

Note

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J. Org. Chem., **Just Accepted Manuscript** • DOI: 10.1021/acs.joc.6b02044 • Publication Date (Web): 13 Sep 2016

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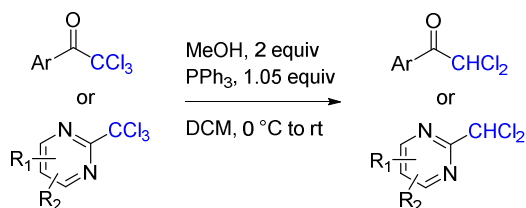
Chemoselective Reduction of Trichloromethyl Compounds to *gem*-Dichloromethyl Groups Following Appel's Reaction Protocol

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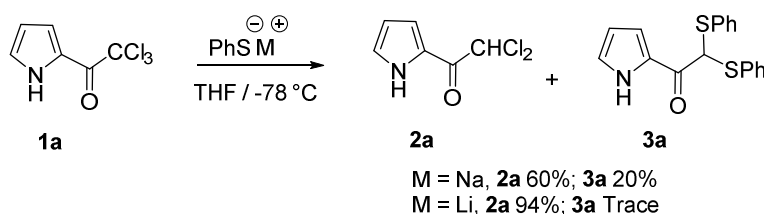
ABSTRACT: A simple and easy reduction of trichloroacetyl compounds following the modification of Appel's reaction protocol, using triphenylphosphine and methanol, afforded the corresponding dichloroacetyl compounds, with the exception of trichloroacetylmorpholine, in yields of 80-98% under very mild experimental conditions. Likewise, when trichloromethyl heterocyclic compounds contain another reactive functional group, the reaction is highly chemoselective giving the dichloromethyl derivative.

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3 The *gem*-dichloromethyl group is an important structural framework present in a number of
4 biologically active compounds such as antibiotics and diuretics.¹ Additionally, some
5 dichloromethyl derivatives are also found important within the agrochemical field² and are
6 well-known to be useful intermediates for the synthesis of heterocycles,³ α,β -unsaturated
7 ketones,⁴ 1,4-diones,⁵ ynols⁶ and cyclopropanes.⁷ Likewise, they are widely used as
8 synthetic precursors to afford the corresponding aldehydes under basic conditions⁸ as well
9 as precursors for *gem*-difluoromethyl groups by the double nucleophilic substitution of the
10 chlorides by fluoride ions.⁹

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23 General methods to prepare dichloromethyl compounds involve Lewis acid-catalyzed
24 acylation of arenes,¹⁰ oxyhalogenation of alkynes,¹¹ and chlorination of ketones which
25 implicates using different types of chlorine sources,¹² such as sulfonyl chloride,¹³ thionyl
26 chloride,¹⁴ *N*-chlorosuccinimide,¹⁵ and 1,3-dichloro-5,5-dimethylhydantoin (DCDMH).¹⁶
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33 However, few methods have been described to allow the formation of *gem*-dichloromethyl
34 compounds employing trichloromethyl derivatives as starting materials. In this context,
35 *gem*-dichloromethyl compounds can be directly synthesized by a mono-dechlorination
36 reaction of the corresponding trichloromethyl derivative via partial hydrogenation using a
37 platinum on a carbon-catalyzed system.¹⁷ Another attractive approach was demonstrated in
38 the seminal work of Hall and co-workers, involves Grignard reagents as electron donors for
39 2,2,2-trichloro-1-arylethanones to synthesize substituted α,α -dichloroketones.¹⁸
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In 2007, while our research group was developing the synthesis of 2-substituted-1,3-dithianes from trichloromethyl compounds, we observed that the reaction of trichloroacetylpyrrole **1a** with 5 equiv of 1,3-propanodithiol and 3 equiv of sodium hydride in dry THF at -40 °C afforded a 71% yield of dichloroacetylpyrrole **2a**.¹⁹ We envisioned that this protocol could be applicable to the development of a convenient one-pot procedure for a direct conversion of trichloromethyl compounds into the dichloromethyl derivatives.

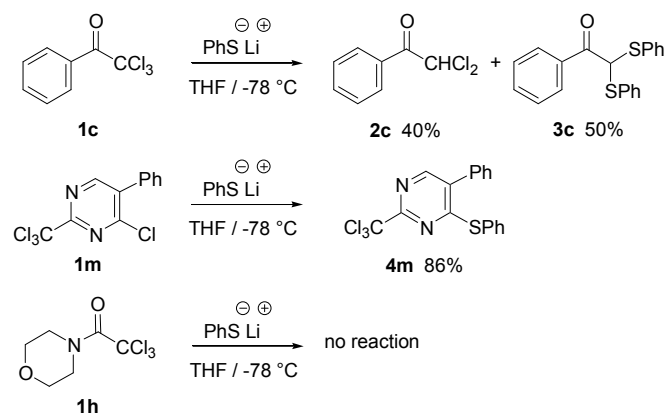
Scheme 1. Reduction of trichloroacetylpyrrole with thiophenolate.



We evaluated the reduction of trichloroacetyl compounds **1** in the presence of sulfur nucleophiles, using the 2-trichloroacetylpyrrole **1a** as a model. When **1a** was reacted with 2.0 equiv of sodium thiophenolate (generated from thiophenol and sodium hydride at room temperature) in THF at -78 °C, after 10 min, a mixture of the dichloroacetylpyrrole **2a** in 60% yield along with bis(phenylthio) compound **3a** in 20% yield were obtained (Scheme 1). The latter compound is suggested to arise as a consequence of a substitution reaction of dichloroacetylpyrrole **2a** by the presence of the thiophenolate ion in the mixture reaction. An improved yield of **2a** (94%) was achieved employing 2.0 equiv of lithium thiophenolate (generated from thiophenol and *n*-BuLi) at -78 °C and only traces of **3a** was observed.

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3 However, the application of this reduction process to trichloroacetophenone **1c** under the
4 same conditions was less successful, affording dichloroacetophenone **2c**¹⁷ in 40% yield
5 along with the respective dithioacetal **3c** in 50% yield (Scheme 2). In fact, it is known that
6 the dechlorination activity is strongly influenced by the electronic environment of the
7 substituents attached to the trichloromethyl group.²⁰ Another setback of this methodology
8 was the poor chemoselectivity observed when trichloromethylpyrimidine **1m** was treated
9 under similar conditions, giving the nucleophilic aromatic substitution product **4m** as the
10 only isolable product in 86% yield which is possibly formed via a Meisenheimer
11 intermediate. Furthermore, the trichloroacetylmorpholine **1h** did not react using the
12 previous reduction conditions even under long periods of time.
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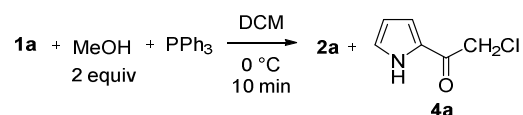
29 **Scheme 2. Reduction process of trichloroacetyl compounds 1 with lithium**
30 **thiophenolate**
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In view of these results, we decided to explore another alternative to carry out the conversion of trichloromethyl compounds to *gem*-dichloromethyl derivatives. It is well documented that the treatment of alcohols with Appel's salt gives the corresponding halide, usually in very good yields.²¹ The Appel's salt can be formed by the reaction between one

equivalent of triphenylphosphine and one equivalent of a tetrahalomethane such as CCl₄ or CBr₄. Mechanistically, one equivalent of haloform is formed as by-product in this halogenation process. We reasoned that in this reaction, trichloromethyl compounds with an electron-withdrawing group **1** could be used instead of tetrahalomethanes to reduce trichloromethyl compounds to *gem*-dichloromethyl derivatives **2**. Although, in 2011 Gilheany group reported the synthesis of pentachloroacetone in regular yield from hexachloroacetone under Appel's reaction conditions using 2-naphthol in toluene solution,²² to date no systematic work has been published employing substrates containing other reactive functional group, to demonstrate chemoselective reactivity and the potential use of this methodology to afford *gem*-dichloromethyl compounds from trichloromethyl derivatives. To examine this alternative, we next studied the reactivity of trichloromethyl compounds under Appel's reaction conditions in order to see if the reduction process occurs in these substrates. At the outset of our study, we used trichloroacetylpyrrole **1a** as a model to evaluate the reduction process in the presence of 2.0 equivalents of methanol with different amounts of triphenylphosphine (Table 1).

Table 1. Optimization of reaction conditions^a



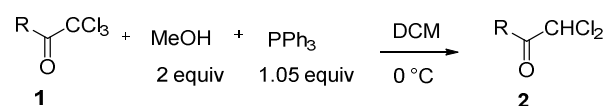
entry	PPh ₃ (mmol)	1a (%)	2a (%)	4a (%)
1	1.2	0	80	10
2	1.0	traces	89	0
3	1.05	0	94	0

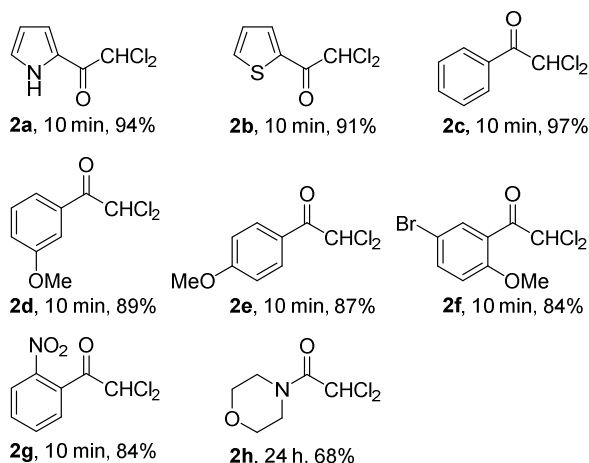
^aReaction conditions: **1a** (1.0 equiv, 1 mmol), MeOH (2.0 equiv), DCM (5.0 mL) under N₂ at 0 °C.

When 1.2 equiv of triphenylphosphine were used, dichloroacetylpyrrole **2a** was obtained in 80% yield and chloroacetylpyrrole **4a** in 10% yield (Table 1, entry 1). The amount of triphenylphosphine was decreased to 1.0 equiv in an attempt to avoid the formation of the over-reduced chloroacetylpyrrole **4a**, affording dichloroacetylpyrrole **2a** in 89% yield and trace amount of starting material. An appreciable change in the yield was observed when a slight excess of triphenylphosphine (1.05 equiv) was used (entry 3) to afford **2a** in 94% yield.

With the optimized reaction conditions in hand, this methodology for the generation of dichloromethyl derivatives **2** was extended. We first investigated the monodechlorination reaction of the more reactive trichloroacetyl derivatives **1b-1g** affording efficiently their corresponding *gem*-dichloroacetyl products **2b-2g** in high yields under short periods of time (Table 2). In contrast, although the trichloroacetylmorpholine **1h** was transformed into the dichloroacetylmorpholine **2h**²³ in acceptable yield (68%), the reaction period was longer (24 h). The distinct reactivity difference in time between **1h** and the trichloroacetyl compounds **1a-1g** could be a result of the corresponding electronic properties of **1h** which is slightly more electron rich than **1a-1g**.

Table 2. Synthesis of dichloroacetyl compounds^a





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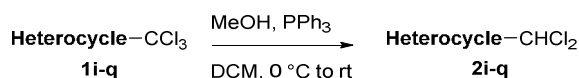
^aReaction conditions: **1a** (1.0 equiv, 1 mmol), MeOH (2.0 equiv), PPh₃ (1.05 equiv), DCM (5.0 mL) under N₂ at 0 °C.

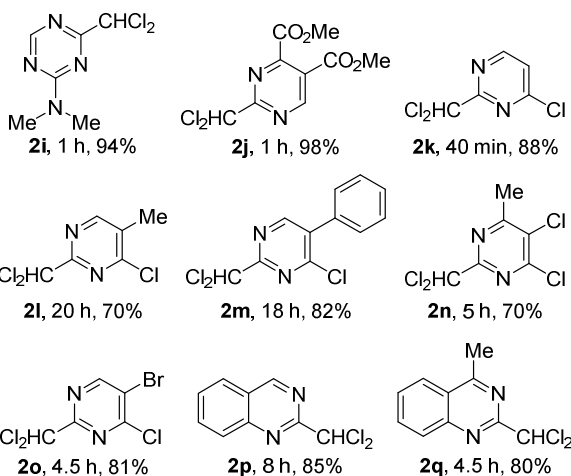
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Lastly, this reduction process was extrapolated to other trichloromethyl compounds containing other reactive functional groups such as **1j-1o**. Such derivatives afforded a highly chemoselective reduction as it is illustrated in dichloromethyl compounds **2j-2o** (Table 3). In each case, the corresponding dichloromethyl compound **2** was the exclusive product affording high yields under moderate periods of time, along with no significant nucleophilic displacement on C-4 or C-5 of the trichloromethylpyrimidines as when sodium/lithium thiophenolate was employed.

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Table 3. Synthesis of dichloromethyl heterocyclic compounds





^aReaction conditions: **1i-q** (1.0 equiv, 1 mmol), MeOH (2.0 equiv), PPh₃ (1.05 equiv), DCM (5.0 mL) under N₂ at 0 °C.

In summary, we have reported an efficient and simple procedure to prepare *gem*-dichloromethyl compounds using Appel's reaction conditions from trichloromethyl derivatives. This dechlorination reaction is found to be highly chemoselective and is expected to be particularly useful in those instances where the trichloromethyl compounds are the usual precursors of dichloromethyl derivatives which are not affordable in good yields by other routes.

EXPERIMENTAL SECTION

General

All moisture-sensitive reactions were carried out in oven-dried glassware under argon atmosphere. Reagents were used without any further purification. Nuclear Magnetic Resonance (NMR) spectra were measured at 300 MHz. ¹H-NMR chemical shifts (δ) are reported in parts per million (ppm) relative to Me₄Si (δ = 0.0 ppm) with coupling constants (*J*) reported in Hertz (Hz). Multiplicities are reported as singlet (s), doublet (d), triplet (t),

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3 quartet (q), multiplet (m), broad singlet (bs). ^{13}C -NMR signals are reported using 77.0 ppm
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6 (CDCl₃) as internal reference.
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9 The 2-trichloroacetylpyrrole **1a** is commercially available, whereas the trichloromethyl
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11 compounds **1b-g**,²⁴ **1i-j**¹⁹ and **1p-q**²⁵ were easily synthesized in good yields by literature
12
13 methods. The trichloroacetylmorpholine **1h** was prepared from trichloroacetyl chloride and
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15 morpholine.
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18 19 **General procedure for synthesis of *gem*-dichloromethyl compounds (2).**

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21 Under nitrogen atmosphere, to a solution of the respective trichloromethyl compound **1** (1.0
22
23 mmol, 1.0 equiv) and methanol (80.0 μL , 2.0 mmol, 2.0 equiv) in anhydrous
24
25 dichloromethane (3.0 mL) at 0 °C, a solution of triphenylphosphine (275 mg, 1.05 mmol,
26
27 1.05 equiv) in anhydrous dichloromethane (1.5 mL) was added dropwise at 0 °C . The
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29 reaction mixture was stirred for the time indicated in Tables 2 and 3. In the reactions that
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31 were more than 10 min, the temperature was allowed to rise to room temperature. After
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33 completion, the reaction was concentrated under *vacuum*. The desired dichloromethyl
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35 product **2** was purified through flash column chromatography on silica gel and eluted with
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37 hexane-EtOAc mixtures.
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43 **2-(Dichloroacetyl)pyrrol (2a).**^{17a} This compound was purified by flash column
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45 chromatography using hexanes-EtOAc (9:1) and obtained as a white solid (167 mg, 94%
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47 yield); crystallization (hexanes-CH₂Cl₂); mp 90-91 °C. ^1H NMR (300 MHz, CDCl₃): δ
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49 10.05 (brs, 1H), 7.24-7.22 (m, 1H), 7.20-7.17 (m, 1H), 6.52 (s, 1H), 6.38 (td, $J = 4.2, 2.5$
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51 Hz, 1H). ^{13}C {1H} NMR (75 MHz, CDCl₃): δ 177.0, 128.2, 126.0, 119.3, 111.8, 67.2.
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53 HRMS (ESI+): calcd for C₆H₆Cl₂NO [M + H]⁺ 177.9826, found 177.9823.
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3 **2-(Dichloroacetyl)thiopene (2b).**^{17b} This compound was purified by flash column
4 chromatography using hexanes-EtOAc (98:2) and obtained as pale yellow oil (177 mg,
5 91% yield). ¹H NMR (300 MHz, CDCl₃): δ 8.01 (dd, 1H, *J* = 3.9, 1.2 Hz), 7.81 (dd, 1H, *J* =
6 4.9, 1.2 Hz), 7.21 (dd, 1H, *J* = 4.9, 3.9 Hz), 6.51 (s, 1H). ¹³C {1H} NMR (75 MHz, CDCl₃):
7 δ 179.7, 137.0, 136.4, 134.8, 128.6, 67.9. HRMS (ESI+): calcd for C₆H₅Cl₂OS [M + H]⁺
8 194.9438, found 194.9435.
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17 **Dichloroacetophenone (2c).**^{17a} This compound was purified by flash column
18 chromatography using hexanes-EtOAc (98:2) and obtained as colorless oil (183 mg, 97%
19 yield). ¹H NMR (300 MHz, CDCl₃): δ 8.08 (d, 2H, *J* = 7.2 Hz), 7.65 (t, 1H, *J* = 7.5 Hz),
20 7.52 (t, 2H, *J* = 8.1 Hz), 6.70 (s, 1H). ¹³C {1H} NMR (75 MHz, CDCl₃): δ 185.9, 134.5,
21 131.3, 129.7, 128.9, 67.7. HRMS (ESI+): calcd for C₈H₇Cl₂O [M + H]⁺ 188.9874, found
22 188.9874.
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32 **3-Methoxy(dichloro)acetophenone (2d).**^{17a} This compound was purified by flash column
33 chromatography using hexanes-EtOAc (9:1) and obtained as a yellow solid (195 mg, 89%
34 yield); crystallization (hexanes-CH₂Cl₂); mp 37-39 °C. ¹H NMR (300 MHz, CDCl₃): δ 7.65
35 (d, *J* = 7.8 Hz, 1H), 7.60 – 7.57 (m, 1H), 7.42 (t, 1H, *J* = 8.1 Hz), 7.19 (dd, 1H, *J* = 8.1, 2.1
36 Hz), 6.69 (s, 1H), 3.87 (s, 3H). ¹³C {1H} NMR (75 MHz, CDCl₃): δ 185.7, 159.9, 132.6,
37 129.8, 122.0, 121.1, 114.0, 67.7, 55.5. HRMS (ESI+): calcd for C₉H₉Cl₂O₂ [M + H]⁺
38 218.9979, found 218.9984.
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48 **4-Methoxy(dichloro)acetophenone (2e).**^{17a} This compound was purified by flash column
49 chromatography using hexanes-EtOAc (9:1) and obtained as pale yellow oil (191 mg, 87%
50 yield). ¹H NMR (300 MHz, CDCl₃): δ 8.08 (d, 2H, *J* = 9 Hz), 6.98 (d, 2H, *J* = 9 Hz), 6.65 (s,
51 1H), 3.90 (s, 3H). ¹³C {1H} NMR (75 MHz, CDCl₃): δ 184.6, 164.6, 132.2, 123.9, 114.2,
52 67.8, 55.6. HRMS (ESI+): calcd for C₉H₉Cl₂O₂ [M + H]⁺ 218.9979, found 218.9974.
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3 **5-Bromo-2-methoxy(dichloro)acetophenone (2f)** This compound was purified by flash
4 column chromatography using hexanes-EtOAc (9:1) and obtained as a white solid (250 mg,
5 84% yield); crystallization (hexanes-CH₂Cl₂); mp 86-87 °C. ¹H NMR (500 MHz, CDCl₃):
6 δ 7.90 (d, 1H, *J* = 2.5 Hz), 7.61 (dd, 1H, *J* = 8.9, 2.5 Hz), 7.01 (s, 1H), 6.88 (d, 1H, *J* = 8.9
7 Hz), 3.94 (s, 3H). ¹³C {1H} NMR (125 MHz, CDCl₃): δ 186.5, 157.3, 137.7, 134.6, 124.4,
8 113.8, 113.7, 70.6, 56.3. HRMS (ESI+): calcd for C₉H₈BrCl₂O₂ [M + H]⁺ 298.9064, found
9 298.9072.

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20 **2-Nitro(dichloro)acetophenone (2g)**. This compound was purified by flash column
21 chromatography using hexanes-EtOAc (9:1) and obtained as an pale yellow solid (197 mg,
22 84% yield); crystallization (hexanes-CH₂Cl₂); mp 83-84 °C. ¹H NMR (300 MHz, CDCl₃): δ
23 8.28 (dd, 1H, *J* = 8.4, 1.2 Hz), 7.85 (dt, 1H, *J* = 7.5, 1.2 Hz), 7.75 (td, 1H, *J* = 8.4, 1.5 Hz),
24 7.62 (dd, 1H, *J* = 7.5, 1.5 Hz), 6.38 (s, 1H). ¹³C {1H} NMR (75 MHz, CDCl₃): δ 189.5,
25 145.3, 135.0, 132.6, 131.7, 123.0, 124.4, 69.6. HRMS (ESI+): calcd for C₈H₆Cl₂NO₃ [M +
26 H]⁺ 233.9724, found 233.9723.

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36 **Dichloroacetylmorpholine (2h)**.²³ This compound was purified by flash column
37 chromatography using hexanes-EtOAc (95:5) and obtained as a white solid (135 mg, 68%
38 yield); crystallization (hexanes-CH₂Cl₂); mp 64-65 °C. ¹H NMR (300 MHz, CDCl₃): δ 6.21
39 (s, 1H), 3.76 – 3.72 (m, 6H), 3.67 – 3.64 (m, 2H). ¹³C {1H} NMR (75 MHz, CDCl₃): δ
40 162.1, 66.5, 66.1, 65.4, 46.9, 43.3. HRMS (ESI+): calcd for C₆H₁₀Cl₂NO₂ [M + H]⁺
41 198.0088, found 198.0087.

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51 **2-N,N-Dimethylamino-4-(dichloromethyl)-1,3,5-triazine (2i)**. This compound was purified
52 by flash column chromatography using hexanes-EtOAc (95:5) and obtained as pale yellow
53 oil (195 mg, 94% yield). ¹H NMR (300 MHz, CDCl₃): δ 8.63 (s, 1H), 6.37 (s, 1H), 3.24 (d,
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3 $J = 1.5$ Hz, 6H). ^{13}C {1H} NMR (75 MHz, CDCl_3): δ 172.0, 166.6, 164.3, 70.3, 36.5, 36.3.

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6 HRMS (ESI+): calcd for $\text{C}_6\text{H}_9\text{Cl}_2\text{N}_4$ $[\text{M} + \text{H}]^+$ 207.0204, found 207.0203.

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8 ***Dimethyl 2-(dichloromethyl)pyrimidine-4,5-dicarboxylate (2j)***.²⁶ This compound was
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10 purified by flash column chromatography using hexanes-EtOAc (95:5) and obtained as a
11
12 colorless oil (274 mg, 98% yield). ^1H NMR (300 MHz, CDCl_3): δ 9.37 (s, 1H), 6.81 (s,
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14 1H), 4.05 (s, 3H), 4.00 (s, 3H). ^{13}C {1H} NMR (75 MHz, CDCl_3): δ 167.4, 164.3, 162.6,
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16 160.3, 159.4, 121.4, 69.6, 53.6, 53.4. HRMS (ESI+): calcd for $\text{C}_9\text{H}_9\text{Cl}_2\text{N}_2\text{O}_4$ $[\text{M} + \text{H}]^+$
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18 278.9939, found 278.9945.

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21 ***4-Chloro-2-(dichloromethyl)pyrimidine (2k)***. This compound was purified by flash
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23 column chromatography with hexanes-EtOAc (95:5) and obtained as a white solid (174 mg,
24
25 88% yield); crystallization (hexanes- CH_2Cl_2); mp 66-68°C. ^1H NMR (300 MHz, CDCl_3): δ
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27 8.74 (d, 1H, $J = 5.4$ Hz), 7.40 (d, 1H, $J = 5.4$ Hz), 6.72 (s, 1H). ^{13}C {1H} NMR (75 MHz,
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29 CDCl_3): δ 165.9, 162.1, 159.0, 121.8, 69.8. HRMS (ESI+): calcd for $\text{C}_5\text{H}_4\text{Cl}_3\text{N}_2$ $[\text{M} + \text{H}]^+$
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31 196.9440, found 196.9437.

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34 ***4-Chloro-2-(dichloromethyl)-5-methylpyrimidine (2l)***. This compound was purified by
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36 flash column chromatography using hexanes-EtOAc (98:2) and obtained as a colorless oil
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38 (148 mg, 70% yield). ^1H NMR (500 MHz, CDCl_3): δ 8.61 (d, $J = 0.5$ Hz, 1H), 6.71 (s,
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40 1H), 2.42 (d, $J = 0.5$ Hz, 3H). ^{13}C {1H} NMR (75 MHz, CDCl_3): δ 163.5, 161.7, 158.8,
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42 130.7, 69.8, 16.3. HRMS (ESI+): calcd for $\text{C}_6\text{H}_6\text{Cl}_3\text{N}_2$ $[\text{M} + \text{H}]^+$ 210.9596, found 210.9596.

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45 ***4-Chloro-2-(dichloromethyl)-5-phenylpyrimidine (2m)*** This compound was purified by
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47 flash column chromatography using hexanes-EtOAc (98:2) and obtained as a white solid
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49 (225 mg, 82% yield); crystallization (hexanes- CH_2Cl_2); mp 82-84 °C. ^1H NMR (500 MHz,
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51 CDCl_3) δ 8.73 (s, 1H), 7.53 – 7.51 (m, 3H), 7.50 – 7.47 (m, 2H), 6.77 (s, 1H). ^{13}C {1H}
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3 NMR (75 MHz, CDCl₃): δ 164.1, 159.9, 159.0, 134.6, 132.7, 129.5, 129.2, 128.8, 69.7.

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5 HRMS (ESI+): calcd for C₁₁H₇Cl₃N₂ [M + H]⁺ 272.9753, found 272.9764.

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8 **4,5-Dichloro-6-methyl-2-(dichloromethyl)pyrimidine (2n)**. This compound was purified
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10 by flash column chromatography using hexanes-EtOAc (99:1) and obtained as a white solid
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12 (172 mg, 70% yield); crystallization (hexanes-CH₂Cl₂); mp 52-53 °C. ¹H NMR (300 MHz,
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14 CDCl₃): δ 6.65 (s, 1H), 2.72 (s, 3H). ¹³C {1H} NMR (125 MHz, CDCl₃): δ 168.0, 161.8,
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16 159.2, 129.2, 69.4, 23.3. HRMS (ESI+): calcd for C₆H₅Cl₄N₂ [M + H]⁺ 244.9206, found
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18 244.9212.

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22 **5-Bromo-4-chloro-2-(dichloromethyl)pyrimidine (2o)**. This compound was purified by
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24 flash column chromatography using hexanes-EtOAc (96:4) and obtained as colorless oil
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26 (224 mg, 81% yield). ¹H NMR (300 MHz, CDCl₃): δ 8.89 (s, 1H), 6.69 (s, 1H). ¹³C {1H}
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28 NMR (75 MHz, CDCl₃): δ 163.9, 161.1, 160.6, 120.5, 69.2. HRMS (ESI+): calcd for
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30 C₅H₃BrCl₃N₂ [M + H]⁺ 276.8524, found 276.8524.

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34 **2-(Dichloromethyl)quinazoline (2p)**. This compound was purified by flash column
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36 chromatography with hexanes-EtOAc (95:5) and obtained as a white solid (181 mg, 85%
37
38 yield); crystallization (hexanes-CH₂Cl₂); mp 124-125°C. ¹H NMR (300 MHz, CDCl₃): δ
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40 9.53 (s, 1H), 8.10 – 7.99 (m, 3H), 7.77- 7.75 (m, 1H), 6.95 (s, 1H). ¹³C {1H} NMR (125
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42 MHz, CDCl₃): δ 162.0, 161.3, 149.6, 135.0, 129.1, 128.7, 127.2, 124.1, 71.4. HRMS
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44 (ESI+): calcd for C₉H₇Cl₂N₂ [M + H]⁺ 212.9986, found 212.9983.

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48 **2-(Dichloromethyl)-4-methylquinazoline (2q)**. This compound was purified by flash
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50 column chromatography with hexanes-EtOAc (95:5) and obtained as a white solid (182 mg,
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52 80% yield); crystallization (hexanes-CH₂Cl₂); mp 138-141°C. ¹H NMR (300 MHz, CDCl₃):
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54 δ 8.14 (d, 1H, *J* = 8.1 Hz), 8.07 (d, 1H, *J* = 8.4 Hz), 7.97 – 7.90 (m, 1H), 7.73 – 7.68 (m,
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56 1H), 6.89 (s, 1H), 3.03 (s, 3H). ¹³C {1H} NMR (125 MHz, CDCl₃): δ 170.5, 160.5, 149.2,
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3 134.3, 129.3, 128.6, 125.1, 123.6, 71.7, 21.9. HRMS (ESI+): calcd for C₁₀H₉Cl₂N₂ [M +
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5 H]⁺ 227.0142, found 227.0142.
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8 **ASSOCIATED CONTENT**

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19 **Notes**

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21 The authors declare no competing financial interest.
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24 **Acknowledgments**

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26
27 The Consejo Nacional de Ciencia y Tecnologia is gratefully acknowledged for a
28
29 postdoctoral fellowship to Ivann Zaragoza (CONACyT-231282). The authors wish to
30
31 thank M. Sc. Maria de las Nieves Zavala Segovia (CCIQS UNAM-UAEM) for obtaining
32
33 NMR spectra and to Prof. Joseph M. Muchowski (UNAM) for helpful discussions and
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35
36 interests in our work.
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41 **Supporting Information**

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44 The Supporting Information is available free of charge on the ACS Publications
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46 website at DOI:

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48 Copies of ¹H NMR and ¹³C NMR spectra for all products (PDF).
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