3.51−3.40 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.1,143.2, 139.6, 137.2, 135.5, 132.4, 130.3, 129.6, 129.1, 128.8, 128.6, 127.8, 127.4, 126.8, 126.4, 44.6, 44.1; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{19}OCl$ $[M + Na]^+$ 369.1022, found 369.1022.

*(E)-1-(4-Iodophenyl)-3,5-diphenylpent-4-en-1-one (**4d**).* 116 mg, 88%; pale yellow colored solid; mp 101−104 °C; IR (KBr, cm^{-1}) 3026, 1687, 1493, 1450, 1392, 698; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89−7.72 (m, 2H), 7.62−7.57 (m, 2H), 7.34−7.15 (m, 10H), 6.43−6.33 (m, 2H), 4.27−4.25 (m, 1H), 3.44−3.41 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.5, 143.2, 138.0, 137.2, 136.4, 132.4, 130.3, 129.6, 128.8, 128.6, 127.8, 127.4, 126.8, 126.3, 101.2, 44.5, 44.1; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{19}IO$ $[M + H]^+$ 439.0559, found 439.0559.

*(E)-1-(4-Nitrophenyl)-3,5-diphenylpent-4-en-1-one (**4e**).* 82 mg, 76%; yellow colored solid; mp 97−100 °C; IR (KBr, cm^{-1}) 3024, 1680, 1493, 1448, 744, 694; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25 (d, J = 8.8 Hz, 2H), 8.03 (d, J = 8.8 Hz, 2H), 7.36−7.29 (m, 6H), 7.25−7.19 (m, 3H), 7.18−7.16 (m, 1H), 6.40−6.35 (m, 2H), 4.30−4.25 (m, 1H), 3.53−3.52 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9,

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150.4, 142.8, 141.6, 137.0, 132.0, 130.5, 129.2, 128.9, 128.6, 127.8, 127.6, 127.0, 126.3, 123.9, 45.2, 44.1; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{19}NO_3$ $[M + H]^+$ 358.1443, found 358.1445.

(E)-3,5-Diphenyl-1-(thiophen-2-yl)pent-4-en-1-one (**4f**). 76 mg, 80%; brown colored liquid; IR (neat, cm^{-1}) 3026, 1660, 1493, 1450, 1413, 1238, 698; ^1H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, J = 3.6 Hz, 1H), 7.58 (d, J = 4.8 Hz, 1H), 7.32−7.29 (m, 5H), 7.25−7.15 (m, 5H), 7.08 (t, J = 4.0 Hz, 1H), 6.41−6.40 (m, 2H), 4.29−4.27 (m, 1H), 3.43−3.38 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.1, 144.6, 143.1, 137.3, 133.8, 132.4, 132, 130.4, 128.8, 128.5, 128.2, 127.8, 127.4, 126.8, 126.4, 45.4, 44.4; HRMS (ESI-Q-TOF) calcd for $C_{21}H_{18}OS$ $[M + H]^+$ 319.1157, found 319.1156.

(E)-3,5-Bis(4-chlorophenyl)-1-phenylpent-4-en-1-one (**4g**). 68 mg, 80%; light yellow colored gummy liquid; IR (KBr, cm^{-1}) 3042, 1685, 1491, 1448, 1406, 1091, 690; ^1H NMR (400 MHz, $CDCl_3$) δ 7.94−7.92 (m, 2H), 7.57−7.55 (m, 1H), 7.46−7.44 (m, 2H), 7.29−7.28 (m, 2H), 7.25−7.25 (m, 2H), 7.23−7.22 (m, 4H), 6.37−6.30 (m, 2H), 4.30−4.26 (m, 1H), 3.52−3.42 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.8, 141.6, 137.1, 135.6, 133.4, 133.2, 132.9, 132.6, 129.4, 129.3, 128.9, 128.8, 128.7, 128.2, 127.6, 44.3, 43.3; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{18}Cl_2O$ $[M + Na]^+$ 403.0632, found 403.0640.

(E)-3,5-Bis(4-chlorophenyl)-1-(p-tolyl)pent-4-en-1-one (**4h**). 72 mg, 82%; yellow colored solid; mp 93−95 °C; IR (neat, cm^{-1}) 3030, 1678, 1491, 1408, 1091, 736; ^1H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, J = 8.0 Hz, 2H), 7.26−7.20 (m, 10H), 6.37−6.27 (m, 2H), 4.28−4.24 (m, 1H), 3.48−3.37 (m, 2H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.3, 144.2, 141.6, 135.5, 134.5, 133, 132.4, 129.4, 129.2, 128.8, 128.6, 128.2, 127.5, 44.1, 43.3, 21.7; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{20}Cl_2O$ $[M + Na]^+$ 417.0789, found 417.0789.

(E)-1,3,5-Tris(4-chlorophenyl)pent-4-en-1-one (**4i**). 81 mg, 87%; yellow colored gummy liquid; IR (neat, cm^{-1}) 3024, 1685, 1491, 1402, 1176, 1012, 825; ^1H NMR (400 MHz, $CDCl_3$) δ 7.88−7.86 (m, 2H), 7.44−7.42 (m, 2H), 7.31−7.30 (m, 2H), 7.25−7.24 (m, 6H), 6.35−6.34 (m, 2H), 4.28−4.25 (m, 1H), 3.46−3.44 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.5, 141.4, 139.8, 135.5, 135.3, 133.2, 132.7, 132.6, 129.6, 129.5, 129.2, 129.1, 129, 128.8, 127.6, 44.3, 43.3; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{17}Cl_3O$ $[M + H]^+$ 415.0423, found 415.0423.

(E)-3,5-Bis(4-chlorophenyl)-1-(4-iodophenyl)pent-4-en-1-one (**4j**). 98 mg, 86%; Yellow colored solid; mp 117−119 °C; IR (KBr, cm^{-1}) 1678, 1489, 1392, 1089, 744, 694; ^1H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, J = 8.0 Hz, 2H), 7.60 (d, J = 8.0 Hz, 2H), 7.27−7.18 (m, 8H), 6.31−6.30 (m, 2H), 4.25−4.21 (m, 1H), 3.41−3.38 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9, 141.3, 138.0, 136.1, 135.4, 133.1, 132.6, 132.5, 129.5, 129.4, 129.2, 128.9, 128.7, 127.5, 101.4, 44.1, 43.2; HRMS (ESI-Q-TOF) calcd for $C_{23}H_{17}Cl_2IO$ $[M + H]^+$ 506.9779, found 506.9779.

(E)-3,5-Bis(4-chlorophenyl)-1-(naphthalen-2-yl)pent-4-en-1-one (**4k**). 75 mg, 78%; orange colored gummy liquid; IR (neat, cm^{-1}) 3055, 1680, 1491, 1412, 1091,746; ^1H NMR (400 MHz, $CDCl_3$) δ 8.43 (s, 1H), 7.99−7.96 (m, 1H), 7.93−7.91 (m, 1H), 7.86−7.83 (m, 2H), 7.59−7.51 (m, 2H), 7.28−7.25 (m, 4H), 7.23−7.21 (m, 4H), 6.40−6.30 (m, 2H), 4.35−4.30 (m, 1H), 3.59−3.57 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 141.6, 135.7, 135.6, 134.3, 133.1, 132.9, 132.6, 129.9, 129.8, 129.6, 129.4, 129.3, 129.1, 128.9, 128.7, 128.5, 127.9, 127.6, 127, 123.8, 44.3, 43.4; HRMS (ESI-Q-TOF) calcd for $C_{27}H_{20}Cl_2O$ $[M + Na]^+$ 453.0789, found 453.0789.

(E)-3,5-Bis(4-chlorophenyl)-1-(thiophen-2-yl)pent-4-en-1-one (**4l**). 76 mg, 88%; brown colored liquid; IR (neat, cm^{-1}) 3096, 1660, 1491, 1413, 1242, 1091, 725; ^1H NMR (400 MHz, $CDCl_3$) δ 7.70−7.69 (m, 1H), 7.61−7.59 (m, 1H), 7.29−7.21 (m, 8H), 7.11−7.08 (m, 1H), 6.33−6.32 (m, 2H), 4.25−4.24 (m, 1H), 3.44−3.32 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) 190.6, 144.3, 141.3, 135.5, 134.1, 133.1, 132.6, 132.1, 129.5, 129.2, 128.9 128.7, 128.3, 127.5, 45.0, 43.6; HRMS (ESI-Q-TOF) calcd for $C_{21}H_{16}Cl_2OS$ $[M + Na]^+$ 409.0197, found 409.0197.

(E)-1-(Benzo[d][1,3]dioxol-5-yl)-3,5-bis(4-chlorophenyl)pent-4-en-1-one (**4m**). 86 mg, 90%; gummy liquid; IR (neat, cm^{-1}) 1671, 1490, 1441, 1254, 1095, 816; ^1H NMR (400 MHz, $CDCl_3$) δ 7.54 (dd, J = 8.0, 1.6 Hz, 1H), 7.40−7.39 (m, 1H), 7.29−7.25 (m, 2H), 7.26−7.21 (m, 6H), 6.83−6.81 (d, J = 8.0 Hz, 1H), 6.36−6.26 (m, 2H), 6.01 (s, 2H),4.27−4.22 (m, 1H), 3.43−3.32 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.6, 151.8, 148.2, 141.5, 135.4, 132.9, 132.8, 132.4, 131.7, 129.2, 129.1, 128.8, 128.7, 128.5, 127.4, 124.3, 107.8, 101.8, 43.8, 43.3; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{18}Cl_2O_3$ $[M + Na]^+$ 447.0531, found 447.0531.

(E)-3-(Benzo[d][1,3]dioxol-5-yl)-5-(4-chlorophenyl)-1-phenylpent-4-en-1-one (**4n**). 72 mg, 82%; (**4n′**), 69 mg, 79%; colorless liquid; IR (neat, cm^{-1}) 3028, 1676, 1489, 1442, 1253, 1093, 736; ^1H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, J = 8.4 Hz, 2H), 7.57−7.53 (m, 1H), 7.47−7.43 (m, 2H), 7.25−7.21 (m, 4H), 6.79−6.75 (m, 3H), 6.37−6.28 (m, 2H), 5.92 (s, 2H),4.23−4.18 (m, 1H), 3.45−3.43 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 148, 146.4, 137.2, 137.1, 135.8, 133.5, 133.3, 132.9, 128.9, 128.8, 128.7, 128.2, 127.6, 120.8, 108.5, 108.3, 101.1, 44.6, 43.7; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{19}ClO_3$ $[M + Na]^+$ 413.0920, found 413.0921.

(E)-3,5-Bis(4-chlorophenyl)-2-methyl-1-phenylpent-4-en-1-one (**4o**). (0.215 mmol of ketone was used) 73 mg, 86%; mixture of diastereomers; colorless liquid; IR (neat, cm^{-1}) 3059, 1682, 1595, 1491, 1448, 1408, 1012, 968, 653; ^1H NMR (400 MHz, $CDCl_3$) δ 7.97−7.94 (m, 1.77 H), 7.82−7.80 (m, 2H), 7.56−7.50 (m, 2H), 7.48−7.43 (m, 2H), 7.41−7.37 (m, 2H), 7.33−7.31 (m, 2H), 7.25−7.24 (m, 4H), 7.24−7.23 (m, 1.7H), 7.22−7.21 (m, 1H), 7.18−7.15 (m, 3H), 7.14−7.10 (m, 2H), 7.02−7.0 (m, 2H), 6.45−6.40 (m, 1H), 6.31−6.27 (m, 1H), 6.22−6.21 (m, 2H), 3.99−3.93 (m, 2H), 3.90−3.88 (m, 1.5H), 1.30−1.25 (m, 3H), 1.04−1.02 (m, 2.5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 203.3, 202.9, 141.2, 140.1, 137.2, 136.7, 135.5, 133.2, 133.1, 132.8, 132.6, 132.2, 131.8, 131.1, 130.8, 130.1, 129.7, 129.1, 128.9, 128.8, 128.7, 128.6, 128.5, 128.2, 128.1, 127.5, 127.4, 51.7, 51.6, 45.5, 17.1, 16.9; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{20}Cl_2O$ $[M + Na]^+$ 417.0789, found 417.0788.

General Procedure for α-Alkylation of Unactivated Ketones with Phenyl Propargyl Alcohols. To a solution of unactivated ketone (0.262 mmol, 1 equiv) and 1,3-diarylprop-2-yn-1-ols (1.2 equiv) in CCl_4 (3 mL), trimethyl orthoformate (1 equiv) and triflic acid (1 equiv) were added. The reaction mixture was stirred at room temperature. After complete consumption of the ketone as revealed by TLC, solvent was evaporated, and the crude product was directly loaded on a silica gel column and eluted with ethyl acetate/hexanes to get the pure alkylated product.

3-(4-Methoxyphenyl)-1,5-diphenylpent-4-yn-1-one (**5a**).[28] 45 mg, 51%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.95−7.94 (m, 2H), 7.55−7.53 (m, 1H), 7.46−7.42 (m, 4H), 7.36−7.34 (m, 2H), 7.25−7.24 (m, 3H), 6.88 (dd, J = 6.8, 2.0 Hz, 2H), 4.60 (t, J = 7.2 Hz, 1H), 3.78 (s, 3H), 3.63 (dd, J = 16.8, 7.6 Hz, 1H) 3.39 (dd, J = 16.4, 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.4, 158.7, 136.9, 133.4, 133.3, 131.7, 128.7, 128.3, 128.2, 127.9, 123.5, 114.2, 91.2, 83.2, 55.4, 47.5, 33.0.

(4-Iodophenyl)-3-(4-methoxyphenyl)-5-phenylpent-4-yn-1-one (**5b**). 75 mg, 61%; light brown colored solid; mp 116−118 °C; IR (KBr, cm^{-1}) 3067, 2926, 1682, 1579, 1460, 1413, 1012, 1358, 1246, 1203, 1184, 1055, 806; ^1H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 8.4 Hz, 2H), 7.65 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 8.8 Hz, 2H) 7.35−7.33 (m, 2H), 7.27−7.26 (m, 3H), 6.87 (d, J = 8.4 Hz, 2H), 4.56 (t, J = 7.2 Hz, 1H), 3.80 (s, 3H), 3.55 (dd, J = 16.4, 7.6 Hz, 1H) 3.35 (dd, J = 16.4, 6.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8, 158.8, 138.1, 136.3, 133.2, 131.8, 129.7, 128.7, 128.3, 128.1, 123.4, 114.2, 101.4, 90.9, 83.4, 55.5, 47.4, 33.2; HRMS (ESI-Q-TOF) calcd for $C_{24}H_{19}IO_2$ $[M + H]^+$ 467.0508, found 467.0507.

1,3,3,3-Tetraphenylpropan-1-one (**7**).[29] Prepared by following the general procedure used for the alkylation of ketones using triphenylmethanol; 77 mg, yield 51%; ^1H NMR (400 MHz, $CDCl_3$) δ 7.82−7.80 (m, 2H), 7.50−7.46 (m, 1H), 7.38−7.34 (m, 2H), 7.28−7.20 (m, 12H), 7.18−7.14 (m, 3H), 4.44 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.1, 146.9, 138.0, 132.7, 129.3, 128.4, 127.8, 127.8, 126.1, 55.9, 49.4; HRMS (ESI) m/z calcd for $C_{27}H_{22}O$ $[M + Na]^+$ 385.1568, found 385.1572.

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■ ASSOCIATED CONTENT

Supporting Information

Compound characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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