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Chemoselective Reduction of the Carbonyl Functionality through Hydrosilylation: Integrating Click Catalysis with Hydrosilylation in One Pot

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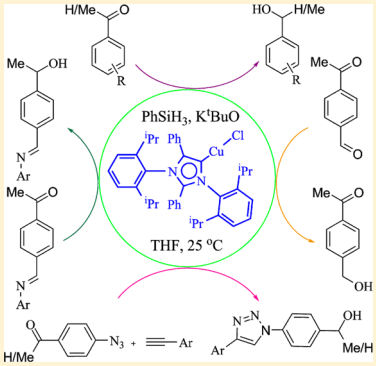
Supporting Information

ABSTRACT: Herein we report the chemoselective reduction of the carbonyl functionality via hydrosilylation using a copper(I) catalyst bearing the abnormal N-heterocyclic carbene **1** with low (0.25 mol %) catalyst loading at ambient temperature in excellent yield within a very short reaction time. The hydrosilylation reaction of α,β-unsaturated carbonyl compounds takes place selectively toward 1,2-addition (C═O) to yield the corresponding allyl alcohols in good yields. Moreover, when two reducible functional groups such as imine and ketone groups are present in the same molecule, this catalyst selectively reduces the ketone functionality. Further, **1** was used in a consecutive fashion by combining the Huisgen cycloaddition and hydrosilylation reactions in one pot, yielding a range of functionalized triazole substituted alcohols in excellent yields.

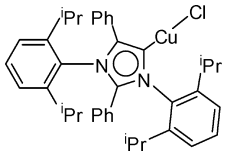


INTRODUCTION

The reduction of the carbonyl moiety to an alcohol via hydride transfer is a ubiquitous process for the synthesis of fine chemicals, leading to molecules with hydroxyl functionalities. It is noteworthy that the abundance of hydroxyl groups in various drug molecules makes their synthesis an important step during organic transformations.[1] Often, commonly used reducing agents such as metal hydrides face chemoselectivity issues, especially when they are aimed at the reduction of carbonyl groups in the presence of another reducible functional group such as olefinic double bonds and cyano, nitro, and imine functionalities.[2] Furthermore, generation of metal waste is a serious environmental concern when these reactions are performed on larger scales and in a noncatalytic fashion. In this regard, catalytic hydrosilylation followed by base hydrolysis has been proved to be an elegant strategy for the reduction of carbonyl groups.[3] In recent years, hydrosilylation of various organic compounds has made substantial progress and became a major tool for synthetic organic chemistry to provide an efficient and versatile access to new compounds.[4] In industry, hydrosilylation has also become an appropriate method to produce organosilicon compounds, in particular with respect to the functionalization of polymers.[5] Hydrosilanes are normally inert toward nonactivated carbonyl compounds,[6] and consequently several transition-metal complexes have evolved as catalysts for hydrosilylation reactions.[7] Later on, reports on metal-free hydrosilylation appeared; most of the known metal-free catalysts operate through either Lewis base or nucleophilic catalyst activation of the hydrosilane.[8] Recently, an organocatalytic version of this particular transformation has been realized.[9] Despite the progress made in both transition-metal and metal-free catalysis in recent years, poor selectivity, long reaction times, stringent reaction conditions, and the toxicity of costly metal catalysts press the need for the development of more sustainable methods for hydrosilylation reactions.

In the present study, we use a copper(I) chloro complex (**1**; Chart 1)[10a] as a catalyst supported with an abnormal N-heterocyclic carbene for hydrosilylation reactions. N-heterocyclic carbenes (NHCs) have played a major role in the design of efficient catalysts for a plethora of organic reactions for more than two decades.[11] In 2001, Crabtree, Faller, and co-workers added a new dimension for designing efficient organometallic catalysts by introducing the abnormal mode of binding of NHC to a metal center.[12] Later on, several other complexes featuring the so-called abnormal mode of binding were reported.[13] Now a number of ligand systems have been reported that are specifically designed to allow the abnormal mode of binding in a quest for better catalysis.[14] It has been observed recently in a number of reports that abnormal NHC-based catalysts can

Chart 1. Copper(I) Chloro Complex 1 with an *a*NHC Backbone



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outperform their "normal" NHC-based analogues.[10d,13a,c,14c] The area of abnormal NHC-based catalyst design was fueled by the recent isolation of the first *a*NHC (1,3-bis(2,6-diisopropylphenyl)-2,4-diphenyl-5-ylidene) by Bertrand and co-workers.[15] In fact, *a*NHC was envisaged as the new cornerstone in the area of organometallic chemistry and catalysis.[16] Our group recently established that the isolated *a*NHC (1,3-bis(2,6-diisopropylphenyl)-2,4-diphenyl-5-ylidene) can be used to design both organometallic and organic catalysts for a number of important chemical transformations.[10] We have reported the first organocatalytic application of the free *a*NHC, which indicated that it can act as a very efficient nucleophile for ring-opening polymerization of cyclic ester monomers, placing it as the most efficient organocatalyst among any known NHCs.[10d] Also recently we established that the *a*NHC can be an excellent building block to design transition-metal-based organometallic catalysts containing palladium for the Suzuki–Miyaura coupling of challenging aryl chloride substrates at ambient temperature under very low catalyst loading conditions.[10c] More recently, we have reported the copper–*a*NHC complex **1** in the Huisgen cycloaddition reaction of a versatile range of azides and alkyne substrates at room temperature.[10a]

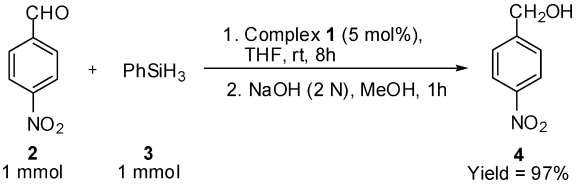
Herein, we describe the chemoselective reduction of carbonyl moieties in excellent yields at room temperature in very short periods of time using **1** as the catalyst.

The high longevity of our catalyst with an *a*NHC ligand, reported earlier for click catalysis,[10a] prompted us to integrate Huisgen cycloaddition reaction (click catalysis) in a consecutive fashion in the same reaction pot, resulting in a range of triazole-substituted alcohols in excellent yield.

RESULTS AND DISCUSSION

Following the synthetic route previously reported by our group,[10a] the *a*NHC-coordinated copper(I) chloride complex **1** was synthesized in good yield. An initial study was performed with the model reaction of 4-nitrobenzaldehyde (**2**) with phenylsilane (**3**) in the presence of **1** (5 mol %) at room temperature in THF (Scheme 1). The progress of the reactions

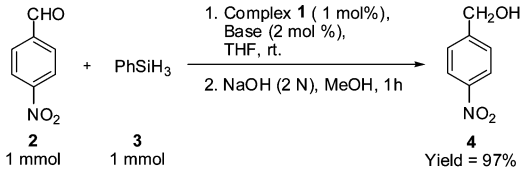
Scheme 1. Reduction of 2 using 1 as Catalyst



was monitored by ^{1}H NMR spectroscopy. After base hydrolysis and workup, the desired 4-nitrobenzyl alcohol (**4**) was obtained in 97% yield within 8 h (Scheme 1).

When the reaction was performed in the absence of catalyst **1**, the starting materials remained unchanged even after 12 h. Earlier Nolan and co-workers had shown that copper NHC alkoxides are precatalysts for the hydrosilylation reaction of carbonyl groups with silanes.[17] It has been established in the literature that the most convenient way to prepare a copper alkoxide is the treatment of a copper halide with a metal alkoxide in THF/PhMe.[18] To accelerate the reaction rate in our system, **1** (1 mol %) was treated with potassium *tert*-butoxide (KO^{t}Bu) (2 mol %) in dry THF under an inert atmosphere. To this solution, when 1 mmol each of **2** and **3** was added, the hydrosilylation reaction was complete within 10 min at ambient temperature. As the use of KO^{t}Bu as a source of alkoxide is very crucial to accelerate the reaction rate (Table 1, entry 1), we

Table 1. Reduction of 2 using 1 as Catalyst with Varying Reaction Conditions[a]



Entry	Silane	Base	Time (min)	Yield (%)[b]
1	$PhSiH_3$	KO^{t}Bu	10	97
2	$PhSiH_3$	NaO^{t}Bu	10	95
3	$PhSiH_3$	NaOMe	10	72
4	Ph_2SiH_2	KO^{t}Bu	10	95
5	Ph_3SiH	KO^{t}Bu	10	11
6	Ph_3SiH	KO^{t}Bu	120	91
7	PMHS	KO^{t}Bu	20	94[c]
8	$PhSiH_3$	KO^{t}Bu	10	95[d]
9	$PhSiH_3$	KO^{t}Bu	10	96[e]
10	$PhSiH_3$	KO^{t}Bu	15	96[f]
11	$PhSiH_3$	KO^{t}Bu	25	93[g]

[a]**2** (1 mmol) was treated with **3** (1 mmol) in the presence of **1** (1 mol %) and base (2 mol %) at room temperature in THF (2 mL) unless otherwise mentioned. [b]Yield of the corresponding alcohol **4**. [c]Reaction was performed in the presence of 2.5 equiv of PMHS. [d]Reaction was performed in PhMe. [e]1.5 mmol of **3** was used. [f]Reaction was performed on a 2 mmol scale with **1** (0.25 mol %) and KO^{t}Bu (0.5 mol %). [g]Reaction was performed on a 4 mmol scale with **1** (0.125 mol %) and KO^{t}Bu (0.25 mol %).

assume *a*NHC-Cu-O^{t}Bu might have been generated in the reaction mixture, as there is a sharp color change observed when 2 equiv of KO^{t}Bu was added to **1**, similar to previously reported observations.[17c,18] Moreover, it may be assumed that addition of the silane **3** can result in σ-bond metathesis between *a*NHC-Cu-O^{t}Bu and **3**, generating the actual active catalyst *a*NHC-Cu-H.[7k,18c] Despite several stoichiometric attempts, we have been unable to isolate the copper alkoxide *a*NHC-Cu-O^{t}Bu or copper hydride species *a*NHC-Cu-H. The reaction process was further simplified by adding all of the components (1 mmol each of **2** and **3**, 1 mol % of **1**, and 2 mol % of KO^{t}Bu) together in THF. This resulted in a similar conversion to the desired product **4** after workup in comparison to the stepwise addition of reagents. Thus, our method utilizes an air-stable *a*NHC-copper chloro complex as a precatalyst in the presence of KO^{t}Bu, making the methodology a straightforward one. To check the effect of the alkoxides, sodium *tert*-butoxide and sodium methoxide were used (Table 1, entries 2 and 3) separately. No significant change in the yield was noticed when we changed the *tert*-butoxide countercation from potassium to sodium. However, altering the alkoxide from *tert*-butoxide to

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methoxide resulted in a detrimental effect on the yield of the product (72%, Table 1, entry 3). Notably, the hydrosilylation reaction is not limited to **3** only; no change in reaction time or yield was observed using diphenylsilane as a source of hydride (Table 1, entry 4). However, treatment of triphenylsilane with **2** under the optimized conditions requires longer reaction times to obtain comparable conversions (Table 1, entries 5 and 6).

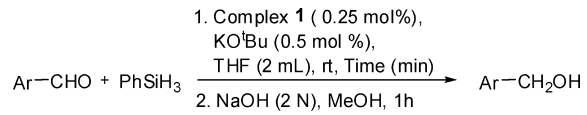
Importantly, the inexpensive and environmentally benign silane polymethylhydrosiloxane (PMHS) was also found to work as an effective reducing reagent under our optimized conditions (Table 1, entry 7; see below for more details). In addition to THF, hydrosilylation reactions catalyzed by **1** can also be performed in PhMe and no change in reactivity was observed when the reaction was performed in PhMe (Table 1, entry 8). On the other hand, the reaction failed when it was performed in protic polar solvents, e.g. EtOH and water, which may be attributed to the instability of the active metal alkoxide generated in situ. Increasing the stoichiometry of the silane did not provide any further beneficial effect in terms of reaction time or conversion (Table 1, entry 9). It is noteworthy that **2** can undergo reduction to **4** with as little as 0.125 mol % of **1**, although a relatively longer reaction time (25 min) is required (Table 1, entry 11). However, keeping in view the operational simplicity for the small-scale reaction, the use of 0.25 mol % of **1** (Table 1, entry 10) was considered as an optimum catalyst loading.

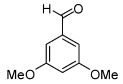
Next, we investigated the scope of the catalyst **1** (0.25 mol %) for the reduction of several functionalized aldehydes in the presence of **3**. Under base-free conditions only the activated aldehyde was reacted after prolonging the reaction time, but on application of the optimized procedure, several functionalized aldehydes were reduced in a very short period of time. Functional groups that are susceptible to reduction, for example, halide, NO_2, and CN, remain unchanged during the reaction (Table 2, entries 2−7, respectively). It was noticed that substitution at the ortho or para position of the aryl ring did not hamper the catalytic activity. Electron-rich as well as electron-deficient groups on the aryl ring did not show any significant influence on the performance of the catalyst. Sterically demanding substrates (Table 2, entry 8) were converted almost quantitatively to afford the corresponding primary alcohols in excellent yields. The functional groups susceptible to base hydrolysis (Table 2, entry 12) survived under our reaction conditions.

Earlier, it was reported that reductions of the carbonyl moiety in heterocyclic compounds either inhibit the catalytic activity or require much larger amounts of catalyst loading and longer reaction times.[7h,k,19] However, no such complications were observed with this present catalytic system. The reaction with heterocyclic carbonyl moieties (Table 2, entries 13−15) proceeded smoothly within very short periods of time in excellent yield.

Encouraged by these results, we explored the scope of reduction of different aromatic and aliphatic ketones. Several functionalized ketones were tested to determine the catalyst's activity as well as its tolerance to different functional groups (Table 3). As shown in Table 3, high catalytic efficiency of **1** was observed for a wide substrate scope of aromatic as well as aliphatic ketones. The functional groups Br (Table 3, entry 2), NO_2 (Table 3, entry 4), and F (Table 3, entry 7) were well tolerated. Ketones bearing electron-withdrawing groups were more reactive than ketones containing electron-donating substituents. It should be noted that the reduction of

Table 2. Reduction of Functionalized Aldehydes using Catalyst 1[a]



Entry	Aldehyde	Time (min)	Yield (%)[b]
			
1	R = 4-H	15	96
2	R = 4-F	15	94
3	R = 4-Cl	15	97
4	R = 4-Br	15	91
5	R = 4-CN	15	94
6	R = 4-CF_3	15	92
7	R = 4-NO_2	15	95
8	R = 2-NO_2	20	90
9	R = 4-Me	15	92
10	R = 4-OMe	15	91
11		20	93
12		15	98[c]
13		20	92
14		15	91
15		20	95

[a]The aldehyde moiety (2 mmol) was treated with **3** (2 mmol) in the presence of **1** (0.25 mol %) and KO^{t}Bu (0.5 mol %) at room temperature in THF (2 mL). [b]Yield of the corresponding alcohol characterized by NMR and MS. [c]Conversion was determined by ^{1}H NMR spectroscopy.

challenging substrates such as 2-acetylpyridine, 3-acetylbenzonitrile, and 2-acetylthiophene failed in the presence of a well-defined normal NHC-copper complex.[7k] However, the present catalyst **1** gave excellent yields of reduced products of 2-acetylpyridine, 3-acetylbenzonitrile, and 2-acetylthiophene (see entries 6, 8, and 9, Table 3). This result clearly highlights that our reaction conditions and catalyst outperform catalyst reported earlier.[7k] However, a carbonyl moiety with a hydroxyl functionality (e.g., 4-hydroxyacetophenone, 2-hydroxybenzaldehyde) failed to give the corresponding alcohol. A sterically hindered ketone, e.g. benzophenone (Table 3, entry 11), took a longer reduction time under the optimized reaction conditions. Overall, the reduction of ketones took slightly more time in comparison to that for the corresponding aldehydes.

Next, we wished to find a cheap, environmentally friendly, and readily available silane source to establish our methodology as economical and greener.[20] Keeping this perception in mind, PMHS was used as a reducing agent for the reduction of the carbonyl functionality (Table 1, entry 7). Very recently, Nikonov and co-workers reported the reduction of the carbonyl moiety with PHMS in combination with KO^{t}Bu/KOH.[8a] More precisely, when 4-nitroacetophenone was treated in the presence of PMHS (5 equiv) and 5 mol % of KO^{t}Bu, almost quantitative conversion in 45 h was reported. However, when we treated the same substrate under our optimized conditions

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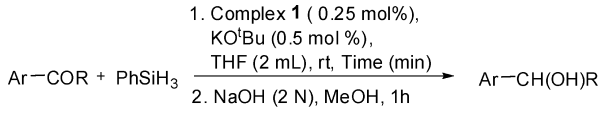
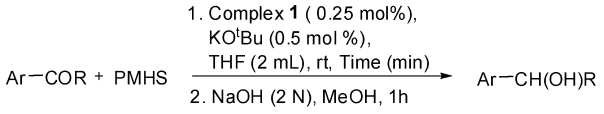
Table 3. Reduction of Functionalized Ketones using Catalyst 1[a]



Entry	Ketone	Time (min)	Yield (%)[b]
1	 R = 4-H	15	94
2	R = 4-Br	20	92
3	R = 2-Cl	25	91
4	R = 4-NO_2	15	95
5	R = 4-OMe	20	93
6	R = 3-CN	25	88
7		20	93
8		25	90
9		25	91
10		20	91
11		30	87
12		25	90

[a]The ketone moiety (2 mmol) was treated with **3** (2 mmol) in the presence of **1** (0.25 mol %) and KO^{t}Bu (0.5 mol %) at room temperature in THF (2 mL). [b]Yield of the corresponding alcohol characterized by NMR and MS.

Table 4. Reduction of Carbonyl Moiety with PMHS using Catalyst 1[a]



Entry	Carbonyl	Time (min)	Yield (%)[b]
1	 R = 4- NO_2	30	91
2	R = 4-H	30	90
3	R = 4-OMe	30	73
4		30	94
5		30	92
6		30	88
7	 R = 4- NO_2	20	94
8	R = 4- CN	20	92
9	R = 4-Cl	20	91
10	R = 4-OMe	20	93
11		25	90
12		20	91

[a]The carbonyl moiety (2 mmol) was treated with PMHS (2.5 equiv, 5 mmol) in the presence of **1** (0.25 mol %) and KO^{t}Bu (0.5 mol %) at room temperature in THF (2 mL). [b]Yield of the corresponding alcohol characterized by NMR and MS.

using the present catalyst **1** (Table 4, entry 1), the corresponding alcohol was obtained in excellent yield within only 30 min. This observation clearly demonstrates the superiority of our methodology and highlights the central role of the catalyst **1** in combination with KO^{t}Bu for the catalytic hydrosilylation using PMHS as a hydride source.

Encouraged by this result, we extended this convenient method to different functionalized carbonyl moieties. Both ketones and aldehydes were reduced quantitatively in very short periods of time. Electron-rich (Table 4, entries 3 and 10) as well as electron-poor (Table 4, entries 1, 7, and 8) substrates were reduced with nearly equal efficiency. Heterocyclic carbonyl compounds were also reduced efficiently (Table 4, entries 4, 11, and 12) without any complications. As expected, longer reaction times were required for ketones in comparison to aldehydes. Nolan and co-workers used Et_3SiH as a hydride source for the hydrosilylation reaction of carbonyl moieties using NHC-copper complexes as catalysts.[7k] Later on, the same group reported cationic copper(I) complexes such as $[(IPr)_2$-Cu]X (X = BF_4, PF_6; IPr = *N*,*N*′-bis(2,6-diisopropylphenyl)-imidazol-2-ylidene)[17c] for the hydrosilylation reaction of the carbonyl moiety. However, none of these copper catalysts used the inexpensive and environmentally benign silane PMHS as a hydride source. However, we found that our present abnormal NHC-copper complex works efficiently using PMHS as a reducing agent.

Next, we became interested in the hydrosilylation reaction of *α*,*β*-unsaturated carbonyl compounds, as there is a possibility of both 1,2-addition (C═O) and 1,4-addition (C═C). A number of complexes with different central metals were used as catalysts for the regioselective hydrosilylation reaction and offered some interesting unprecedented selectivity.[21] Apart from the nature of the central metal atom of a complex, there are several other parameters which also affect the selectivity. Apparently, the copper catalyst prefers 1,4-addition, but by tuning the interplay between steric and electronic factors of the ligand on copper, one can change the selectivity.[22] Stryker and co-workers reported that the phosphine ligand has a remarkable effect on the chemoselectivity of the reduction. They found that, on addition of dialkylarylphosphines to Stryker's reagent, 1,4-reduction is suppressed and an allylic alcohol was the major product due to preferential 1,2-reduction.[23] Chan and co-workers reported that their catalyst hydridotetrakis-(triphenylphosphine)rhodium is an efficient catalyst for the 1,4-reduction of *α*,*β*-unsaturated carbonyl compounds with monohydrosilanes.[24] Interestingly, when the silane is changed from monohydrosilanes to di- or trihydrosilanes for the hydrosilylation reactions, the selectivity changed completely and the 1,2-reduction predominated.[24] When we subjected *trans*-cinnamaldehyde (**5**) to a hydrosilylation reaction in the presence of **1** under our optimized conditions (Table 5, entry 1), excellent chemoselectivity was obtained toward 1,2-

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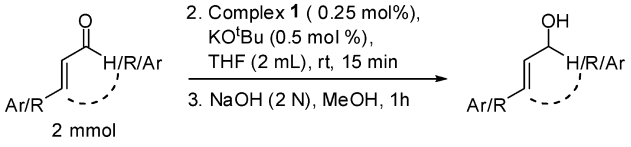
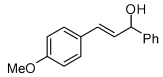
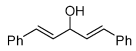
Table 5. Chemoselective Reduction of α,β-Unsaturated Carbonyl Compounds[a]



Entry	Product	Time (min)	Yield (%)[b,c]
1		15	92
2		20	38[d]
3		25	89
4		20	93

[a]The α,β-unsaturated carbonyl moiety (2 mmol) was treated with **3** (2 mmol) in the presence of **1** (0.25 mol %) and KO^{t}Bu (0.5 mol %) at room temperature in THF (2 mL). [b]Exclusive selectivity was determined with ^{1}H NMR spectroscopy. [c]Yield of the corresponding alcohol characterized by NMR and MS. [d]Conversion was determined by comparing the integral values of olefinic protons of the product and starting material in ^{1}H NMR.

addition. It is noteworthy that the α,β-unsaturated carbonyl compounds upon reduction with silane sometime prefer 1,4-addition.[7j,25] Moreover, treatment of **5** with 2 equiv of silane (**3**) under the optimized conditions resulted in exclusively 1,2-addition reduction, yielding the cinnamyl alcohol exclusively. However, when we treated **5** in the presence of PMHS, the selectivity decreased and we got a mixture (68:32) of cinnamyl alcohol and 3-phenylpropan-1-ol.

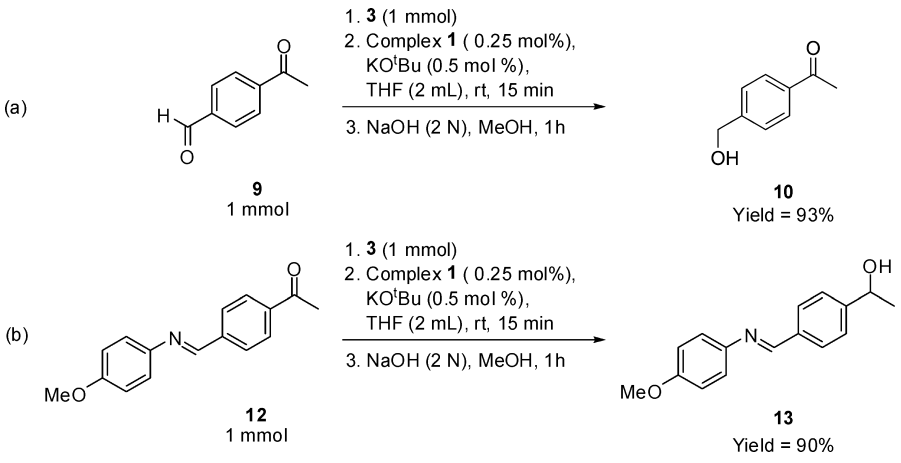
Intrigued by these preliminary catalytic results, we examined several other α,β-unsaturated carbonyl compounds, e.g. 3-ethoxycyclohex-2-enone (**6**; Table 5, entry 2), (*E*)-3-(4-methoxyphenyl)-1-phenylprop-2-en-1-one (**7**; Table 5, entry 3), and (1*E*,4*E*)-1,5-diphenylpenta-1,4-dien-3-one (**8**; Table 5, entry 4) separately with **3** under optimized conditions (Table 5, entries 2−4). Excellent chemoselectivity was obtained to afford the corresponding allylic alcohol after routine base hydrolysis. The treatment of **6** with **3** (Table 5, entry 2) gives exclusive selectivity toward 1,2-addition, but poor conversion was observed by ^{1}H NMR spectroscopy (determined by comparing the integral value of olefinic protons of the product and starting material in ^{1}H NMR) even after prolonging the reaction time and increasing the catalyst loading. Moreover, the attempted reduction of the conjugated enone 2-cyclohexen-1-one did not provide any beneficial role in terms of selectivity. While the reaction of 2-cyclohexen-1-one was complete in 15 min with **3**, we ended up with an equimolar (1:1) mixture of cyclohexenol and cyclohexanol.

Further, the chemoselective reduction of the carbonyl group also has been accomplished when the hydrosilylation was carried out in the presence of both aldehyde and ketone functionalities.[26] When 4-acetylbenzaldehyde (**9**) was treated with **3** under the optimized conditions, likewise with a few other reported catalysts,[26a,b] the aldehyde group was exclusively reduced to the corresponding primary alcohol to give 1-(4-(hydroxymethyl)phenyl)ethanone (**10**; Scheme 2a). It is worth mentioning that the compound **10** is a reactive intermediate for the synthesis of HIV reverse transcriptase and integrase (RT and RI).[27] Though the selectivity of the reaction for the aldehyde over ketone is reasonably expected and can be explained in terms of their electrophilicities, it may be noted that routinely used reagents employed for carbonyl group reduction, such as sodium borohydride, is too reactive and does not show any chemoselectivity with **9**. The treatment of **9** with sodium borohydride (1 equiv) in the presence of MeOH at room temperature shows that both the aldehyde and ketone functionalities undergo reduction to give 1-(4-(hydroxymethyl)phenyl)ethanol (**11**) in 94% yield.

Interestingly, this catalytic system is tolerant toward imine functional groups,[7j,25a] as shown by the complete reduction of the C═O functionality of (*E*)-1-(4-((4-methoxyphenylimino)methyl)phenyl)ethanone (**12**) in the presence of a C═N bond to give 1-(4-((4-methoxyphenylimino)methyl)phenyl)ethanol (**13**; Scheme 2b). In contrast, when **12** was treated with sodium borohydride (1 equiv) in the presence of MeOH at room temperature, reduction of both the ketone and imine groups took place to give 1-(4-((4-methoxyphenylamino)methyl)-phenyl)ethanol (**14**) in 94% yield.

Finally, some effort was directed to integration of the Huisgen cycloaddition (click) and hydrosilylation reactions in a consecutive fashion in one pot. To the best of our knowledge, no catalyst system has been reported that integrates the Huisgen cycloaddition and hydrosilylation reactions in one pot

Scheme 2. Selective Reduction of C═O Functionality using Catalyst 1



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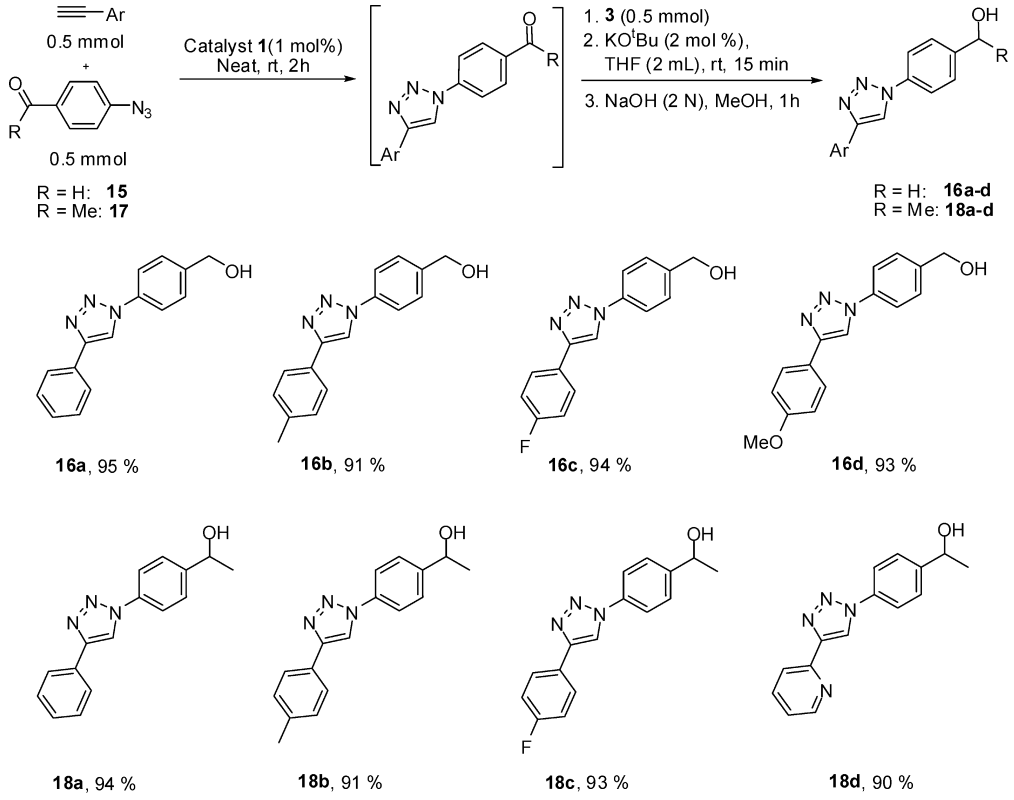
Scheme 3. Integrating Huisgen Cycloaddition and Hydrosilylation Reactions in One Pot



in a consecutive fashion. The emerging influence of sustainable chemistry in organic synthesis augmented the need of multiple catalytic cycles in a single vessel for the synthesis of complex compounds,[28] as it minimizes the time in a cost-effective manner by eliminating the need for isolation and purification of intermediates. In biological chemistry, there are several examples[29] in which arrays of catalytic (enzymatic) reactions are integrated, reminiscent of the concept of multiple catalysis.[30] In these processes, the product of one cycle acts as the substrate of the next catalytic cycle.[31] The synthesis of aromatic substituted triazole with a hydroxyl functionality requires a two-step process such as a Huisgen cycloaddition reaction and catalytic reduction of the carbonyl functionality followed by hydrolysis. Usually, this can be accomplished in two different catalytic steps followed by workup using copper catalyst in a stepwise manner, which is a tedious process. To integrate these two catalytic steps, however, one needs to use a robust catalyst which can stay alive during both catalytic processes, avoiding any workup between these two catalytic steps. We adopted herein an alternate strategy where we first synthesized the triazole-containing carbonyl functionality followed by reduction and hydrolysis to give an aromatic substituted triazole with a hydroxyl functionality within the same reaction pot using catalyst **1**. We anticipate that this strategy can be successful because of the stability of the abnormal NHC-copper complex, which can remain active in a multistep catalytic process.

Earlier we reported the activity of **1** in a number of Huisgen cycloaddition reactions dealing with a versatile range of substrates.[10a] We noticed that the strong binding ability of the *a*NHC ligand to the copper center leads to a long-lived catalyst which stays active for 10 consecutive catalytic cycles without any reduction in catalytic activity. This result along with the excellent catalytic activity in hydrosilylation reactions prompted us to integrate the Huisgen cycloaddition with a hydrosilylation reaction in the same reaction pot. We performed all of these multiple catalytic experiments with 1 mol % of catalyst loading. Initially, 4-azidobenzaldehyde (**15**) was treated with phenylacetylene in the presence of *a*NHC copper(I) complex **1** (1 mol %) at room temperature (Scheme 3). Within 2 h, the reaction mixture solidified, indicating completion of the Huisgen cycloaddition reaction, and THF was added in the same pot to make the reaction mixture homogeneous, followed by addition of phenylsilane (**3**) and KO^{t}Bu (1 mol %). Immediately after the addition of base, the color of the solution changed from pale yellow to brown. The reaction mixture was stirred for 20 min. To our delight, after the base hydrolysis, we got the desired hydrosilylated product (4-(4-phenyl-1*H*-1,2,3-triazol-1-yl)phenyl)methanol (**16a**) in excellent yield. To establish the generality of this catalytic protocol, several other alkyne substrates were treated with **15** in this consecutive fashion. In all of the reactions, the yields were observed to be excellent (Scheme 3; **16a**−**d**).

Furthermore, to extrapolate the scope of this multiple catalysis, 4-azidoacetophenone (**17**) was treated with different functionalized alkyne substrates. Without exception, we got the corresponding 1,2,3-triazole substituted secondary alcohols (Scheme 3; **18a**−**d**) in excellent yields within very short periods of time.

CONCLUSION

In conclusion, we have established a copper(I) compound bearing an abnormal N-heterocyclic carbene as a versatile and highly efficient catalyst for the chemoselective reduction of the carbonyl functionality via hydrosilylation, which acts at low (0.25 mol %) catalyst loading at ambient temperature. Different

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electron-rich and electron-deficient functionalized aromatic carbonyls and aliphatic ketones were successfully reduced by this catalytic protocol, resulting in nearly quantitative yields. This catalyst is equally effective for heterocyclic carbonyl compounds and gives the corresponding alcohol after traditional base workup in good to excellent yields within very short periods of time. The catalyst can successfully catalyze the hydrosilylation reaction of α,β-unsaturated carbonyl compounds and prefers selectivity toward 1,2-addition (C=O) to give the corresponding allyl alcohol in good yields. Moreover, in the same molecule when both imine and ketone groups were present, this catalyst selectively reduced the ketone functionality. All of these results clearly establish the ability of our catalyst to perform hydrosilylation reactions in a chemoselective way. Furthermore, the copper(I) chloro complex **1** was used as a multiple catalyst for combining the Huisgen cycloaddition and hydrosilylation reactions in one pot. This unique protocol was generalized with different structural motifs to synthesize several primary and secondary alcohols with the triazole scaffold in one pot.

EXPERIMENTAL SECTION

General Considerations. All manipulations were performed under a dry and oxygen-free atmosphere (argon) using standard Schlenk techniques or inside a glovebox maintained at below 0.1 ppm of O_2 and H_2O levels, utilizing oven-dried (130 °C) glassware after evacuation while hot prior to use. All solvents were distilled from Na/benzophenone prior to use. All chemicals were purchased and used as received. The ^{1}H and ^{13}C{^{1}H} NMR spectra were recorded on 400 and 500 MHz spectrometers in $CDCl_3$/DMSO-d_6 with residual undeuterated solvent ($CDCl_3$, 7.26/77.0; DMSO-d_6, 2.50/39.5) as an internal standard. Chemical shifts (δ) are given in ppm, and J values are given in Hz. The IR spectra were recorded either as KBr pellets (for solids) or as the neat compound or a CCl_4 solution (for liquids) on the spectrometer. The HR-MS data were obtained using a Q-TOF instrument. The melting points were measured in a sealed glass tube on a melting point apparatus and were uncorrected. Open-column chromatography and thin-layer chromatography (TLC) were performed on silica gel (CDH silica gel 60−120 mesh). Evaporation of solvents was performed at reduced pressure using a rotary evaporator.

General Procedure for the Hydrosilylation of Carbonyl Compounds. In an oven-dried Schlenk flask fitted with septum, complex **1** (3 mg, 0.005 mmol, 0.25 mol %) and potassium *tert*-butoxide (1.2 mg, 0.01 mmol, 0.5 mol %) were charged inside a glovebox and stirred in dry THF (2 mL) at room temperature for 5 min before adding phenylsilane (252 μL, 2 mmol, 1 equiv) and the carbonyl compound (1 mmol) through the septum using a syringe. In cases where the starting carbonyl substrate is a solid, it was added after dissolving it in THF. The final reaction mixture was stirred for the requisite time, and the reaction was monitored by TLC. After consumption of the starting material, the reaction mixture was opened to the air and MeOH (1 mL) was added followed by aqueous NaOH (2 M, 2 mL). The resulting mixture was stirred for 1 h and subsequently extracted with DCM (3 × 30 mL). The organic phase was concentrated in vacuo, and the purity of the residue was checked by ^{1}H NMR spectroscopy. Flash chromatography (a mixture of EtOAc and petroleum ether was used as the eluent, and the ratio of EtOAc to petroleum ether was adjusted accordingly) was then performed unless the crude product was estimated to be greater than 95% pure.

General Procedure for Integration of Huisgen Cycloaddition and Hydrosilylation Reactions in One Pot. In an oven-dried 25 mL Schlenk flask, alkyne (0.5 mmol), azide (0.5 mmol), and complex **1** (3.2 mg, 1 mol %) were charged inside a glovebox. The reaction mixture was stirred at room temperature for 2 h. After the solidification of the reaction mixture, potassium *tert*-butoxide (1.2 mg, 0.01 mmol, 2 mol %) was added and the Schlenk flask was fitted with a screw cap septum. Dry THF (2 mL) was added through the septum using a syringe, followed by phenylsilane (64 μL, 0.5 mmol, 1 equiv). The final reaction mixture was stirred for 15 min. The reaction mixture was opened to the air, and MeOH (1 mL) was added followed by aqueous NaOH (2 M, 2 mL). The resulting mixture was stirred for 1 h and subsequently extracted with DCM (3 × 30 mL). The organic phase was concentrated in vacuo, and the purity of the residue was checked by ^{1}H NMR. Flash chromatography (a mixture of EtOAc and petroleum ether was used as the eluent, and the ratio of EtOAc to petroleum ether was adjusted accordingly) was then performed unless the crude product was estimated to be greater than 95% pure.

Procedure for the Synthesis of 3-Formylphenyl Acetate (Substrate Table 2, Entry 12). Acylation was carried out by modifying the reported procedure.[32a] 3-Hydroxybenzaldehyde (610 mg, 5 mmol) was dissoved in DCM (10 mL), and the solution was cooled to 0 °C. Triethylamine (670 mg, 0.92 mL, 6.67 mmol) and a catalytic amount of dimethylaminopyridine (DMAP) were added to the stirred solution. Acetyl chloride (431 mg, 0.39 mL, 5.5 mmol) was added dropwise. The mixture was warmed to room temperature, and stirred for another 3 h. The solvent was removed in vacuo, and the reaction mixture was diluted with H_2O (5 mL) and extracted with EtOAc (3 × 5 mL). The combined EtOAc extracts were washed with saturated brine (15 mL), dried (Na_2SO_4), and concentrated under reduced pressure to afford the acetylated product (760 mg, 93%). ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 2.22 (s, 3H), 7.24−7.26 (m, 1H), 7.44 (t, J = 7.6 Hz, 1H), 7.50−7.51 (m, 1H), 7.62−7.65 (m, 1H), 9.88 (s, 1H).

Procedure for the Synthesis of (*E*)-3-(4-Methoxyphenyl)-1-phenylprop-2-en-1-one (Substrate Table 5, Entry 3). The enone was synthesized by following the reported procedure.[32b] Acetophenone (600 mg, 5 mmol) in EtOH (2.5 mL) was treated with LiOH·H_2O (20 mg, 0.5 mmol, 10 mol %) with stirring for 10 min at room temperature (~25−30 °C) followed by 4-methoxybenzaldehyde (680 mg, 5 mmol, 1 equiv). The mixture was stirred until complete consumption of the starting materials (45 min, monitored by TLC). After the completion of the reaction, a yellow precipitate was formed. EtOH was removed under reduced pressure. The residue was diluted with water (5 mL), neutralized with 2% aqueous HCl, and extracted with EtOAc (3 × 5 mL). The combined EtOAc extracts were washed with brine solution (5 mL), dried (Na_2SO_4), and concentrated under reduced pressure to afford the desired product (1.14 g, 96%). ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 3.86 (s, 3H), 6.93−6.96 (m, 2H), 7.41 (d, J = 15.5 Hz, 1H), 7.48−7.51 (m, 2H), 7.60−7.61 (m, 3H), 7.78 (d, J = 15.5 Hz, 1H), 8.00−8.02 (m, 2H).

Procedure for the Synthesis of (*E*)-1-(4-((4-Methoxyphenylimino)methyl)phenyl)ethanone (Scheme 2b, Substrate 12). A mixture of 3-acetylbenzaldehyde (296 mg, 2 mmol, 1 equiv) and 4-methoxyaniline (246 mg, 2 mmol, 1 equiv) was stirred at room temperature in EtOH (2 mL). After completion of the reaction (1 h, monitored by TLC), a yellow precipitate was formed and the crude mixture was recrystallized from ethanol to afford (*E*)-1-(4-((4-methoxyphenylimino)methyl)phenyl)ethanone (409 mg, 82%). ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 2.66 (s, 3H), 3.84 (s, 3H), 6.94−6.96 (m, 2H), 7.26−7.29 (m, 2H), 7.97−7.99 (m, 2H), 8.03−8.06 (m, 2H), 8.54 (s, 1H).

Procedure for the Synthesis of 4-Azidobenzaldehyde (Scheme 3, Substrate 15). Azide formation was carried out by slightly modifying the reported procedure.[32c] KF (348 mg, 6 mmol, 1.2 equiv), $TMSN_3$ (690 mg, 6 mmol, 1.2 equiv), and CuCl (50 mg, 0.5 mmol, 10 mol %) were sequentially added to a solution of 4-formylphenylboronic acid (750 mg, 5 mmol, 1 equiv) in MeOH (4 mL). The resulting solution was then stirred at reflux until the starting material had disappeared as monitored by TLC. The reaction mixture was concentrated under reduced pressure, and the crude product was purified by silica gel chromatography (a mixture of EtOAc and petroleum ether was used as the eluent, and the ratio of EtOAc to petroleum ether was adjusted accordingly) to give the desired product, 4-azidobenzaldehyde (602 mg, 82%). ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 7.14−7.16 (m, 2H), 7.88−7.89 (m, 2H), 9.94 (s, 1H).

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Following the same procedure, 4-acetylphenylboronic acid was converted to the corresponding 4-azidoacetophenone (**17**; 676 mg, 84% yield). ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 2.58 (s, 3H), 7.08−7.09 (m, 2H), 7.95−7.97 (m, 2H).

Characterization of the Compounds. *Phenylmethanol (Table 2, Entry 1).*[32d] Clear liquid, 207 mg, yield 96%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.66 (d, J = 2.5 Hz, 2H), 7.31−7.32 (m, 1H), 7.33−7.39 (m, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.9, 126.9, 127.5, 128.4, 140.7.

(4-Fluorophenyl)methanol (Table 2, Entry 2).[32d] Clear liquid, 236 mg, yield 94%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.65 (s, 2H), 7.00−7.04 (m, 2H), 7.29−7.33 (m, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.4, 115.2 (d, J_{CF} = 21.1 Hz), 128.6 (d, J_{CF} = 8.0 Hz), 136.6, 161.3 (d, J_{CF} = 244.0 Hz).

(4-Chlorophenyl)methanol (Table 2, Entry 3).[32d] White crystalline solid, 275 mg, yield 97%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.67 (s, 2H), 7.26−7.32 (m, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.2, 128.2, 128.5, 133.2, 139.1. These data are identical with those for Table 4, entry 9.

(4-Bromophenyl)methanol (Table 2, Entry 4).[32d] Clear liquid, 340 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.65 (s, 2H), 7.23 (d, J = 8.4 Hz, 2H), 7.48 (d, J = 8.4 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.4, 121.4, 128.5, 131.6, 139.7.

4-(Hydroxymethyl)benzonitrile (Table 2, Entry 5).[32e] Clear liquid, 250 mg, yield 94%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.77 (s, 2H), 7.47 (d, J = 7.6 Hz, 2H), 7.63 (d, J = 7.6 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 63.4, 110.2, 118.7, 126.7, 131.9, 146.5. These data are identical with those for Table 4, entry 8.

(4-(Trifluoromethyl)phenyl)methanol (Table 2, Entry 6).[32e] Clear liquid, 323 mg, yield 92%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.75 (s, 2H), 7.46 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 8.4 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.3, 124.1 (q, J_{CF} = 270.0 Hz, consist of four peaks 120.9, 123.0, 125.2, 127.4), 125.3 (q, J_{CF} = 3.7 Hz, consists of four peaks 125.3, 125.3, 125.4, 125.4), 126.7, 129.6 (q, J_{CF} = 32.2 Hz, consist of four peaks 129.3, 129.5, 129.8, 130.1), 144.7.

(4-Nitrophenyl)methanol (Table 2, Entry 7).[32d] Yellow amorphous solid, 290 mg, yield 95%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.84 (s, 2H), 7.53 (d, J = 8.4 Hz, 2H), 8.22 (d, J = 8.4 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 63.8, 123.6, 126.9, 147.1, 148.3. These data are identical with those for Table 4, entry 7.

(2-Nitrophenyl)methanol (Table 2, Entry 8).[32e] Clear liquid, 275 mg, yield 90%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 4.97 (s, 2H), 7.47 (dt, J = 9.0, 1.5 Hz, 1H), 7.67 (dt, J = 8.5, 1.5 Hz, 1H), 7.73−7.47 (m, 1H), 8.1 (dd, J = 8.0, 1 Hz, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 62.5, 124.9, 128.48, 129.9, 134.1, 136.8.

(4-Methylphenyl)methanol (Table 2, Entry 9).[32d] Clear liquid, 224 mg, yield 92%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 2.36 (s, 3H), 4.61 (d, J = 8.0 Hz, 2H), 7.17 (d, J = 7.5 Hz, 2H), 7.25 (d, J = 7.5 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 65.0, 127.0, 129.1, 137.2, 137.8.

(4-Methoxyphenyl)methanol (Table 2, Entry 10).[32d] Clear liquid, 251 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 3.77 (s, 3H), 4.53 (s, 2H), 6.86 (d, J = 8.5 Hz, 2H), 7.23 (d, J = 8.5 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 55.1, 64.5, 113.7, 128.5, 133.0, 158.9. These data are identical with those for Table 4, entry 10.

(3,5-Dimethoxyphenyl)methanol (Table 2, Entry 11).[32f] Clear liquid, 312 mg, yield 93%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 3.77 (s, 6H), 4.59 (d, J = 4 Hz, 2H), 6.36(s, 1H), 6.49 (d, J = 2 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 55.3, 65.1, 99.5, 104.5, 143.4, 160.9.

Pyridin-2-ylmethanol (Table 2, Entry 13).[32g] Clear liquid, 200 mg, yield 92%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 4.74 (s, 2H), 7.18 (d, J = 6.0 Hz, 1H), 7.66 (t, J = 7.5 Hz, 1H), 7.27 (t, J = 5.0 Hz, 1H), 8.50 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 64.2, 120.6, 122.3, 136.8, 148.4, 159.3. These data are identical with those for Table 4, entry 11.

Furan-2-ylmethanol (Table 2, Entry 14).[32h] Pale brown liquid, 178 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 4.61 (s, 2H), 6.29 (d, J = 3 Hz, 1H), 6.32−6.34 (m, 1H), 7.39 (d, J = 2 Hz, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 57.3, 107.7, 110.3, 142.5, 153.9. These data are identical with those for Table 4, entry 12.

Thiophen-2-ylmethanol (Table 2, Entry 15).[32d] Clear liquid, 216 mg, yield 95%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 5.06 (d, J = 1.5 Hz, 2H), 7.26−7.28 (m, 2H), 7.56−7.57 (m, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 59.7, 125.3, 1254, 126.7, 143.9.

1-Phenylethanol (Table 3, Entry 1).[32d] Clear liquid, 229 mg, yield 94%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.50 (d, J = 6.0 Hz, 3H), 4.90 (q, J = 6.0 Hz, 1H), 7.25−7.30 (m, 1H), 7.35−7.39 (m, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.0, 70.2, 125.3, 127.2, 128.3, 145.7. These data are identical with those for Table 4, entry 2.

1-(4-Bromophenyl)ethanol (Table 3, Entry 2).[32h] White amorphous solid, 369 mg, yield 92%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.44 (d, J = 6.8 Hz, 3H), 4.83 (q, J = 6.8 Hz, 1H), 7.23 (d, J = 7.6 Hz, 2H), 7.45 (d, J = 7.6 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.1, 69.6, 121.0, 127.1, 131.4, 144.7.

1-(2-Chlorophenyl)ethanol (Table 3, Entry 3).[32i] Clear liquid, 284 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.49 (d, J = 6.1 Hz, 3H), 5.29 (q, J = 6.1 Hz, 1H), 7.19−7.21(m, 1H), 7.26−7.31 (m, 2H), 7.58−7.60 (m, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 23.4, 66.9, 126.3, 127.1, 128.3, 129.3, 131.6, 143.0.

1-(4-Nitrophenyl)ethanol (Table 3, Entry 4).[32e] Yellow amorphous solid, 317 mg, yield 95%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.51 (d, J = 6.8 Hz, 3H), 5.00 (q, J = 6.8 Hz, 1H), 7.53(d, J = 9.1 Hz, 2H), 8.19 (d, J = 9.1 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.3, 69.3, 123.6, 126.1, 146.9, 153.1. These data are identical with those for Table 4, entry 1.

1-(4-Methoxyphenyl)ethanol (Table 3, Entry 5).[32e] Clear liquid, 282 mg, yield 93%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.48 (d, J = 6.1 Hz, 3H), 3.80 (s, 3H), 4.86 (q, J = 6.1 Hz, 1H), 6.87(d, J = 8.4 Hz, 2H), 7.30 (d, J = 8.4 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 24.9, 55.2, 69.8, 113.7, 126.6, 137.9, 158.8. These data are identical with those for Table 4, entry 3.

1-(3-Cyanophenyl)ethanol (Table 3, Entry 6).[32j] Clear liquid, 258 mg, yield 88%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.48 (d, J = 6.1 Hz, 3H), 4.92 (q, J = 6.1 Hz, 1H), 7.44 (t, J = 8 Hz, 1H), 7.52−7.55 (m, 1H), 7.60 (d, J = 7.6 Hz, 1H), 7.66 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) δ (ppm): 25.1, 68.9, 111.9, 118.8, 128.9, 129.0, 129.9, 130.7, 147.2.

1-(2,6-Difluorophenyl)ethanol (Table 3, Entry 7). Clear liquid, 293 mg, yield 93%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.61 (d, J = 7.0 Hz, 3H), 5.25 (q, J = 7.0 Hz, 1H), 6.83−6.89 (m, 2H), 7.15−7.26 (m, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 23.3, 62.36, 111.6 (dd, J_{CF} = 20.5, 6.0 Hz), 120.5 (t, J_{CF} = 16.5 Hz), 128.9 (t, J_{CF} = 10.7 Hz), 160.7 (dd, J_{CF} = 246.4, 8.9 Hz). HRMS m/z (ESI): calcd for $C_8H_7F_2NaO$ $[M + Na]^+$ 180.0363, found 180.0368.

1-(Pyridin-2-yl)ethanol (Table 3, Entry 8).[32i] White amorphous solid, 221 mg, yield 90%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.50 (d, J = 6.1 Hz, 3H), 4.89 (q, J = 6.1 Hz, 1H), 7.21−7.40 (m, 1H), 7.26−7.29 (m, 1H), 7.67−7.70 (m, 1H), 8.53−8.54 (d, J = 4.6 Hz, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 24.2, 66.8, 119.8, 122.2, 136.9, 147.9, 162.9. These data are identical with those for Table 4, entry 4.

1-(Thiophen-2-yl)ethanol (Table 3, Entry 9).[32k] Clear liquid, 233 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.60 (d, J = 6.1 Hz, 3H), 5.12 (q, J = 6.1 Hz, 1H), 6.95−6.98 (m, 2H), 7.24 (d, J = 6.1 Hz, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz) δ (ppm): 25.1, 66.0, 123.1, 124.3, 126.5, 149.8.

1-Phenylpropan-1-ol (Table 3, Entry 10).[32l] Clear liquid, 247 mg, yield 91%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 0.90 (t, J = 7.6 Hz, 3H), 1.75−1.81 (m, 3H, OH merged), 4.58 (t, J = 6.1 Hz, 1H), 7.24−7.33 (m, 5H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 10.1, 31.8, 76.0, 125.9, 127.5, 128.4, 144.5. These data are identical with those for Table 4, entry 5.

Diphenylmethanol (Table 3, Entry 11).[32m] Yellow amorphous solid, 320 mg, yield 87%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 5.83 (s, 1H), 7.23−7.24 (m, 2H), 7.31−7.38(m, 8H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 76.1, 126.4, 127.4, 128.4, 143.7. These data are identical with those for Table 4, entry 6.

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Cyclohexanol (Table 3, Entry 12).[32e] Clear liquid, 180 mg, yield 90%. ^{1}H NMR ($CDCl_3$, 400 MHz) δ (ppm): 1.11−1.16 (m, 1H), 1.18−1.28 (m, 4H), 1.50−1.53 (m, 1H), 1.69−1.71(m, 2H), 1.84−1.86 (m, 2H), 2.20 (s, 1H), 3.54−3.58 (m, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 24.1, 25.4, 35.4, 70.2.

(E)-3-Phenylprop-2-en-1-ol (Table 5, Entry 1).[32d] Clear liquid, 246 mg, yield 92%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 4.33 (dd, J = 5.5, 1 Hz, 2H), 6.38 (td, J = 16.5, 5 Hz, 1H), 6.63 (d, J = 16 Hz, 1H), 7.25−7.28 (m, 1H), 7.32−7.35 (m, 2H), 7.39−7.41 (m, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 63.5, 126.4, 127.6, 128.4, 128.5, 130.9, 136.6.

(E)-3-(4-Methoxyphenyl)-1-phenylprop-2-en-1-ol (Table 5, Entry 3).[32n] Yellow amorphous solid, 498 mg, yield 89%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 3.81 (s, 3H), 5.36 (d, J = 7 Hz, 1H), 6.25 (dd, J = 15.5, 6.5 Hz, 1H), 6.63 (d, J = 15.5 Hz, 1H), 6.83−6.85 (m, 2H), 7.29−7.33 (m, 3H), 7.36−7.38 (m, 2H), 7.43−7.44 (m, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 55.2, 75.2, 113.9, 126.7, 127.7, 127.8, 128.5, 129.2, 129.4, 130.2 142.9, 159.3.

(1E,4E)-1,5-Diphenylpenta-1,4-dien-3-ol (Table 5, Entry 4).[32o] White amorphous solid, 438 mg, yield 93%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 5.03 (t, J = 6.5, 1 Hz, 1H), 6.35 (dd, J = 11.5, 16 Hz, 2H), 6.71 (d, J = 16 Hz, 2H), 7.28−7.31 (m, 2H), 7.36−7.38 (m, 4H), 7.44−7.46 (m, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 73.7, 126.6, 127.8, 128.6, 130.3, 130.9, 136.5.

1-(4-(Hydroxymethyl)phenyl)ethanone (Scheme 2, ***10****).*[32e] Clear liquid, 139 mg, yield 93%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 2.6 (s, 3H), 4.77 (s, 2H), 7.45 (d, J = 8 Hz, 2H), 7.94 (d, J = 8 Hz, 2H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 26.6, 64.3, 126.5, 128.5, 136.0, 146.5. 196.2.

1-(4-(Hydroxymethyl)phenyl)ethanol (Scheme 2, Reduction with NaBH$_4$, ***11****).*[32p] Clear liquid, 143 mg, yield 94%. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 1.49 (d, J = 6.5 Hz, 3H), 4.69 (s, 2H), 4.91 (q, J = 6.5 Hz, 1H), 7.36−7.39 (m, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.2, 65.1, 70.2, 125.6, 127.2, 140.1, 145.3.

1-(4-((4-Methoxyphenylimino)methyl)phenyl)ethanol (Scheme 2, ***13****).* Pale yellow amorphous solid, 229 mg, yield 90%. Mp: 81−83 °C. IR (ν_{max}): 3436, 2073, 1625, 1508, 1247 cm^{-1}. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 1.52 (d, J = 6.5 Hz, 3H), 3.83 (s, 3H), 4.96 (q, J = 6.5 Hz, 1H), 6.92−6.94 (m, 2H), 7.23−7.25 (m, 2H), 7.47 (d, J = 8 Hz, 2H), 7.87 (d, J = 8 Hz, 2H), 8.47 (s, 1H); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.2, 55.4, 69.9, 114.3, 122.1, 125.7, 128.7, 136.5, 144.7, 148.9, 158.1, 158.2. HRMS m/z (ESI): calcd for $C_{16}H_{18}NO_2$ $[M + H]^+$ 256.1259, found 256.1262.

1-(4-((4-Methoxyphenylamino)methyl)phenyl)ethanol (Scheme 2, Reduction with NaBH$_4$, ***14****).* Pale brown amorphous solid, 241 mg, yield 94%. Mp: 82−84 °C. IR (ν_{max}): 3430, 2078, 1637, 1516, 1239, 1118 cm^{-1}. ^{1}H NMR ($CDCl_3$, 500 MHz) δ (ppm): 1.49 (d, J = 6.5 Hz, 3H), 3.74 (s, 3H), 4.27 (s, 2H), 4.89 (q, J = 6.5 Hz, 1H), 6.60−6.62 (m, 2H), 6.76−6.78 (m, 2H), 7.36 (bs, 4H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.1, 48.9, 55.7, 70.1, 114.1, 114.9, 125.6, 127.6, 138.8, 142.2, 144.7, 152.1. HRMS m/z (ESI): calcd for $C_{16}H_{20}NO_2$ $[M + H]^+$ 258.1262, found 258.1265.

(4-(4-Phenyl-1H-1,2,3-triazol-1-yl)phenyl)methanol (Scheme 3, ***16a****).*[32q] Yellow amorphous solid, 119 mg, yield 95%. Mp: 169−171 °C. IR (ν_{max}): 3436, 2339, 1634, 1131 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 4.60 (d, J = 4.5 Hz, 2H), 5.38 (t, J = 4.5 Hz, 1H), 7.38 (t, J = 7.0 Hz, 1H), 7.50 (t, J = 7.5 Hz, 2H), 7.56 (d, J = 8.0 Hz, 2H), 7.91 (d, J = 8.0 Hz, 2H), 7.95 (d, J = 7.5 Hz, 2H), 9.29 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 62.2, 119.5, 119.7, 125.3, 127.6, 128.2, 128.9, 130.3, 135.2, 143.3, 147.2.

(4-(4-(4-Methylphenyl)-1H-1,2,3-triazol-1-yl)phenyl)methanol (Scheme 3, ***16b****).* Yellow amorphous solid, 120 mg, yield 91%. Mp: 176−178 °C. IR (ν_{max}): 3435, 2365, 2078, 1636 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 2.34 (s, 3H), 4.60 (d, J = 4.0 Hz, 2H), 5.38 (bs, 1H), 7.30 (d, J = 8.0 Hz, 2H), 7.55 (d, J = 8.5 Hz, 2H), 7.84 (d, J = 7.5 Hz, 2H), 7.89 (d, J = 8.5 Hz, 2H), 9.22 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 20.8, 62.2, 119.1, 119.7, 125.3, 127.5, 127.6, 129.5, 135.3, 137.6, 143.2, 147.3. HRMS m/z (ESI): calcd for $C_{16}H_{14}N_3NaO$ $[M + Na]^+$ 287.1035, found 287.1039.

(4-(4-(4-Fluorophenyl)-1H-1,2,3-triazol-1-yl)phenyl)methanol (Scheme 3, ***16c****).* Yellow amorphous solid, 126 mg, yield 94%. Mp: 196−198 °C. IR (ν_{max}): 3436, 2365, 2078, 1637 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 4.60 (d, J = 5.5 Hz, 2H), 5.37 (d, J = 5.5 Hz, 1H), 7.33−7.37 (m, 2H), 7.57 (d, J = 8.5 Hz, 2H), 7.89 (d, J = 8.5 Hz, 2H), 7.96−7.99 (m, 2H), 9.27 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 62.2, 116.0 (d, J_{CF} = 25.0 Hz), 119.5, 119.7, 127.3 (d, J_{CF} = 12.5 Hz), 127.7, 135.2, 143.3, 146.4, 161.0 (d, J_{CF} = 237.5 Hz). HRMS m/z (ESI): calcd for $C_{15}H_{13}FN_3O$ $[M + H]^+$ 270.0964, found 270.0962.

(4-(4-(4-Methoxyphenyl)-1H-1,2,3-triazol-1-yl)phenyl)methanol (Scheme 3, ***16d****).* Yellow amorphous solid, 130 mg, yield 93%. Mp: 175−177 °C. IR (ν_{max}): 3433, 2365, 2066, 1633, 1522, 1250 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 3.80 (s, 3H), 4.59 (d, J = 4.5 Hz, 2H), 5.37 (t, J = 4.5 Hz, 1H), 7.06 (d, J = 9.0 Hz, 2H), 7.55 (d, J = 8.5 Hz, 2H), 7.86−7.90 (m, 4H), 9.16 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 55.2, 62.2, 114.4, 118.5, 119.6, 122.8, 126.7, 127.6, 135.3, 143.2, 147.2, 159.3. HRMS m/z (ESI): calcd for $C_{16}H_{16}N_3O_2$ $[M + H]^+$ 282.1164, found 282.1167.

1-(4-(4-Phenyl-1H-1,2,3-triazol-1-yl)phenyl)ethanol (Scheme 3, ***18a****).* Yellow amorphous solid, 124 mg, yield 94%. Mp: 172−174 °C. IR (ν_{max}): 3436, 2356, 2075, 1636 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 1.37 (d, J = 6.5 Hz, 3H), 4.82 (q, J = 6.5 Hz, 1H), 7.38 (t, J = 7.5 Hz, 1H), 7.50 (t, J = 7.5 Hz, 2H), 7.58 (d, J = 8.5 Hz, 2H), 7.89 (d, J = 8.5 Hz, 2H), 7.95 (d, J = 8.5 Hz, 2H), 9.27 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.8, 67.5, 119.6, 119.7, 125.3, 126.7, 128.2, 128.9, 130.3, 135.2, 147.2, 148.1. HRMS m/z (ESI): calcd for $C_{16}H_{16}N_3O$ $[M + Na]^+$ 266.1215, found 266.1218.

1-(4-(4-(4-Methylphenyl)-1H-1,2,3-triazol-1-yl)phenyl)ethanol (Scheme 3, ***18b****).* Yellow amorphous solid, 126 mg, yield 91%. Mp: 168−170 °C. IR (ν_{max}): 3441, 2085, 1635, 1131 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 1.38 (d, J = 6.5 Hz, 3H), 2.35 (s, 3H), 4.83 (q, J = 6.5 Hz, 1H), 5.34 (d, J = 4 Hz, 1H), 7.31 (d, J = 8.0 Hz, 2H), 7.58 (d, J = 7.5 Hz, 2H), 7.84 (d, J = 8.0 Hz, 2H), 7.89 (d, J = 8.5 Hz, 2H), 9.21 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 20.8, 25.8, 67.5, 119.1, 119.7, 125.2, 126.6, 127.5, 127.9, 129.5, 135.2, 137.5, 147.3, 148.0. HRMS m/z (ESI): calcd for $C_{17}H_{17}N_3O$ $[M]^+$ 279.1372, found 279.1375.

1-(4-(4-(4-Fluorophenyl)-1H-1,2,3-triazol-1-yl)phenyl)ethanol (Scheme 3, ***18c****).* Yellow amorphous solid, 131 mg, yield 93%. Mp: 171−173 °C. IR (ν_{max}): 3428, 2314, 1633, 1228 cm^{-1}; ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 1.37 (d, J = 6.5 Hz, 3H), 4.82 (q, J = 6.5 Hz, 1H), 5.34 (bs, 1H), 7.32−7.36 (m, 2H), 7.58 (d, J = 8.5 Hz, 2H), 7.87 (d, J = 8.5 Hz, 2H), 7.97−7.99 (m, 2H), 9.25 (s, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.8, 67.5, 115.8, (d, J_{CF} = 25.0 Hz), 119.5, 119.7, 126.7, 127.3 (d, J_{CF} = 12.5 Hz), 135.1, 146.3, 148.1, 161.9 (d, J_{CF} = 250.0 Hz). HRMS m/z (ESI): calcd for $C_{16}H_{15}FN_3O$ $[M + H]^+$ 284.1121, found 284.1126.

1-(4-(4-(Pyridin-2-yl)-1H-1,2,3-triazol-1-yl)phenyl)ethanol (Scheme 3, ***18d****).* Yellow amorphous solid, 119 mg, yield 90%. Mp: 175−177 °C. IR (ν_{max}): 3442, 2310, 1628, 1226 cm^{-1}. ^{1}H NMR (DMSO-d_6, 500 MHz) δ (ppm): 1.37 (d, J = 6.5 Hz, 3H), 4.82 (q, J = 6.5 Hz, 1H), 5.36 (bs, 1H), 7.36−7.38 (m, 1H), 7.57 (t, J = 8.5 Hz, 2H), 7.91 (dt, J = 8.0, 2.0 Hz, 3H), 8.12 (d, J = 8.0 Hz, 1H), 8.64 (d, J = 4.0 Hz, 1H), 9.28 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 125 MHz) δ (ppm): 25.8, 67.6, 119.8, 119.9, 121.2, 123.3, 126.6, 135.1, 137.3, 148.1, 148.2, 148.6, 149.6. HRMS m/z (ESI): calcd for $C_{15}H_{13}N_4NaO$ $[M + Na]^+$ 288.0987, found 288.0988.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Figures giving NMR spectra of a few starting materials, known compounds, and all of the unknown compounds. 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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