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Metal-Free Decarboxylative Trichlorination of Alkynyl Carboxylic Acids: Synthesis of Trichloromethyl Ketones.

Aravindan Jayaraman, Eunjeong Cho, Francis Mariaraj Irudayanathan, Jimin Kim, Sunwoo Lee*

Department of Chemistry, Chonnam National University, Gwangju 500-757, Republic of Korea
Fax: (+82) 62-530-3389
E-mail: sunwoo@chonnam.ac.kr

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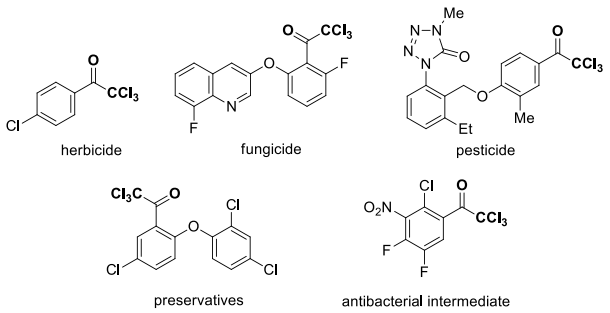
Abstract. 2,2,2-Trichloroacetophenone derivatives were synthesized via decarboxylative trichlorination from arylpropiolic acids and trichloroisocyanuric acid (TCCA). The reaction was performed in the presence of water at room temperature, and the desired products were obtained in good yields. The reaction showed good functional group tolerance towards halides, cyano, nitro, ketone, ester and aldehyde groups. In addition, the 2,2,2-trichloroacetophenone derivatives were readily transformed into esters, amides, and hydrazides. Based on experiments with $H_2{}^{18}O$ (water-^{18}O), we proposed a cationic reaction pathway as the mechanism and suggested two different pathways for producing aryl- and alkyl-substituted propiolic acids

Keywords: Metal-free; propiolic acid; trichloroisocyanuric acid; room temperature; trichloromethyl ketone;

Introduction

Trichloromethyl ketones have received considerable attention as key structures in various bioactive compounds such as agricultural herbicides, fungicides, and pesticides (Figure 1),[1] and have been used as valuable building blocks in organic syntheses. In addition, they can be employed as acyl chloride surrogates, because they are stable, not sensitive to moisture, and are readily purified by column chromatography.[2]

Figure 1. Bioactive 2,2,2-trichloroacetophenone derivatives.



Although they contain potentially reactive functional groups and have a variety of potential applications, their general preparation methods have not been well established. Oxidation of 1-aryl or 1-alkyl 2,2,2-trichloroethanol, which is prepared from the reaction of an aldehyde with sodium trichloroacetate or chloroform, was reported (Scheme 1a).[3] Togo reported that Grignard reagents react with chloral followed by reaction with tBuOCl to produce trichloromethyl ketones (Scheme 1b).[4] One example of a palladium-catalyzed coupling reaction with phenyl boronic acid and trichloroacetonitrile has also been reported (Scheme 1c).[5] However, these methods have disadvantages such as the requirement of inert conditions, lack of functional group tolerance, and harsh reaction conditions.

As part of our ongoing interest in decarboxylative reactions of propiolic acid derivatives, we found that 2,2,2-trichloroacetophenone formed when phenylpropiolic acid was reacted with trichloroisocyanuric acid (TCCA). TCCA is a commonly used chlorinating agent[6] and has several advantages such as low cost, commercial availability, stability, and easy handling.[7] Thus, we envision that this transformation could be useful in providing a variety of 2,2,2-trichloroacetophenone derivatives because diverse aryl propiolic acid derivatives can be readily prepared from aryl halides and propiolic acid.[8] Herein, we report a simple and mild synthetic method for the preparation of 2,2,2-trichloroacetophenones from decarboxylative trichlorination of aryl propiolic acids.

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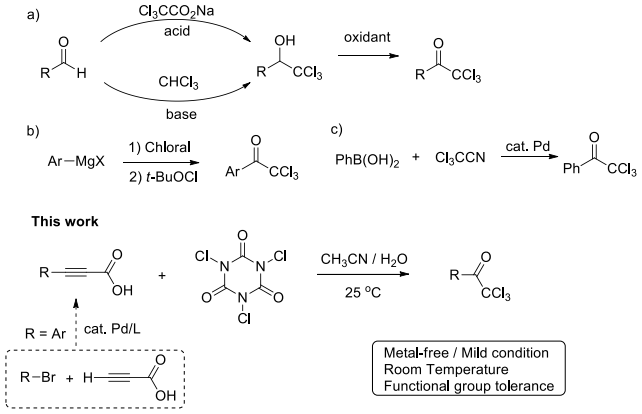
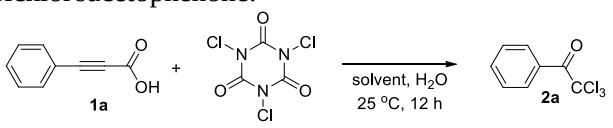


Scheme 1. Synthesis of 2,2,2-trichloroacetophenones.

Results and Discussion

Phenylpropiolic acid was reacted with TCCA in CH_3CN/H_2O at room temperature. We first employed metal catalysts which have shown good activty towards decarboxylative couplings. The reactions using $Pd(OAc)_2$ and $Pd(PPh_3)_2Cl_2$ afforded 2,2,2-trichloroacetophenone **(2a)** in 37% and 45% yields, respectively (entries 1 and 2). Other metal catalysts such as CuI, AgOAc, and $Ni(acac)_2$ gave the desired products in moderate yields (entries 3 – 5). Surprisingly, **2a** was formed with 61% yield in the absence of a metal catalyst (entry 6). When the reaction was conducted in the absence of H_2O, a trace amount of the desired product was formed (entry 7). When the amount of H_2O was increased to 16 equiv, the product yield reached 86% (entry 8). Ether-type solvents such as THF and 1,4-dioxane gave unsatisfactory results (entries 9 and 10). When the reaction was conducted in DMSO, the products‘ yield was very poor because of heating in the reaction mixture (entry 11). In DMF and DMAc, the desired products were obtained in good yields, but were lower than that obtained in CH_3CN (entry 12 and 13).

Table 1. Optimization of the synthesis of 2,2,2-trichloroacetophenone.[a]

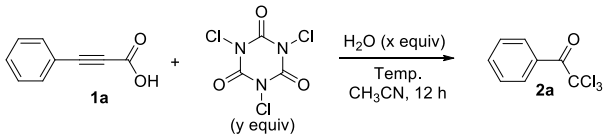


Entry	Solvent	catalyst	H_2O (equiv)	**2a** Yield (%)[b]
1	CH_3CN	$Pd(OAc)_2$	6.0	37
2	CH_3CN	$Pd(PPh_3)_2Cl_2$	6.0	45
3	CH_3CN	CuI	6.0	41
4	CH_3CN	AgOAc	6.0	49
5	CH_3CN	$Ni(acac)_2$	6.0	40
6	CH_3CN	-	6.0	61
7	CH_3CN	-	-	trace
8	CH_3CN	-	16.0	86
9	THF	-	16.0	37
10	1,4-dioxane	-	16.0	58
11[c]	DMSO	-	16.0	trace
12[c]	DMF	-	16.0	81
13[c]	DMAc	-	16.0	72

[a]*Reaction conditions:* **1a** (0.3 mmol) and TCCA (0.3 mmol) were reacted with H_2O (x equiv) in solvent (1.0 mL) at 25 °C. [b]Determined by gas chromatography (GC) with an internal standard. [c]Reaction temperature: 0 °C to 25 °C

To improve the product yield, we further studied the amount of water and TCCA used as well as reaction temperature effects. The results of these investigations are summarized in Table 2. The reactions performed with 16.0 equiv of water provided maximized **2a** yields (entries 1 – 6). When 1.1 equiv of TCCA was used, the product yield increased to 89% (entry 7). However, when that amount was increased to 1.2 and 1.5 equiv of TCCA, the product yields decreased to 73% and 67%, respectively (entries 8 and 9). Increasing the reaction temperature to 50 and 80 °C did not give satisfactory results (entries 10 and 11). Based on these results, the optimized condtions are as follows: alkynyl carboxylic acid (1.0 equiv), TCCA (1.1 equiv) and H_2O (16.0 equiv) reacted in CH_3CN at 25 °C for 12h.

Table 2. The effect of the amount of water, TCCA and temperature.[a]



Entry	H_2O (x equiv)	TCCA (y equiv)	Temp. (°C)	**2a** Yield (%)[b]
1	2.0	1.0	25	13
2	4.0	1.0	25	33
3	10.0	1.0	25	75
4	14.0	1.0	25	79
5	25.0	1.0	25	75
6	30.0	1.0	25	60
7	16.0	1.1	25	89
8	16.0	1.2	25	73
9	16.0	1.5	25	67
10	16.0	1.1	50	77
11	16.0	1.1	80	52

[a]*Reaction conditions:* **1a** (0.3 mmol) and TCCA (y equiv) were reacted with H_2O (x equiv) in CH_3CN (1.0 mL). [b]Determined by gas chromatography with an internal standard.

Next the substrate scope was evaluated and various aryl propiolic acids were tested, and the results are summarized in Table 3. As expected, 2,2,2-trichloroacetophenone (**2a**) was obtained in 89% isolated yield from phenylpropiolic acid (**1a**). Phenylpropiolic acids with halides such as chloride, bromide, and fluoride were transformed into the corresponding 2,2,2-trichloroacetophenone derivatives **2b**, **2c**, **2d**, **2e**, **2f**, and **2g** in 63%, 70%, 61%, 75%, 68% and 72% yields, respectively. Trifluoromethyl-substituted propiolic acid gave the desired product **2h** with 68% yield. Arylpropiolic acids containing carbonyl derivative groups such as cyano, ketone, and ester moieties provided the desired products **2i**, **2j**, and **2k** in good yields. However, arylpropiolic acid with an aldehyde group afforded **2l** in 42% yield. 1-Naphthyl- and 4’-biphenyl propiolic acids afforded **2m** and **2n** in 51% and 57% yields, respectively. 3-(Thiophen-2-yl)propiolic acid

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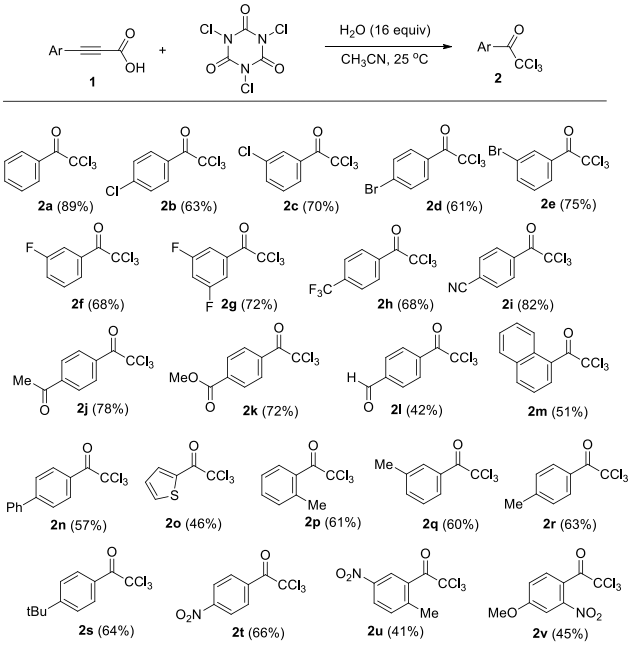
provided **2o** in 46% yield. *Ortho*-, *meta*-, and *para*-methyl-substituted phenylpropiolic acids showed similar reactivities in the transformation, and gave 2,2,2-trichloroacetophenone derivatives **2p**, **2q**, and **2r** in 61%, 60%, and 63% yields, respectively. 3-(4-*tert*-Butyl)phenylpropiolic acid gave the desired product **2s** in 64% yield. The nitro-substituted phenylpropiolic acids were transformed into the desired products **2t**, **2u**, and **2v** in 66%, 41%, and 45% yields, respectively.

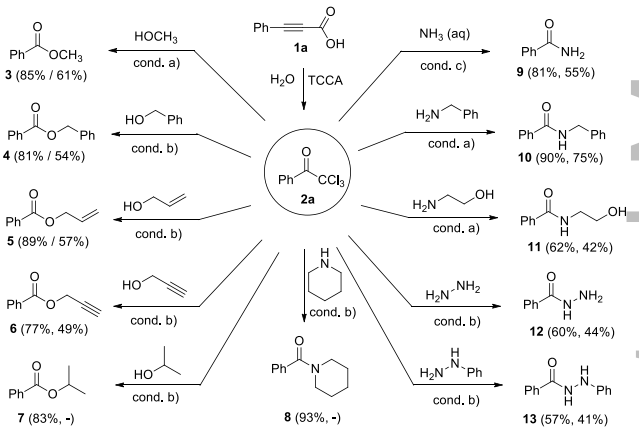
Table 3. Synthesis of 2,2,2-trichloromethyl ketone derivatives.[a]



[a]*Reaction conditions*: **1** (2.0 mmol), TCCA (2.2 mmol), and H_2O (32.0 mmol) were reacted in CH_3CN (5.0 mL) at 25 °C for 12 h. The numbers in parentheses are isolated yields.

Based on the obtained results, we can arrive at the following conclusions: 1) the electronic properties of the substituents on the phenyl ring affected the transformation, and aryl propiolic acids with electron-withdrawing groups afforded the desired products in good yields. For starting materials with electron-donating groups, the product yield depended on the substituent. Alkyl-substituents on the phenyl ring afforded the desired products in moderate yields. However, we failed to obtain the desired product for precursors with methoxy-substituents; 2) no steric effects were observed in this transformation; 3) the tolerance of other carbonyl substituents, such as ketone, ester, and aldehyde, provided an opportunity for further transformation; 4) tolerated halide functionalities could be used as coupling partners in metal-catalyzed cross coupling reactions; and 5) trichloromethyl ketones were readily purified by column chromatography on silica gel and were stable toward moisture at room temperature. However, we found that hydrolysis took place when it was allowed to react with water at high temperatures. (>80 °C)

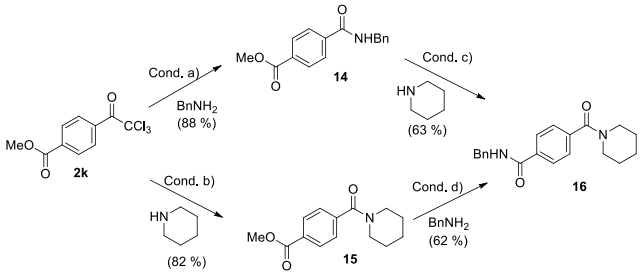
Aryl esters and amides are important core structures in organic synthesis and they can be prepared via acyl substitution reactions. Specifically, esters are easily prepared and stable, and can be readily transformed into other carbonyl-containing compounds.[9] Amides are key functional groups in biomolecules.[10] Numerous synthetic methods for the preparation of esters and amides have been developed. Among them, the substitution of acyl halides with alcohols or amines are the most straightforward, due to the high reactivity of the acyl halides. However, the use of acyl chlorides has some drawbacks such as instability and moisture sensitivity. As an alternative reagent and surrogate, we used 2,2,2-trichloromethyl ketones in acyl substitution reactions. As shown in Scheme 2, a number of alcohols, amines, and hydrazines reacted with trichloroacetophenone. The reactions with methanol, benzyl alcohol, allyl alcohols, propargyl alcohols, and isopropanol provided esters **3**, **4**, **5**, **6**, and **7** in good yields. The reaction with ammonia gave benzamide **9** in 81% yield. Secondary and primary amines afforded amides **8** and **10** in good yields. As expected, an amino alcohol afforded **11** in 62% yield. Hydrazines afforded **12** and **13** in good yields. When the acyl substitution reactions were sequentially conducted with phenylpropiolic acid, the desired esters, amides, and hydrazides were formed, although their yields were a bit lower than those of the direct substitution reactions.



Scheme 2. Transformations of 2,2,2-trichloroacetophenone. Conditions: a) Et_3N, 50 °C, THF; b) DBU, 30 °C, THF; c) 25 °C, THF. The numbers in parentheses are the isolated yields (yield from **2a** / yield of sequential reaction from **1a**).

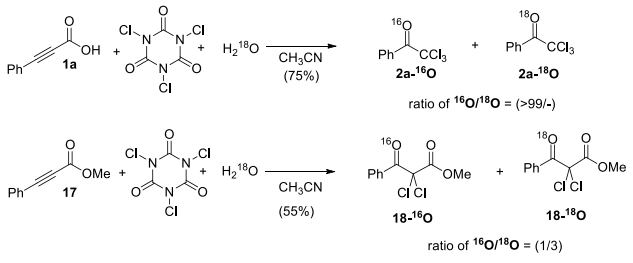
To evaluate the reactivity of 2,2,2-trichloromethyl ketones in acyl substitution reactions, **2k** was allowed to react with piperidine or benzylamine. As shown in Scheme 3, substituted amides **14** and **15** bearing methyl esters were formed in 88%, and 82% yields, respectively. Primary and secondary amines were not substituted at the ester, but instead at the trichloromethyl ketone group. These results revealed that the trichloromethyl ketone group was more reactive than the esters in the acyl substitution reaction. This selectivity allowed for further transformation at the ester group. Finally,

unsymmetrically substituted diamide **16** was obtained from **14** and **15** using the developed procedure.



Scheme 3. Synthesis of unsymmetrically substituted diamide. Conditions: a) DBU, 25 °C, toluene; b) KOtBu, 30 °C, THF; C) NaOMe, 80 °C, piperidine (neat); d) NaOMe, 60 °C, benzylamine (neat). The numbers in parentheses are the isolated yields.

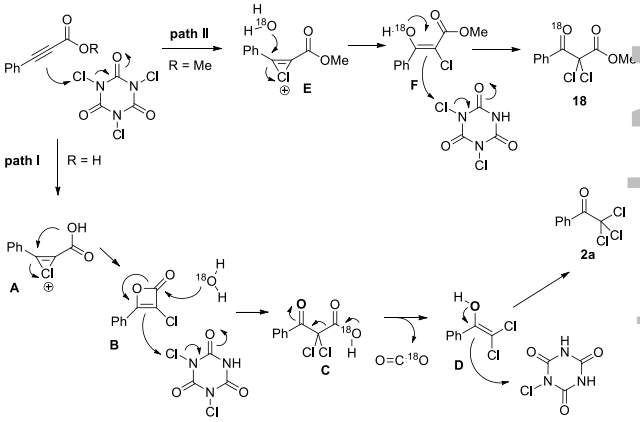
To study the reaction pathway, phenylpropiolic acid and methyl phenylpropiolate were independently allowed to react with water bearing oxygen-18 ($H_2{}^{18}O$) in the presence of TCCA, as shown in Scheme 4. In the case of the reaction between **1a** and $H_2{}^{18}O$, the exact mass for 2,2,2-trichloroacetophenone bearing oxygen-18 was not found in the measured high-resolution mass spectrometry (HRMS). HRMS revealed a molecular mass of 222.9484, which is the exact molecular mass of **2a** ($C_8H_5Cl_3O$, m/z calculated for $[M+H]^+$: 222.9484) with oxygen-16. When methyl phenylpropiolate **17** was reacted with $H_2{}^{18}O$, dichlorinated product **18** was formed in 55% yield. A molecular mass of 248.9974 was observed in HRMS, which corresponded to $C_{10}H_8Cl_2{}^{16}O_2{}^{18}O$ (m/z calculated for $[M+H]^+$: 248.9971). Analysis of the HRMS data revealed that the ratio of **18-^{16}O** to **18-^{18}O** was 1:3, suggesting that water reacts differently in these two reactions. When phenylacetylene was employed in the reaction with TCCA and $H_2{}^{18}O$, 2,2-dichloroacetophenone with incorporated oxygen-18 was found in HRMS. ($C_8H_7Cl_2{}^{18}O$, m/z calculated for $[M+H]^+$: 190.9909, found : 190.9850).



Scheme 4. Determination of the role of water in the developed reaction.

When phenylpropiolic acid and TCCA were reacted in the presence of the radical scavenger BHT (2,6-di-*tert*-butyl-4-methylphenol) with 1.0 and 3.0 equiv, the product yields were 65% and 60%, respectively. These results indicate that cationic chloride is likely involved in the major reaction pathway in this synthetic process.

Based on our results, we propose two different reaction pathways, as shown in Scheme 5. Phenylproiolic acid could react with TCCA to generate alkenyl chloronium intermediate **A**, which is followed by intramolecular cyclization to provide cyclic ester **B**. Nucleophilic attack by water on the carbonyl carbon of ester **B** would drive the ring opening. Further reaction with dichlorocyanuric acid would produce the dichlorinated intermediate **C**. Subsequent decarboxylation would give dichlrovinyl alcohol **D**, which would then react with monochlorocyanuric acid to give the desired 2,2,2-trichloroacetophenone. Reaction pathway **I** was supported by the lack of formation of **2a-^{18}O**, because the oxygen from water could be released as carbon dioxide via decarboxylation. In the case of the reaction with methyl phenylpropiolate, water could add to alkenyl chloronium intermediate **E** to give monochlorinated **F**. Then reaction with dichlorocyanuric acid would provide **18**. In this pathway, the oxygen originating from the water molecule remains in the final product.

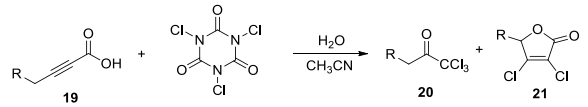


Scheme 5. Proposed reaction pathway for aryl-substituted propiolic acid and ester.

To expand this methodology toward alkyl-substituted propiolic acids, we employed 2-octynoic, 2-hexynoic, and 2-pentynoic acids. The results are summarized in Table 4. When 2-octynoic acid was allowed to react with TCCA under the optimized conditions, 1,1,1-trichloroheptan-2-one (**20a**) and dichlorinated furanone **21a** were obtained in 25% and 21% yields, respectively. In addition, unidentified mixtures were detected by GC-MS (entry 1). However, trichloroacetyl compounds could not be obtained from 2-hexynoic and 2-pentynoic acids. Based on GC-MS analysis, dichlorinated lactones **21b**

and **21c** were isolated in 15% and 12% yields, respectively (entries 2 and 3).

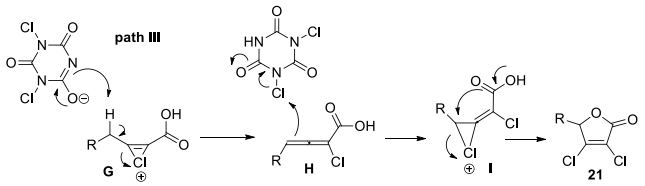
Table 4. Reaction of alkyl-substituted propiolic acids and TCCA.[a]



Entry	Propiolic acid		Product (yield)	
1	**19a**	R = n-C_4H_9	**20a** (25%)	**21a** (21%)
2	**19b**	R = C_2H_5	**20b** (-)	**21b** (15%)
3	**19c**	R = CH_3	**20c** (-)	**21c** (12%)

[a]*Reaction conditions:* **19** (2.0 mmol), TCCA (2.0 mmol), and H_2O (32.0 mmol) were reacted in CH_3CN (5.0 mL) at 25 °C for 6 h. The numbers in parentheses are the isolated yields.

To explain the formation of dichlorinated furanone **21**, we proposed reaction pathway **III**, as shown in Scheme 6. Alkyl-substituted propiolic acid produced the alkenyl chlorinium intermediate **G**. The dichlorocyanuric acid abstracts a proton from **G** to give the allenic intermediate **H**, which further reacts with dichlorocyanuric acid to afford the cyclic chlorinium intermediate **I**. Finally, cyclization of the carboxylic acid produces dichlorofuranone **21.**



Scheme 6. Proposed reaction pathway for alkyl-substituted propiolic acid.

Conclusion

In summary, we developed a novel synthetic method for the preparation of 2,2,2-trichloroacetophenones from arylpropiolic acids and trichloroisocyanuric acid. This reaction was conducted at room temperature in the absence of metal catalyst and showed good functional group tolerance towards halide, cyano, nitro, ketone, and ester groups. We demonstrated that 2,2,2-trichloroacetophenones could be easily transformed into their corresponding esters, amides, and hydrazides. In addition, trichloromethyl ketones showed higher reactivities in the acyl substitution reaction than the esters. Based on the experimental results obtained using $H_2{}^{18}O$, we proposed a mechanism for the formation of intermediate **B**, 3-chloro-2H-oxet-2-one. Although alkyl-substituted propiolic acids resulted in low or no yields of the trichloroacetyl compounds, dichlorofuranones were successfully obtained.

Experimental Section

Experimental Procedure 1: To a 20-mL screw cap vial added aryl propiolic acid (2.0 mmol, 1.0 equiv), trichloroisocyanuric acid (511 mg, 2.2 mmol, 1.1 equiv) and water (576 mg, 32.0 mmol, 16.0 equiv) in acetonitrile (5.0 mL). The solution was stirred at 25 °C for 12 h. The resulting mixture charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing the EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to obtain the desired product.

2,2,2-Trichloro-1-phenylethanone (**2a**)[11] : Phenylpropiolic acid (292 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-phenylethanone (**2a**) (398 mg, 1.78 mmol, 89% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.26 (d, *J* = 7.4 Hz, 2H), 7.64 (t, *J* = 7.5 Hz, 1H), 7.50 (t, *J* = 7.5 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 181.2, 134.3, 131.5, 129.1, 128.4, 95.4; HRMS (FAB) m/z cacld. for $C_8H_5Cl_3O$ $[M+H]^+$: 222.9484, found: 222.9482.

2,2,2-Trichloro-1-(4-chlorophenyl)ethanone (**2b**)[11] : 3-(3-chlorophenyl)propiolic acid (361 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(4-chlorophenyl)ethanone (**2b**) (325 mg, 1.26 mmol, 63% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.20 (s, 1H), 8.14 (d, *J* = 8.0 Hz, 1H), 7.61 (d, *J* = 8.0 Hz, 1H), 7.44 (t, *J* = 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 180.1, 134.7, 134.2, 131.3, 130.7, 129.6, 129.4, 94.9; HRMS (FAB) m/z cacld. for $C_8H_4Cl_4O$ $[M+H]^+$: 256.9095, found: 256.9095.

2,2,2-trichloro-1-(3-chlorophenyl)ethanone (**2c**) : 3-(3-chlorophenyl)propiolic acid (361 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(3-chlorophenyl)ethanone (**2c**) (361 mg, 1.4 mmol, 70% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.20 (s, 1H), 8.14 (d, *J* = 8.0 Hz, 1H), 7.61 (d, *J* = 8.0 Hz, 1H), 7.44 (t, *J* = 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 180.1, 134.7, 134.2, 131.3, 130.7, 129.6, 129.4, 94.9; HRMS (FAB) m/z cacld. for $C_8H_4Cl_4O$ $[M+H]^+$: 256.9095, found: 256.9095.

1-(4-Bromophenyl)-2,2,2-trichloroethanone (**2d**)[12] : 3-(4-Bromophenyl)propiolic acid (450 mg, 2.0 mmol) afforded 1-(4-bromophenyl)-2,2,2-trichloroethanone (**2d**) (369 mg, 1.22 mmol, 61% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.9 Hz, 2H), 7.64 (d, *J* = 9.0 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 180.4, 132.9, 131.8, 129.9, 127.8, 95.1; HRMS (FAB) m/z cacld. for $C_8H_4BrCl_3O$ $[M+H]^+$: 300.8589, found: 300.8589.

1-(3-Bromophenyl)-2,2,2-trichloroethanone (**2e**) : 3-(3-Bromophenyl)propiolic acid (450 mg, 2.0 mmol) afforded 1-(3-bromophenyl)-2,2,2-trichloroethanone (**2e**) (453 mg, 1.5 mmol, 75% yield) as a colorless liquid; ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.35 (s, 1H), 8.19 (d, *J* = 6.7 Hz, 1H), 7.75 (d, *J* = 8.0 Hz, 1H),

7.38 (t, J = 8.0 Hz, 1H); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 180.0, 137.0, 134.1, 130.9, 129.8, 122.5, 94.8; HRMS (FAB) m/z cacld. for $C_8H_4BrCl_3O$ $[M+H]^+$: 300.8589, found: 300.8589.

1-(3-Fluorophenyl)-2,2,2-trichloroethanone (**2f**) : 3-(3-Fluorophenyl)propiolic acid (328 mg, 2.0 mmol) afforded 1-(3-fluorophenyl)-2,2,2-trichloroethanone (**2f**) (338 mg, 1.36 mmol, 68% yield) as a colorless liquid; ^1H NMR (600 MHz, $CDCl_3$) δ 8.05-8.07 (m, 1H), 7.92-7.95 (m, 1H), 7.47-7.51 (m, 1H), 7.33-7.37 (m, 1H); $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 182.7 (d, J_{C-F} = 2.5 Hz), 164.6 (d, J_{C-F} = 246.8 Hz), 133.5 (d, J_{C-F} = 7.0 Hz), 132.7 (d, J_{C-F} = 7.7 Hz), 129.8 (d, J_{C-F} = 3.2 Hz), 124.0 (d, J_{C-F} = 21.2 Hz), 120.9 (d, J_{C-F} = 23.9 Hz), 97.5; HRMS (FAB) m/z cacld. for $C_8H_4FCl_3O$ $[M+H]^+$: 240.9390, found: 240.9392.

2,2,2-Trichloro-1-(3,5-difluorophenyl)ethanone (**2g**) : 3-(3,5-Difluorophenyl)propiolic acid (364.2 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(3,5-difluorophenyl)ethanone (**2g**) (373.6 mg, 1.44 mmol, 72% yield) as a colorless liquid; ^1H NMR (500 MHz, $CDCl_3$) δ 7.80-7.75 (m, 2H), 7.13-7.08 (m, 1H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 179.1 (t, J_{C-F} = 2.8 Hz), 163.4 (d, J_{C-F} = 11.9 Hz), 161.4 (d, J_{C-F} = 11.9 Hz), 131.8 (t, J_{C-F} = 8.7 Hz), 114.7 (d, J_{C-F} = 7.1 Hz), 114.5 (d, J_{C-F} = 7.1 Hz), 109.8 (t, J_{C-F} = 25.1 Hz), 94.5; HRMS (FAB) m/z cacld. for $C_8H_3Cl_3F_2O$ $[M]^+$: 257.9218, found: 257.9221.

2,2,2-Trichloro-1-(4-(trifluoromethyl)phenyl)ethanone(2h)[11] : 3-(4-Trifluoromethyl)propiolic acid (428 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(4-(trifluoromethyl)phenyl)ethanone (**2h**) (396 mg, 1.36 mmol, 68% yield) as a colorless liquid; ^1H NMR (500 MHz, $CDCl_3$) δ 8.37 (d, J = 8.2 Hz, 2H), 7.77 (d, J = 8.3 Hz, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.5, 135.3 (q, J_{C-F} = 32.9 Hz), 132.3 (d, J_{C-F} = 1.0 Hz), 131.7, 125.5 (q, J_{C-F} = 3.7 Hz), 123.2 (q, J_{C-F} = 271.4 Hz), 94.8; HRMS (FAB) m/z cacld. for $C_8H_4Cl_3F_3O$ $[M+H]^+$: 290.9358, found: 290.9358.

4-(2,2,2-Trichloroacetyl)benzonitrile (**2i**) : 3-(4-Cyanophenyl)propiolic acid (342 mg, 2.0 mmol) afforded 4-(2,2,2-trichloroacetyl)benzonitrile (**2i**) (408 mg, 1.64 mmol, 82% yield) as a colorless liquid; ^1H NMR (500 MHz, $CDCl_3$) δ 8.34 (d, J = 8.8 Hz, 2H), 7.80 (d, J = 8.8 Hz, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.2, 132.8, 132.1, 131.7, 117.4, 117.4, 94.5; HRMS (FAB) m/z cacld. for $C_9H_4Cl_3NO$ $[M+H]^+$: 247.9437, found: 247.9439.

1-(4-Acetylphenyl)-2,2,2-trichloroethanone (**2j**) : 3-(4-Acetylphenyl)propiolic acid (376 mg, 2.0 mmol) afforded 1-(4-acetylphenyl)-2,2,2-trichloroethanone (**2j**) (414 mg, 1.56 mmol, 78% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.32 (d, J = 8.9 Hz, 2H), 8.04 (d, J = 8.9 Hz, 2H), 2.66 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 197.0, 180.9, 140.7, 132.8, 131.6, 128.0, 95.0, 26.9; HRMS (FAB) m/z cacld. for $C_{10}H_7Cl_3O_2$ $[M+H]^+$: 264.9590, found: 264.9589.

Methyl 4-(2,2,2-trichloroacetyl)benzoate (**2k**) : 3-(4-(Methoxycarbonyl)phenyl)propiolic acid (563 mg, 2.0 mmol) afforded methyl 4-(2,2,2-trichloroacetyl)benzoate (**2k**) (405 mg, 1.44 mmol, 72% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.29 (d, J = 8.9 Hz, 2H), 8.14 (d, J = 8.9 Hz, 2H), 3.97 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.9, 165.8, 134.7, 132.8, 131.3, 129.4, 95.0, 52.6; HRMS (FAB) m/z cacld. for $C_{10}H_7Cl_3O_3$ $[M+H]^+$: 280.9539, found: 280.9540.

4-(2,2,2-trichloroacetyl)benzaldehyde (**2l**) : 3-(4-formylphenyl)propiolic acid (348 mg, 2.0 mmol) afforded 4-(2,2,2-trichloroacetyl)benzaldehyde (**2l**) (211 mg, 0.84 mmol, 42% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 10.13 (s, 1H), 8.39 (d, J = 8.3 Hz, 2H), 8.01 (d, J = 8.8 Hz, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 191.2, 180.9, 139.4, 134.0, 131.9, 129.3, 94.8; HRMS (FAB) m/z cacld. for $C_9H_5Cl_3O_2$ $[M+H]^+$: 250.9433, found: 250.9433.

2,2,2-Trichloro-1-(naphthalen-1-yl)ethanone (**2m**)[1] : 3-(Naphthalen-1-yl)propiolic acid (392.4 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(naphthalen-1-yl)ethanone (**2m**) (279 mg, 1.02 mmol, 51% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.16 (d, J = 7.3 Hz, 1H), 8.04 (d, J = 8.3 Hz, 1H), 7.98 (d, J = 7.7 Hz, 1H), 7.91 (d, J = 7.4 Hz, 1H), 7.61 (t, J = 6.9 Hz, 1H), 7.57 (t, J = 6.8 Hz, 1H), 7.52 (t, J = 7.3 Hz, 1H); $^{13}C\{^1H\}$ NMR (151 MHz, $CDCl_3$) δ 186.0, 133.5, 132.6, 131.0, 129.9, 128.6, 128.0, 127.3, 126.7, 125.1. 123.8, 96.1; HRMS (FAB) m/z cacld. for $C_{12}H_7Cl_3O_3$ $[M+H]^+$: 272.9641, found: 272.9642.

1-([1,1'-Biphenyl]-4-yl)-2,2,2-trichloroethanone (**2n**) : 3-([1,1'-Biphenyl]-4-yl)propiolic acid (444 mg, 2.0 mmol) afforded 1-([1,1'-biphenyl]-4-yl)-2,2,2-trichloroethanone (**2n**) (342 mg, 1.14 mmol, 57% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.35 (d, J = 8.9 Hz, 2H), 7.72 (d, J = 8.9 Hz, 2H), 7.64-7.67 (m, 2H), 7.50 (t, J = 7.2 Hz, 2H), 7.44 (t, J = 7.4 Hz, 1H); $^{13}C\{^1H\}$ (125 MHz, $CDCl_3$) δ 180.8, 147.0, 139.3, 132.2, 129.1, 128.7, 127.6, 127.3, 127.0, 95.5; HRMS (FAB) m/z cacld. for $C_{14}H_9Cl_3O$ $[M+H]^+$: 298.9797, found: 298.9797.

2,2,2-Trichloro-1-(thiophen-2-yl)ethanone (**2o**)[11] : 3-(Thiophen-2-yl)propiolic acid (304 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(thiophen-2-yl)ethanone (**2o**) (211 mg, 0.92 mmol, 46% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.17 (dd, J = 4.0, 1.1 Hz, 1H), 7.80 (dd, J = 5.0, 1.1 Hz, 1H), 7.20 (dd, J = 5.0, 4.0 Hz, 1H); $^{13}C\{^1H\}$ (125 MHz, $CDCl_3$) δ 175.1, 137.1, 136.7, 134.0, 128.4, 95.0; HRMS (FAB) m/z cacld. for $C_6H_3Cl_3OS$ $[M+H]^+$: 228.9048, found: 228.9048.

2,2,2-Trichloro-1-(o-tolyl)ethanone (**2p**)[11] : 3-(o-Tolyl)propiolic acid (320 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(o-tolyl)ethanone (**2p**) (290 mg, 1.22 mmol, 61% yield); ^1H NMR (500 MHz, $CDCl_3$) δ

7.91 (d, *J* = 7.9 Hz, 1H), 7.44 (t, *J* = 7.6 Hz, 1H), 7.33 (d, *J* = 7.7 Hz, 1H), 7.27 (t, *J* = 6.6 Hz, 1H), 2.43 (s, 3H); $^{13}C\{^1H\}$ (125 MHz, $CDCl_3$) δ 186.1, 138.7, 132.2, 131.7, 131.5, 128.3, 125.1, 96.0, 20.7; HRMS (FAB) m/z cacld. for $C_9H_7Cl_3O$ $[M+H]^+$: 236.9641, found: 236.9641.

2,2,2-Trichloro-1-(m-tolyl)ethanone (**2q**)[11] : 3-(m-Tolyl)propiolic acid (320 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(m-tolyl)ethanone (**2q**) (285 mg, 1.2 mmol, 60% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, *J* = 7.9 Hz, 1H), 8.04 (s, 1H), 7.44 (d, *J* = 7.6 Hz, 1H), 7.38 (t, *J* = 7.7 Hz, 1H), 2.44 (s, 3H); $^{13}C\{^1H\}$ (125 MHz, $CDCl_3$) δ 181.5, 138.4, 135.1, 132.0, 129.1, 128.6, 128.2, 95.6, 21.4; HRMS (FAB) m/z cacld. for $C_9H_7Cl_3O$ $[M+H]^+$: 236.9641, found: 236.9641.

2,2,2-Trichloro-1-(p-tolyl)ethanone (**2r**)[11] : 3-(p-Tolyl)propiolic acid (320 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(p-tolyl)ethanone (**2r**) (299 mg, 1.26 mmol, 63% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.17 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.7, 2H), 2.44 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.9, 145.6, 131.7, 129.1, 126.2, 95.6, 21.8; HRMS (FAB) m/z cacld. for $C_9H_7Cl_3O$ $[M+H]^+$: 236.9641, found: 236.9641.

1-(4-(Tert-butyl)phenyl)-2,2,2-trichloroethanone (**2s**)[13] : 3-(4-(Tert-butyl)phenyl)propiolic acid (404 mg, 2.0 mmol) afforded 1-(4-(tert-butyl)phenyl)-2,2,2-trichloroethanone (**2s**) (358 mg, 1.28 mmol, 64% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.22 (d, *J* = 9.0 Hz, 2H), 7.51 (d, *J* = 9.0 Hz, 2H), 1.36 (s, 9H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.8, 158.4, 131.7, 126.1, 125.5, 95.6, 35.3, 31.0; HRMS (FAB) m/z cacld. for $C_{12}H_{11}Cl_3O$ $[M+H]^+$: 279.0110, found: 279.0110.

2,2,2-Trichloro-1-(4-nitrophenyl)ethanone (**2t**)[12] : 3-(4-Nitrophenyl)propiolic acid (382 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(4-nitrophenyl)ethanone **(2t**) (354 mg, 1.32 mmol, 66% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.41 (d, *J* = 9.2 Hz, 2H), 8.34 (d, *J* = 9.1 Hz, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 180.1, 150.6, 134.5, 132.4, 123.5, 94.5; HRMS (FAB) m/z cacld. for $C_8H_4Cl_3NO_3$ $[M]^+$: 266.9257, found: 266.9257

2,2,2-Trichloro-1-(2-methyl-5-nitrophenyl)ethanone (**2u**) : 3-(2-methyl-5-nitrophenyl)propiolic acid (410 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(2-methyl-5-nitrophenyl)ethanone **(2u**) (232 mg, 0.82 mmol, 41% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 8.74 (d, *J* = 2.4 Hz, 1H), 8.29 (dd, *J* = 8.5, 2.4 Hz, 1H), 7.51 (d, *J* = 8.5 Hz, 1H), 2.51 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 184.3, 145.9, 145.3, 133.5, 132.4, 125.9, 123.2, 95.1, 20.9; HRMS (FAB) m/z cacld. for $C_9H_6Cl_3NO_3$ $[M+H]^+$: 281.9492, found: 281.9492.

2,2,2-Trichloro-1-(4-methoxy-2-nitrophenyl)ethanone (2v) : 3-(4-methoxy-2-nitrophenyl)propiolic acid (442 mg, 2.0 mmol) afforded 2,2,2-trichloro-1-(4-methoxy-2-nitrophenyl)ethanone **(2v**) (267 mg, 0.9 mmol, 45% yield); ^1H NMR (500 MHz, $CDCl_3$) δ 7.74 (d, *J* = 2.5 Hz, 1H), δ 7.58 (d, *J* = 8.5 Hz, 1H), 7.30 (dd, *J* = 8.6, 2.6 Hz, 1H), 3.95 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 186.3, 161.9, 147.4, 129.9, 122.5, 120.5, 109.3, 94.8, 56.3; HRMS (FAB) m/z cacld. for $C_9H_7Cl_3NO_4$ $[M+H]^+$: 297.9441, found: 297.9441.

Experimental Procedure 2 (Transformation of 2,2,2-trichloroacetophenone):

To a 20-mL screw cap vial added 2,2,2-trichloro-1-phenylethanone **(2a)** (1.5 mmol, 1.0 equiv), amine or alcohol (1.5 mmol, 1.0 equiv), Et_3N or DBU (1.5 mmol, 1.0 equiv), in THF (5.0 mL). The solution was stirred at 25-50 °C for 12 h. The resulting mixture charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing the EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give the desired product.

Methyl benzoate (**3**)[14] : Followed by procedure 2 with triethylamine (152 mg, 1.5 mmol, 1.0 equiv) and methanol (96 mg, 3.0 mmol, 2.0 equiv) afforded methyl benzoate (**3**) (174 mg, 1.28 mmol, 85%); ^1H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, *J* = 7.1 Hz, 2H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.43 (t, *J* = 8.0 Hz, 2H), 3.91 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 167.1, 132.9, 130.1, 129.5, 128.3, 52.1; MS (EI) m/z = 136 (M^+).

Benzyl benzoate (**4**)[15] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and benzyl alcohol (162 mg, 1.5 mmol, 1.0 equiv) afforded benzyl benzoate (**4**) (257 mg, 1.21 mmol, 81%); ^1H NMR (500 MHz, $CDCl_3$) δ 8.10-8.13 (m, 2H), 7.56-7.59 (m, 1H), 7.48-7.49 (m, 1H), 7.40-7.47 (m, 5H), 7.35-7.38 (m, 1H), 5.40 (s, 2H). $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 166.4, 136.1, 133.1, 130.2, 129.7, 128.6, 128.4, 128.3, 128.2, 66.7; MS (EI) m/z = 212 (M^+).

Allyl benzoate (**5**)[16] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and allyl alcohol (87 mg, 1.5 mmol, 1.0 equiv) afforded allyl benzoate (**5**) (215 mg, 1.33 mmol, 89%); ^1H NMR (500 MHz, $CDCl_3$) δ 8.06-8.08 (m, 2H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.43 (t, *J* = 7.4 Hz, 2H), 6.0-6.07 (m, 1H), 5.42 (dq, *J* = 17.2, 1.5 Hz, 1H), 5.29 (dq, *J* = 10.5, 1.3 Hz, 1H), 4.83 (dt, *J* = 5.7, 1.5 Hz, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 166.2, 133.0, 132.2, 130.1, 129.6, 128.4, 118.2, 65.5; MS (EI) m/z = 162 (M^+).

Prop-2-yn-1-yl benzoate (**6**)[16] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and propargyl alcohol (84 mg, 1.5 mmol, 1.0 equiv) afforded prop-2-yn-1-yl benzoate (**6**) (184 mg, 1.15

mmol, 77%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, *J* = 7.2 Hz, 2H), 7.57 (t, *J* = 7.5 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 2H), 4.92 (d, *J* = 2.5 Hz, 2H), 2.52 (t, *J* = 2.5 Hz, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 165.8, 133.3, 129.8, 129.4, 128.4, 77.7, 75.0, 52.5; MS (EI) m/z = 160 (M^+).

Isopropyl benzoate (7)[17] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and isopropyl alcohol (180 mg, 3.0 mmol, 2.0 equiv) afforded isopropyl benzoate (**7**) (203 mg, 1.24 mmol, 83%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, *J* = 7.1 Hz, 2H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.43 (t, *J* = 7.4 Hz, 2H), 5.26 (sept, *J* = 6.3 Hz, 1H), 1.37 (d, *J* = 6.3 Hz, 6H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 166.1, 132.7, 130.9, 129.5, 128.2, 68.3, 22.0; MS (EI) m/z = 164 (M^+).

Phenyl(piperidin-1-yl)methanone (**8**)[18] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and piperidine (128 mg, 1.5 mmol, 1.0 equiv) afforded phenyl(piperidin-1-yl)methanone (**8**) (263 mg, 1.39 mmol, 93%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37 (s, 5H), 3.69 (s, 2H), 3.32 (s, 2H), 1.65 (s, 4H), 1.49 (s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 170.3, 136.5, 129.3, 128.4, 126.8, 48.8, 43.1, 26.5, 25.6, 24.6; MS (EI) m/z = 189 (M^+).

Benzamide (**9**)[19] : Followed by procedure 2 with aq.ammonia (210 mg, 6.0 mmol, 4.0 equiv) afforded benzamide (**9**) (146 mg, 1.21 mmol, 81%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.82 (d, *J* = 7.2 Hz, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.44 (t, *J* = 7.4 Hz, 2H), 6.24 (br s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 169.7, 133.4, 132.0, 128.6, 127.3; MS (EI) m/z = 121 (M^+).

***N*-Benzylbenzamide** (**10**)[18] : Followed by procedure 2 with triethylamine (152 mg, 1.5 mmol, 1.0 equiv) and benzylamine (161 mg, 1.5 mmol, 1.0 equiv) afforded *N*-benzylbenzamide (**10**) (285 mg, 1.35 mmol, 90%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.79 (d, *J* = 7.1 Hz, 2H), 7.49 (t, *J* = 7.4 Hz, 1H), 7.42 (t, *J* = 7.8 Hz, 2H), 7.27-7.36 (m, 5H), 6.54 (s, 1H), 4.64 (d, *J* = 5.7 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 167.3, 138.1, 134.3, 131.5, 128.7, 128.5, 127.8, 127.5, 126.9, 44.1; MS (EI) m/z = 211 (M^+).

***N*-(2-Hydroxyethyl)benzamide** (**11**)[20] : Followed by procedure 2 with triethylamine (152 mg, 1.5 mmol, 1.0 equiv) and 2-aminoethanol (92 mg, 1.5 mmol, 1.0 equiv) afforded *N*-(2-hydroxyethyl)benzamide (**11**) (154 mg, 0.93 mmol, 62%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70-7.72 (m, 2H), 7.40 (t, *J* = 7.5 Hz, 1H), 7.34 (s, 1H), 7.29 (t, *J* = 7.4 Hz, 2H), 4.25 (s, 1H), 3.70 (t, *J* = 4.7 Hz, 2H), 3.49 (m, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 168.7, 133.9, 131.5, 128.4, 126.9, 61.5, 42.7; MS (EI) m/z = 165 (M^+).

Benzohydrazide (**12**)[21] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and hydrazine monohydrate (150 mg, 3.0 mmol, 2.0 equiv) afforded benzohydrazide (**12**) (122 mg, 0.9 mmol, 60%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.74-7.76 (m, 2H), 7.50 (t, *J* = 7.4 Hz, 1H), 7.41 (t, *J* = 7.8 Hz, 2H), 3.9 (br s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 168.7, 132.6, 131.9, 128.7, 126.9; MS (EI) m/z = 136 (M^+).

***N'*-Phenylbenzohydrazide** (**13**)[22] : Followed by procedure 2 with DBU (228 mg, 1.5 mmol, 1.0 equiv) and phenylhydrazine (162 mg, 1.5 mmol, 1.0 equiv) afforded *N'*-phenylbenzohydrazide (**13**) (181 mg, 0.85 mmol, 57%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.11 (s 1H), 7.83 (d, *J* = 7.5 Hz, 2H), 7.56 (t, *J* = 7.4 , 1H), 7.46 (t, *J* = 7.7 , 2H), 7.22-7,26 (m, 2H), 6.92 (t, *J* = 7.9, 3 H), 6.4 (s, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 167.8, 148.0, 132.3, 129.2, 128.8, 127.1, 121.5, 113.8; MS (EI) m/z = 212 (M^+).

Experimental Procedure 3 (Sequential reaction - transformation of 2,2,2- trichloroacetophenone):

To a 20-mL screw cap vial added phenyl propiolic acid (219 mg, 1.5 mmol, 1.0 equiv), trichloroisocyanuric acid (349 mg, 1.5 mmol, 1.0 equiv) and water (432 mg, 24.0 mmol, 16.0 equiv) in acetonitrile (4.0 mL). The solution was stirred at 25 °C for 12 h. Then charged amine or alcohol (3.0 mmol, 2.0 equiv) and Et_3N or DBU (3.0 mmol, 2.0 equiv). The solution was further stirred at 25 °C for 12 h. The resulting mixture charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing the EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give the desired product.

Methyl benzoate (**3**)[14] : Followed by procedure 3 with triethylamine (303 mg, 3.0 mmol, 2.0 equiv) and methanol (96 mg, 3.0 mmol, 2.0 equiv) afforded methyl benzoate (**3)** (124 mg, 0.91 mmol, 61%).

Benzyl benzoate (**4**)[15] : Followed by procedure 3 with DBU (457 mg, 3.0 mmol, 2.0 equiv) and benzyl alcohol (162 mg, 3.0 mmol, 2.0 equiv) afforded benzyl benzoate (**4**) (172 mg, 0.81 mmol, 54%).

Allyl benzoate (**5**)[16] : Followed by procedure 3 with DBU (457 mg, 3.0 mmol, 2.0 equiv) and allyl alcohol (87 mg, 3.0 mmol, 2.0 equiv) afforded allyl benzoate (**5**) (138 mg, 0.85 mmol, 57%).

Prop-2-yn-1-yl benzoate (**6**)[16] : Followed by procedure 3 with DBU (457 mg, 3.0 mmol, 2.0 equiv) and propargyl alcohol (84 mg, 3.0 mmol, 2.0 equiv) afforded prop-2-yn-1-yl benzoate (**6**) (117 mg, 0.73 mmol, 49%).

Benzamide (**9**)[19] : Followed by procedure 3 with aq.ammonia (210 mg, 6.0 mmol, 4.0 equiv) afforded benzamide (**9**) (99 mg, 0.82 mmol, 55%).

***N*-Benzylbenzamide** (**10**)[18] : Followed by procedure 3 with triethylamine (303 mg, 3.0 mmol, 2.0 equiv) and benzylamine (161 mg, 3.0 mmol, 2.0 equiv)

afforded *N*-benzylbenzamide (**10**) (238 mg, 1.13 mmol, 75%).

***N*-(2-Hydroxyethyl)benzamide** (**11**)[20] : Followed by procedure 3 with triethylamine (303 mg, 3.0 mmol, 2.0 equiv) and 2-aminoethanol (92 mg, 3.0 mmol, 2.0 equiv) afforded *N*-(2-hydroxyethyl)benzamide (**11**) (104 mg, 0.63 mmol, 42%).

Benzohydrazide (**12**)[21] : Followed by procedure 3 with DBU (457 mg, 3.0 mmol, 2.0 equiv) and hydrazine monohydrate (150 mg, 3.0 mmol, 2.0 equiv) afforded benzohydrazide (**12**) (90 mg, 0.66 mmol, 44%).

***N'*-Phenylbenzohydrazide** (**13**)[22] : Followed by procedure 3 with DBU (457 mg, 3.0 mmol, 2.0 equiv) and phenylhydrazine (162 mg, 3.0 mmol, 2.0 equiv) afforded *N*'-phenylbenzohydrazide (**13**) (132 mg, 0.62 mmol, 41%).

Experimental Procedure (Unsymmetrical diamide):

Methyl 4-(benzylcarbamoyl)benzoate (**14**)[23] : To a 20-mL screw cap vial added methyl 4-(2,2,2-trichloroacetyl)benzoate (**2k**) (422 mg, 1.5 mmol), benzylamine (161 mg, 1.5 mmol, 1.0 equiv) and DBU (228 mg, 1.5 mmol, 1.0 equiv) in toluene (7 mL). The solution was stirred at 25 °C for 12 h. The resulting mixture was charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give methyl 4-(benzylcarbamoyl)benzoate (**14**) (355 mg, 1.32 mmol, 88% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (d, *J* = 8.7 Hz, 2H), 7.83 (d, *J* = 8.6 Hz, 2H), 7.29-7.35 (m, 5H), 6.68 (br s, 1H), 4.63 (d, *J* = 5.7, 2H), 3.92 (s, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 166.5, 166.3, 138.3, 137.8, 132.7, 129.8, 128.8, 128.0, 127.8, 127.1, 52.4, 44.3; MS (EI) m/z = 269 (M^+).

Methyl 4-(piperidine-1-carbonyl)benzoate (**15**)[24] : To a 20-mL screw cap vial added methyl 4-(2,2,2-trichloroacetyl)benzoate (**2k**) (422 mg, 1.5 mmol), piperidine (127 mg, 1.5 mmol, 1.0 equiv) and potassium tertiary butoxide (168 mg, 1.5 mmol, 1.0 equiv) in THF (7 mL). The solution was stirred at 25 °C for 12 h. The resulting mixture was charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give methyl 4-(piperidine-1-carbonyl)benzoate (**15**) (304 mg, 1.23 mmol, 82% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (d, *J* = 8.2 Hz, 2H), 7.43 (d, *J* = 8.2 Hz, 2H), 3.91 (s, 3H), 3.70 (br s, 2H), 3.27 (br s, 2H), 1.67 (br s, 4H), 1.49 (br s, 2H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 169.2, 166.4, 140.8, 130.8, 129.8, 126.7, 52.3, 48.6, 43.1, 26.5, 25.6, 24.5; MS (EI) m/z = 247 (M^+).

***N*-Benzyl-4-(piperidine-1-carbonyl)benzamide** (**16**) **from** (**14**) : To a 20-mL screw cap vial added methyl 4-(benzylcarbamoyl)benzoate (**14**) (404 mg, 1.5 mmol), piperidine (5.0 ml) and NaOMe (243 mg, 4.5 mmol, 3.0 equiv). The reaction mixture was warmed to 80°C and maintained for 24 h. Cooled to 25 °C charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give *N*-benzyl-4-(piperidine-1-carbonyl)benzamide (**16**) (303 mg, 0.94 mmol, 63% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.5 Hz, 2H), 7.28-7.34 (m, 7H), 7.03 (t, *J* = 5.5 Hz, 1H), 4.62 (d, *J* = 5.8 Hz, 2H), 3.65 (br s, 2H), 3.24 (br s, 2H), 1.65 (br s, 4H), 1.47 (br s, 2H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 169.3, 166.7, 138.6, 138.4, 135.2, 128.4, 127.7, 127.2, 127.1, 126.4, 48.5, 43.7, 42.9, 26.3, 25.4, 24.3; HRMS (EI) m/z cacld. for $C_{20}H_{22}N_2O_2$ $[M]^+$: 322.1681, found: 322.1678.

***N*-Benzyl-4-(piperidine-1-carbonyl)benzamide** (**16**) **from** (**15**) : To a 20-mL screw cap vial added methyl 4-(piperidine-1-carbonyl)benzoate (**15**) (371 mg, 1.5 mmol), benzylamine (5 ml) and NaOMe (162 mg, 3.0 mmol, 2.0 equiv). The reaction mixture was warmed to 60 °C and maintained for 24 h. Then cooled to 25 °C charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give *N*-benzyl-4-(piperidine-1-carbonyl)benzamide (**16**) (300 mg, 0.93 mmol, 62% yield).

Experimental Procedure 1 ($H_2{}^{18}O$ was used):

Methyl 2,2-dichloro-3-oxo-3-phenylpropanoate (**18**) : Methyl 3-phenylpropiolate (17) (320 mg, 2.0 mmol) afforded methyl 2,2-dichloro-3-oxo-3-phenylpropanoate (**18**) (272 mg, 1.1 mmol, 55% yield); NMR (500 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.4 Hz, 2H), 7.61 (t, *J* = 7.4 Hz, 1H), 7.47 (t, *J* = 7.7 Hz, 2H), 3.85 (s, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 183.3, 164.6, 134.3, 130.7, 130.1, 128.7, 81.7, 55.0; HRMS (FAB) m/z cacld. for $C_{10}H_8Cl_2{}^{16}O_2{}^{18}O$ $[M+H]^+$: 248.9971, found: 248.9974.

Experimental Procedure 4:

To a 20-mL screw cap vial added alkyl propiolic acid (280 mg, 2.0 mmol, 1.0 equiv), trichloroisocyanuric acid (465 mg, 2.0 mmol, 1.0 equiv) and water (576

mg, 32.0 mmol, 16.0 equiv) in acetonitrile (5.0 mL). The solution was stirred at 25 °C for 6 h. The resulting mixture charged to the separating funnel added water, extracted with EtOAc. The organic layer washed with water and dried over anhydrous $MgSO_4$. After removing the EtOAc under vacuum, the crude product was purified by column chromatography on a silica gel column with n-hexane/ethyl acetate as eluent to give the desired product and dichlorinated lactone.

1,1,1-Trichloroheptan-2-one (**20a**)[25] : 2-Octynoic acid (**19a**) (435 mg, 2.0 mmol) afforded 1,1,1-trichloroheptan-2-one (**20a**) (105 mg, 0.5 mmol, 25% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.97 (t, *J* = 7.3 Hz, 2H), 1.74 (pent., *J* = 7.4 Hz, 2H), 1.37-1.20 (m, 4H), 0.91 (t, *J* = 7.2 Hz, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 190.6, 96.5, 33.9, 31.0, 24.5, 22.3, 13.9; HRMS (EI) m/z cacld. for $C_7H_{11}Cl_3O$ $[M]^+$: 215.9875, found: 215.9875.

5-Butyl-3,4-dichlorofuran-2(5H)-one (**21a**) : 2-Octynoic acid (**19a**) (435 mg, 2.0 mmol) afforded 5-butyl-3,4-dichlorofuran-2(5H)-one (**21a**) (88 mg, 0.42 mmol, 21% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.96 (dd, *J* = 7.6, 3.5 Hz, 1H), 2.02-2.08 (m, 1H), 1.64-1.71 (m, 1H), 1.42-1.34 (m, 4H), 0.91 (t, *J* = 7.2 Hz, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 165.4, 152.6, 120.8, 82.2, 31.4, 25.7, 22.1, 13.7; HRMS (EI) m/z cacld. for $C_8H_{10}Cl_2O_2$ $[M]^+$: 208.0058, found: 208.0056.

3,4-Dichloro-5-ethylfuran-2(5H)-one (**21b**) : 2-Hexynoic acid (**19b**) (224 mg, 2.0 mmol) afforded 3,4-dichloro-5-ethylfuran-2(5H)-one (**21b**) (54 mg, 0.3 mmol, 15% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.96 (dd, *J* = 6.7, 3.8 Hz, 1H), 2.07-2.16 (m, 1H), 1.70-1.78 (m, 1H), 0.96 (t, *J* = 7.4 Hz, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 165.4, 152.3, 121.0, 83.0, 24.8, 7.6; HRMS (EI) m/z cacld. for $C_6H_6Cl_2O_2$ $[M]^+$: 179.9745, found: 179.9747.

3,4-Dichloro-5-methylfuran-2(5H)-one (**21c**) : 2-Pentynoic acid (**19c**) (196 mg, 2.0 mmol) afforded 3,4-dichloro-5-methylfuran-2(5H)-one (**21c**) (40 mg, 0.24 mmol, 12% yield) as a colorless liquid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.04 (q, *J* = 6.8 Hz, 1H), 1.59 (d, *J* = 6.8 Hz, 3H). ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 165.1, 153.5, 120.8, 78.8, 18.0; HRMS (EI) m/z cacld. for $C_5H_4Cl_2O_2$ $[M]^+$: 165.9588, found: 165.9590.

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FULL PAPER

Metal-Free Decarboxylative Trichlorination of Alkynyl Carboxylic Acids: Synthesis of Trichloromethylketones.

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Aravindan Jayaraman, Eunjeong Cho, Francis Mariaraj Irudayanathan, Jimin Kim, Sunwoo Lee*