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Facile synthesis of 2-unsubstituted benzofuran-3-carboxylates using diazo(trimethylsilyl)methylmagnesium bromide

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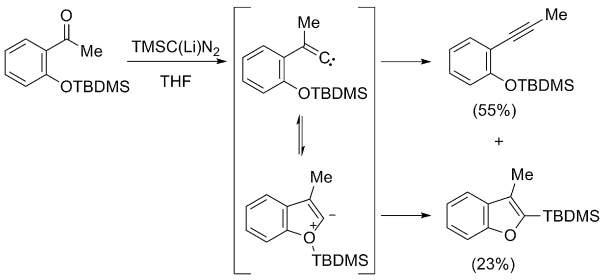
ABSTRACT

Diazo(trimethylsilyl)methylmagnesium bromide reacted with (*o*-methoxyphenyl)(oxo)acetates to readily afford 2-unsubstituted benzofuran-3-carboxylates via oxonium ylides formed from the initially generated alkylidenecarbene intermediates.

1. Introduction

Benzofuran is a promising pharmacophore for drug discovery and a large number of synthetic methodologies for its derivatives have been developed.[1] However, the synthetic approaches to 2-unsubstituted benzofuran-3-carboxylates are limited,[2–5] while there are many methods for the synthesis of 2-substituted ones.[6] The methods applicable to the synthesis of various 2-unsubstituted derivatives are only the following ways: i) reaction of salicylaldehydes with ethyl diazoacetate,[2] ii) Michael addition of *o*-iodophenol to ethyl propiolate followed by intramolecular Heck reaction,[3] and iii) copper-catalyzed cyclization of 2-(*o*-bromophenyl)-2-formylacetates prepared by formylation of *o*-bromophenylacetates.[4] Thus, alternate methods are highly in demand.

We have previously developed various reactions using trimethylsilyldiazomethane ($TMSCHN_2$),[7] including the reaction of *o*-(*tert*-butyldimethylsiloxy)acetophenone with lithium trimethylsilyldiazomethane [$TMSC(Li)N_2$], which gave the 3-methyl-2-siloxybenzofuran as a minor product, together with 1-(*o*-siloxyphenyl)propyne (Scheme 1).[8] The benzofuran was produced via the oxonium ylide formed from the initially generated alkylidenecarbene intermediate followed by 1,2-migration of the TBDMS group. We considered that 2-unsubstituted benzofuran-3-carboxylates could be prepared, if α-ketoesters bearing an *o*-oxyphenyl moiety, like (*o*-alkoxyphenyl)(oxo)acetates, were used as substrates. Here, we wish to describe our results on the reaction of (*o*-alkoxyphenyl)(oxo)acetates with lithium and magnesium bromide salts of $TMSCHN_2$ to preferentially give the desired 2-unsubstituted benzofuran-3-carboxylates.



Scheme 1. Our previous report.

2. Results and discussion

Reactions of (*o*-methoxyphenyl)(oxo)acetates **1** and **2** with metal salts of $TMSCHN_2$ were investigated to optimize reaction conditions. The results are summarized in Table 1. The ethyl ester **1** reacted with

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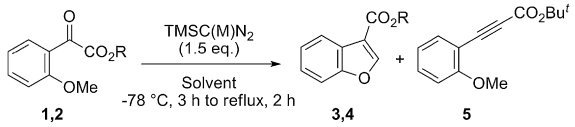
TMSC(Li)N_2 to produce the desired ethyl benzofuran-3-carboxylate **3** in low yield (24%) though the starting **1** completely disappeared by TLC (entry 1). The low yield of the reaction was considered to be due to the competition of the reaction of TMSC(Li)N_2 with the ethyl ester moiety of **1**.[9] Therefore, the ethyl ester **1** was replaced by the more bulky *tert*-butyl ester **2**. As expected, **2** brought about a significant improvement in the yield and benzofuran **4** was obtained in 41% yield together with small amounts of the alkyne **5** as a by-product (entry 2). Replacement of TMSC(Li)N_2 by the less reactive TMSC(MgBr)N_2[10] was also effective and afforded **4** in 55% yield (entry 4). THF was suitable as a reaction solvent though Et_2O could also be used (entries 2 and 3).

Table 1
Reaction of (*o*-methoxyphenyl)(oxo)acetates

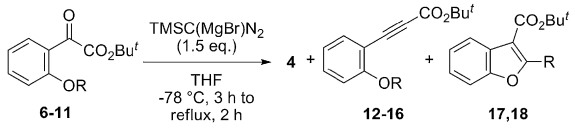


Entry	Substrate	M	Solvent	Yield (%)
1	**1** (R=Et)	Li	THF	24 (**3**)
2	**2** (R=^{t}Bu)	Li	THF	41 (**4**), 9 (**5**)
3[a]	**2**	Li	Et_2O	37 (**4**), 19 (**5**)
4	**2**	MgBr	THF	55 (**4**), 16 (**5**)

[a] The reaction was carried out at −78 °C for 3 h then refluxed for 6 h.

Under the optimized reaction conditions, shown in entry 4 of Table 1, the effect of an *o*-alkoxy group on the reaction was investigated (entries 1-6 in Table 2). In analogy with **2**, **6** bearing an ethyl group for R underwent the reaction to give the desired **4** and the alkyne **12** in 44 and 9% yield, respectively (entry 2). Allyl (**7**), methoxyethyl (**8**), and tetrahydropyranyl (THP) (**10**) derivatives also smoothly reacted with TMSC(MgBr)N_2 to give the benzofuran **4** in good yields (entries 3, 4, and 6). Interestingly, when the methoxymethyl derivative **9** was used as a substrate, not only the benzofuran **4** and the alkyne **15**, but also 2,3-disubstituted benzofuran **17** was obtained in 42, 14, and 30% yields, respectively (entry 5). In all cases, the benzofuran-3-carboxylate **4** was obtained as a major product. In contrast with these results, the *o*-siloxy derivative **11** gave 2,3-disubstituted benzofuran **18** as a major product though a small amount of **4** was obtained (entry 7).

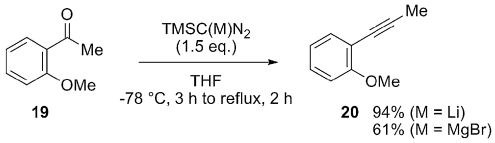
Table 2
Reaction of *tert*-butyl (*o*-oxyphenyl)(oxo)acetates with TMSC(MgBr)N_2



Entry	Substrate	Yield (%)
1[a]	**2** (R=Me)	55 (**4**), 16 (**5**)
2	**6** (R=Et)	41 (**4**), 6 (**12**)
3	**7** (R=Allyl)	55 (**4**), 9 (**13**)
4	**8** (R=MeO(CH_2)$_2$)	56 (**4**), 16 (**14**)
5	**9** (R=MeOCH_2)	42 (**4**), 14 (**15**), 30 (**17**)
6	**10** (R=THP[b])	53 (**4**)
7	**11** (R=TBDMS)	8[c] (**4**), 10[c] (**16**), 28 (**18**)

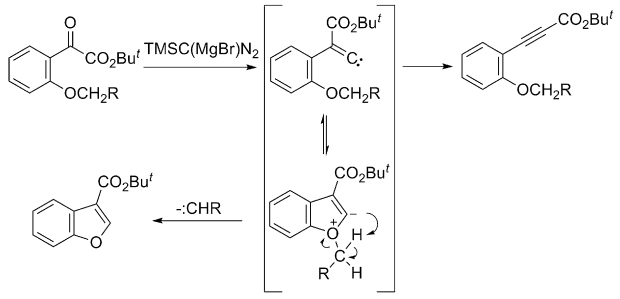
[a] Entry 4 in Table 1.
[b] Tetrahydropyranyl.
[c] The yields of **4** and **16** obtained as a mixture were estimated by ^{1}H NMR measurement.

Based on these results, we chose the methoxy group to use as the *o*-alkoxy moiety of (*o*-alkoxyphenyl)(oxo)acetates since the methoxy derivative is effective in this reaction system and can be easily synthesized (see Experimental section for details). It should be noted that reactions of 2′-methoxyacetophenone **19** with both TMSC(Li)N_2 and TMSC(MgBr)N_2 gave only the alkyne **20** and the corresponding benzofuran was not detected at all (Eq. 1).



(1)

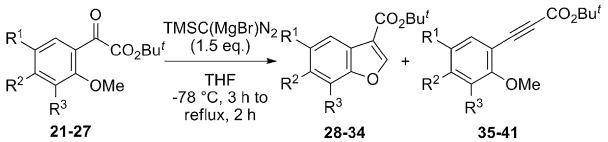
A proposed reaction mechanism of this new synthesis of 2-unsubstituted benzofuran-3-carboxylates is shown in Scheme 2. In analogy with the formation of 3-methyl-2-siloxybenzofuran from 2′-siloxyacetophenone,[8] the first step is the generation of an alkylidenecarbene intermediate from an α-ketoester. Subsequent cyclization would then form an oxonium ylide, from which an alkylene (:CHR) is eliminated to give a benzofuran-3-carboxylate.



Scheme 2. Plausible reaction mechanism.

Next, to investigate the generality of the substrates, reactions of TMSC(MgBr)N_2 with various *tert*-butyl (*o*-methoxyphenyl)(oxo)-acetates **21**–**27** were carried out (Table 3). Substrates with methoxy (**21**), methyl (**22**), and chloro (**23**) groups at R^1 afforded the desired benzofurans **28**–**30** in moderate yields (40–47%) (entries 2–4). When the R^2 group was an electron-donating group such as a methoxy group, the reaction proceeded smoothly to give the corresponding benzofuran **31** in good yield, while the substitution of an electron-withdrawing group such as a chloro group decreased the yield of the benzofuran **32** (entries 5 and 6). In the case of the naphthyl derivative **26**, the yield of benzofuran **33** decreased (33%) and that of the alkyne **40** increased (29%), presumably due to the better migrating ability of the naphthyl group (entry 7). Substitution of a methyl group at R^3 also affected the reaction and the yield of **34** decreased (entry 8). Unfortunately, this reaction was not applicable

Table 3
Reaction of various *tert*-butyl (*o*-methoxyphenyl)(oxo)acetates with TMSC(MgBr)N_2



Entry	Substrate	Yield (%)
1[a]	**2** (R^1=R^2=R^3=H)	55 (**4**), 16 (**5**)
2	**21** (R^1=MeO, R^2=R^3=H)	47 (**28**), 12 (**35**)
3	**22** (R^1=Me, R^2=R^3=H)	42 (**29**), 15 (**36**)
4	**23** (R^1=Cl, R^2=R^3=H)	40 (**30**), 13 (**37**)
5	**24** (R^1=H, R^2=MeO, R^3=H)	62 (**31**), 9 (**38**)
6	**25** (R^1=H, R^2=Cl, R^3=H)	49 (**32**), 17 (**39**)
7	**26** (R^1, R^2=–CH=CH–CH=CH–, R^3=H)	33 (**33**), 29 (**40**)
8	**27** (R^1=R^2=H, R^3=Me)	32 (**34**), 19 (**41**)

[a] Entry 4 in Table 1.

to substrates **42**–**44** bearing heteroaromatics like pyridine, pyrimidine, and thiophene (Fig. 1). In the case of **42** and **43**, no benzofuran derivatives were detected and the corresponding alkynes **45** and **46** were obtained in low yields, respectively. The thiophene derivative **44** gave a complex mixture.

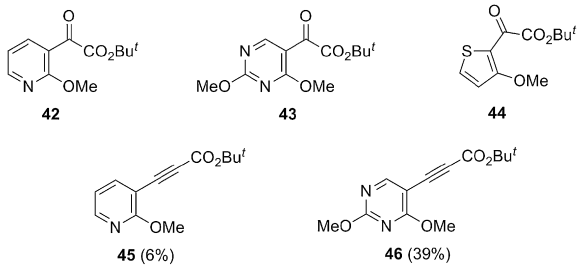


Figure 1. Substrates **42**–**44** and products **45** and **46**.

3. Conclusion

We found that 2-unsubstituted benzofuran-3-carboxylates could be synthesized from (*o*-methoxyphenyl)(oxo)acetates, easily prepared by the reaction of the corresponding (*o*-methoxyphenyl)magnesium bromides with di-*tert*-butyl oxalate, using TMSC(MgBr)N_2. The present method is accessible to 2-unsubstituted benzofuran-3-carboxylates from new substrates and will provide an added flexibility in benzofuran synthesis.

4. Experimental

4.1. General

IR spectra were measured on a SHIMADZU FTIR-8400S spectrophotometer. ^{1}H and ^{13}C NMR spectra were measured on a JEOL JNM-EX-270 NMR spectrometer, operating at 270 MHz for ^{1}H NMR and at 68 MHz for ^{13}C NMR. ^{1}H and ^{13}C NMR spectra were reported in δ units, parts per million (ppm) downfield from tetramethylsilane (δ=0). EIMS spectra were measured on a JEOL JMS-SX-102A instrument. Silica gel column chromatography was performed on Fuji Silysia BW200, BW820MH or FL60D silica gel. A solution of $MgBr_2$ in Et_2O/toluene (1:1) was prepared from $MgBr_2$ etherate (Aldrich) dried well under reduced pressure at 100 °C, anhydrous Et_2O, and anhydrous toluene.

4.2. Synthesis of substrate

General Procedure: Under an argon atmosphere, a solution of arylmagnesium bromide, prepared from aryl bromide (5 mmol) and magnesium turning (0.17 g, 7 mmol) in anhydrous THF (5 ml), was added dropwise to a solution of di-*tert*-butyl oxalate (1.42 g, 7 mmol) in anhydrous THF (10 ml) at −78 °C and the mixture was stirred at −78 °C for 2 h. After the addition of satd NH_4Cl aq, the mixture was extracted with AcOEt three times. The combined organic extracts were washed with H_2O and brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (hexane–AcOEt or hexane–$CHCl_3$ system) to give the following products.

*4.2.1. Ethyl (2-methoxyphenyl)(oxo)acetate (**1**).* See Ref. 11

*4.2.2. tert-Butyl (2-methoxyphenyl)(oxo)acetate (**2**).* Prepared from 2-bromoanisole, according to the above general procedure. Yellow oil; yield 60%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.86 (3H, s), 6.97 (1H, d, *J*=8.1 Hz), 7.04 (1H, t, *J*=8.1 Hz), 7.55 (1H, t, *J*=8.1 Hz), 7.86 (1H, d, *J*=8.1 Hz); ^{13}C NMR ($CDCl_3$) δ 27.76, 55.44, 83.04, 111.62, 120.75, 122.22, 130.36, 135.84, 159.72, 164.14, 186.27; IR (neat) 1728, 1670 cm^{-1}; FABMS: 237 (MH^+). HRMS calcd for $C_{13}H_{17}O_4$: 237.1127. Found 237.1130.

*4.2.3. tert-Butyl (2-ethoxyphenyl)(oxo)acetate (**6**).* Prepared from 1-bromo-2-ethoxybenzene,[12] according to the above general procedure. Yellow oil; yield 98%; ^{1}H NMR ($CDCl_3$) δ 1.41 (3H, t, *J*=7.0 Hz), 1.59 (9H, s), 4.19 (2H, q, *J*=7.0 Hz), 6.96 (1H, d, *J*=8.2 Hz), 7.03 (1H, t, *J*=7.6 Hz), 7.53 (1H, dd, *J*=7.6, 8.2 Hz), 7.82 (1H, d, *J*=7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 14.54, 28.13, 64.62, 83.42, 112.54, 120.78, 123.38, 131.01, 135.53, 159.08, 164.02, 187.12; IR (neat) 1728, 1668 cm^{-1}; FABMS: 251 (MH^+). HRMS calcd for $C_{14}H_{19}O_4$: 251.1283. Found 251.1283.

*4.2.4. tert-Butyl [2-(allyloxy)phenyl](oxo)acetate (**7**).* Prepared from 2-allyloxy-1-bromobenzene,[13] according to the above general procedure. Yellow oil; yield 67%; ^{1}H NMR ($CDCl_3$) δ 1.58 (9H, s), 4.68 (2H, d, *J*=4.9 Hz), 5.29 (1H, dd, *J*=1.6, 10.8 Hz), 5.38 (1H, dd, *J*=1.6, 17 Hz), 5.93–6.07 (1H, m), 6.94 (1H, d, *J*=7.3 Hz), 7.05 (1H, t, *J*=7.3 Hz), 7.52 (1H, t, *J*=7.3 Hz), 7.85 (1H, d, *J*=7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 28.06, 69.60, 83.48, 113.08, 118.13, 121.08, 123.22, 130.91, 132.17, 135.53, 158.89, 164.12, 186.81; IR (neat) 1728, 1670 cm^{-1}; EIMS *m*/*z*: 262 (M^+, 1.2), 161 (100). HRMS calcd for $C_{15}H_{18}O_4$: 262.1205. Found 262.1198.

*4.2.5. tert-Butyl [2-(2-methoxyethoxy)phenyl](oxo)acetate (**8**).* The corresponding arylmagnesium bromide, 2-(2-methoxyethoxy)-phenylmagnesium bromide, was prepared from (2-methoxyethoxy)benzene (5 mmol), *n*-BuLi (1.65 M in hexane, 5 mmol), and $MgBr_2$ (1.0 M in Et_2O, 6 mmol). Thereafter, the desired **8** was prepared according to the above general procedure. Yellow oil; yield 11%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.39 (3H, s), 3.72 (2H, t, *J*=5.1 Hz), 4.26 (2H, t, *J*=5.1 Hz), 7.06 (2H, t, *J*=7.6 Hz), 7.53 (1H, t, *J*=7.6 Hz), 7.81 (1H, d, *J*=7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 28.1, 59.1, 68.9, 70.6, 83.5, 113.6, 121.3, 123.7, 130.9, 135.5, 159.3, 163.9, 186.9; IR (neat) 1728, 1670 cm^{-1}; FABMS: 281 (MH^+). HRMS calcd for $C_{15}H_{21}O_5$: 281.1389. Found 281.1390.

*4.2.6. tert-Butyl [2-(methoxymethoxy)phenyl](oxo)acetate (**9**).* Prepared from 1-bromo-2-(methoxymethoxy)benzene,[14] according to the above general procedure. Yellow oil; yield 80%; ^{1}H NMR ($CDCl_3$) δ 1.68 (9H, s), 3.48 (3H, s), 5.22 (s, 2H), 7.11 (1H, t, *J*=7.3 Hz), 7.22 (1H, d, *J*=8.1 Hz), 7.54 (1H, t, *J*=8.1 Hz), 7.88 (1H, d, *J*=7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 28.8, 57.2, 84.1, 95.1, 115.5, 122.8, 123.9, 131.5, 136.4, 158.3, 164.9, 187.2; IR (neat) 1730, 1670 cm^{-1}; EIMS *m*/*z*: 266 (M^+, 0.4), 165 (100). HRMS calcd for $C_{14}H_{18}O_5$: 266.1154. Found 266.1175.

*4.2.7. tert-Butyl {2-[(tetrahydro-2H-pyran-2-yl)methoxy]phenyl}(oxo)-acetate (**10**).* Prepared from 1-bromo-2-[(tetrahydro-2*H*-pyran-2-yl)]benzene,[15] according to the above general procedure. Yellow oil; yield 16%; ^{1}H NMR ($CDCl_3$) δ 1.58 (9H, s), 1.62–2.03 (6H, m), 3.58–3.63 (1H, m), 3.79–3.88 (1H, m), 5.50 (1H, t, *J*=3.2 Hz), 7.07 (1H, t, *J*=8.1 Hz), 7.22 (1H, d, *J*=8.1 Hz), 7.51 (1H, t, *J*=8.1 Hz), 7.71 (1H, d, *J*=8.1 Hz); ^{13}C NMR ($CDCl_3$) δ 18.50, 24.66, 27.74, 29.49, 62.03, 83.34, 96.93, 115.19, 121.17, 123.95, 130.31, 134.64, 156.64, 163.08, 187.26; IR (neat) 1726, 1685 cm^{-1}; FABMS: 307 (MH^+). HRMS calcd for $C_{17}H_{23}O_5$: 307.1545. Found 307.1537.

*4.2.8. tert-Butyl [2-(tert-butyldimethylsilyloxy)phenyl](oxo)acetate (**11**).* *p*-TsOH monohydrate was added to a solution of **9** (3.46 g, 13 mmol) in CH_2Cl_2/MeOH (4:1, 50 ml) and the mixture was stirred at room temperature for 90 h. After addition of H_2O, the whole mixture was extracted with AcOEt three times. The combined organic extracts were washed with satd $NaHCO_3$ aq and brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (hexane/AcOEt=20:1) to give *tert*-butyl (2-hydroxyphenyl)(oxo)acetate (2.11 g, 71%). Yellow oil;

^{1}H NMR ($CDCl_3$) δ 1.65 (9H, s), 6.96 (1H, t, J=7.8 Hz), 7.03 (1H, d, J=7.8 Hz), 7.56 (1H, t, J=7.8 Hz), 7.62 (1H, d, J=7.8 Hz), 11.21 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.13, 85.48, 115.86, 118.46, 119.54, 131.90, 137.75, 161.97, 163.56, 191.18; IR (neat) 3186, 1733, 1639 cm^{-1}; EIMS m/z: 222 (M^+, 1.0), 57 (100). HRMS calcd for $C_{12}H_{14}O_4$: 222.0892. Found 222.0889. Under an argon atmosphere, TBDMSCl (710 mg, 4.70 mmol) and imidazole (669 mg, 9.83 mmol) were added to a solution of *tert*-butyl (2-hydroxyphenyl)(oxo)acetate (873 mg, 3.93 mmol) in DMF (5 ml) at room temperature and the mixture was stirred for 12 h. After addition of H_2O, the mixture was extracted with Et_2O three times. The combined organic extracts were washed with H_2O and brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography (hexane/AcOEt=100:1) to give the desired **11** (965 mg, 73%). Yellow oil; ^{1}H NMR ($CDCl_3$) δ 0.23 (6H, s), 0.96 (9H, s), 1.55 (9H, s), 6.90 (1H, d, J=8.7 Hz), 7.01 (1H, t, J=8.7 Hz), 7.41 (1H, t, J=8.7 Hz), 7.54 (1H, d, J=8.7 Hz); ^{13}C NMR ($CDCl_3$) δ −3.95, 14.25, 18.66, 25.96, 28.07, 83.84, 120.74, 121.04, 126.43, 131.17, 134.18, 155.96, 162.93, 187.83; IR (neat) 1728, 1690, 1258 cm^{-1}; EIS m/z: 279 (M^+, 9.0), 223 (100). HRMS calcd for $C_{14}H_{19}O_4Si$: 279.1053. Found 279.1055.

*4.2.9. tert-Butyl (2,5-dimethoxyphenyl)(oxo)acetate (**21**).* Prepared from 1-bromo-2,5-dimethoxybenzene, according to the above general procedure. Brown oil; yield 89%; ^{1}H NMR ($CDCl_3$) δ 1.60 (9H, s), 3.81 (3H, s), 3.83 (3H, s), 6.93 (1H, d, J=9.2 Hz), 7.14 (1H, dd, J=3.2, 9.2 Hz), 7.37 (1H, d, J=3.2 Hz); ^{13}C NMR ($CDCl_3$) δ 28.10, 55.90, 56.44, 83.37, 112.99, 113.76, 122.89, 123.55, 153.81, 154.80, 164.34, 186.20; IR (neat) 1730, 1670 cm^{-1}; EIMS m/z: 266 (M^+, 22.0), 165 (100). HRMS calcd for $C_{14}H_{18}O_5$: 266.1154. Found 266.1148.

*4.2.10. tert-Butyl (2-methoxy-5-methylphenyl)(oxo)acetate (**22**).* Prepared from 1-bromo-2-methoxy-5-methylbenzene, according to the above general procedure. Yellow oil; yield 91%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 2.32 (3H, s), 3.84 (3H, s), 6.87 (1H, d, J=8.4 Hz), 7.36 (1H, dd, J=2.2, 8.4 Hz), 7.67 (1H, d, J=2.2 Hz); ^{13}C NMR ($CDCl_3$) δ 20.31, 28.09, 55.84, 83.24, 111.85, 122.43, 130.53, 130.85, 136.55, 158.14, 164.44, 186.67; IR (neat) 1730, 1668 cm^{-1}; EIMS m/z: 250 (M^+, 2.2), 149 (100). HRMS calcd for $C_{14}H_{18}O_4$: 250.1205. Found 250.1201.

*4.2.11. tert-Butyl (5-chloro-2-methoxyphenyl)(oxo)acetate (**23**).* Prepared from 1-bromo-5-chloro-2-methoxybenzene, according to the above general procedure. White solid (mp 73–74 °C); yield 84%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.87 (3H, s), 6.93 (1H, d, J=8.9 Hz), 7.50 (1H, dd, J=2.7, 8.9 Hz), 7.81 (1H, d, J=2.7 Hz); ^{13}C NMR ($CDCl_3$) δ 28.03, 56.12, 83.77, 113.35, 123.95, 126.52, 130.26, 135.33, 158.37, 163.63, 185.31; IR (Nujol) 1730, 1678 cm^{-1}; EIMS m/z: 272 (M^+, 0.4), 270 (M^+, 1.3), 169 (100). HRMS calcd for $C_{13}H_{15}{}^{35}ClO_4$: 270.0659. Found 270.0672.

*4.2.12. tert-Butyl (2,4-dimethoxyphenyl)(oxo)acetate (**24**).* Prepared from 1-bromo-2,4-dimethoxybenzene, according to the above general procedure. White solid (mp 81–83 °C); yield 62%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.85 (3H, s), 3.87 (3H, s), 6.43 (1H, d, J=2.2 Hz), 6.58 (1H, dd, J=2.2, 8.9 Hz), 7.89 (1H, d, J=8.9 Hz); ^{13}C NMR ($CDCl_3$) δ 28.07, 55.64, 55.68, 82.99, 98.03, 106.45, 115.77, 132.88, 161.98, 164.95, 166.30, 184.94; IR (Nujol) 1716, 1666 cm^{-1}; EIMS m/z: 266 (M^+, 3.4), 165 (100). HRMS calcd for $C_{14}H_{18}O_5$: 266.1154. Found 266.1128.

*4.2.13. tert-Butyl (4-chloro-2-methoxyphenyl)(oxo)acetate (**25**).* Prepared from 1-bromo-4-chloro-2-methoxybenzene, according to the above general procedure. Yellow oil; yield 63%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.88 (3H, s), 6.98 (1H, s), 7.04 (1H, d, J=8.4 Hz), 7.81 (1H, d, J=8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 28.02, 56.03, 83.58, 112.49, 121.32, 121.59, 131.92, 141.92, 160.25, 163.92, 185.37; IR (neat) 1730, 1670 cm^{-1}; FABMS: 271 (MH^+), 273 (MH^+). HRMS calcd for $C_{13}H_{16}{}^{35}ClO_4$: 271.0737. Found 271.0714. Calcd for $C_{13}H_{16}{}^{37}ClO_4$: 273.0708. Found 273.0718.

*4.2.14. tert-Butyl (3-methoxynaphth-2-yl)(oxo)acetate (**26**).* Prepared from 2-bromo-3-methoxynaphthalene, according to the above general procedure. Yellow solid (mp 135–137 °C); yield 63%; ^{1}H NMR ($CDCl_3$) δ 1.61 (9H, s), 3.96 (3H, s), 7.18 (1H, s), 7.38 (1H, t, J=8.1 Hz), 7.54 (1H, t, J=8.1 Hz), 7.73 (1H, d, J=8.1 Hz), 7.86 (1H, d, J=8.1 Hz), 8.38 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 28.07, 55.61, 83.48, 106.44, 124.53, 124.61, 126.46, 127.93, 129.14, 129.48, 133.01, 137.27, 155.79, 163.88, 186.95; IR (Nujol) 1714, 1672 cm^{-1}; EIMS m/z: 286 (M^+, 4.7), 185 (100). HRMS calcd for $C_{17}H_{18}O_4$: 286.1205. Found 286.1196.

*4.2.15. tert-Butyl (2-methoxy-3-methylphenyl)(oxo)acetate (**27**).* Prepared from 1-bromo-2-methoxy-3-methylbenzene,[16] according to the above general procedure. Colorless oil; yield 83%; ^{1}H NMR ($CDCl_3$) δ 1.60 (9H, s), 2.34 (3H, s), 3.75 (3H, s), 7.13 (1H, t, J=7.6 Hz), 7.44 (1H, d, J=7.6 Hz), 7.70 (1H, d, J=7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 15.99, 27.97, 62.18, 83.58, 124.24, 127.25, 128.28, 131.62, 137.70, 159.75, 164.21, 187.36; IR (neat) 1730, 1676 cm^{-1}; EIMS m/z: 250 (M^+, 0.5), 149 (100). HRMS calcd for $C_{14}H_{18}O_4$: 250.1205. Found 250.1199.

*4.2.16. tert-Butyl (2-methoxypyridin-3-yl)(oxo)acetate (**42**).* Prepared from 3-bromo-2-methoxypyridine, according to the above general procedure. Yellow oil; yield 35%; ^{1}H NMR ($CDCl_3$) δ 1.60 (9H, s), 4.02 (3H, s), 7.03 (1H, dd, J=4.5, 7.0 Hz), 8.17 (1H, dd, J=2.0, 7.0 Hz), 8.39 (1H, dd, J=2.0, 4.5 Hz); ^{13}C NMR ($CDCl_3$) δ 28.07, 53.82, 83.96, 117.01, 117.34, 140.21, 152.74, 162.63, 163.59, 185.69; IR (neat) 1731, 1676 cm^{-1}; FABMS: 238 (MH^+). HRMS calcd for $C_{12}H_{16}NO_4$: 238.1079. Found 238.1094.

*4.2.17. tert-Butyl (2,4-dimethoxypyrimidin-5-yl)(oxo)acetate (**43**).* Prepared from 5-bromo-2,4-dimethoxypyrimidine, according to the above general procedure. Yellow oil; yield 50%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 4.07 (3H, s), 4.09 (3H, s), 8.86 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.03, 54.48, 55.78, 84.24, 109.80, 163.08, 163.17, 167.59, 169.66, 183.09; IR (neat) 1737, 1674 cm^{-1}; FABMS: 269 (MH^+). HRMS calcd for $C_{12}H_{17}N_2O_5$: 269.1137. Found 269.1139.

*4.2.18. tert-Butyl (3-methoxythien-2-yl)(oxo)acetate (**44**).* Prepared from 2-bromo-3-methoxythiophene[17] [^{1}H NMR ($CDCl_3$) δ 3.89 (3H, s), 6.76 (1H, d, J=5.9 Hz), 7.20 (1H, d, J=5.9 Hz); ^{13}C NMR ($CDCl_3$) δ 59.18, 90.72, 116.33, 124.19, 155.09; EIMS m/z: 194 (M^+, 95.2), 192 (M^+, 94.6), 57 (100). HRMS calcd for $C_5H_5{}^{79}BrOS$: 191.9245. Found 191.9251. Calcd for $C_5H_5{}^{81}BrOS$: 193.9224. Found 193.9224.], according to the above general procedure. Brown oil; yield 7%; ^{1}H NMR ($CDCl_3$) δ 1.59 (9H, s), 3.96 (3H, s), 6.87 (1H, d, J=5.4 Hz), 7.70 (1H, d, J=5.4 Hz); ^{13}C NMR ($CDCl_3$) δ 27.95, 58.86, 83.85, 115.62, 117.12, 136.52, 163.50, 163.70, 178.18; IR (neat) 1731, 1633 cm^{-1}; EIMS m/z: 242 (M^+, 1.6), 141 (100). HRMS calcd for $C_{11}H_{14}O_4S$: 242.0613. Found 242.0611.

4.3. Reaction of substrates with TMSC(MgBr)N_2

Under an argon atmosphere, *n*-BuLi (1.65 M in hexane, 0.91 ml, 1.5 mmol) was added dropwise to a solution of $TMSCHN_2$ (1.73 M in hexane, 0.87 ml, 1.5 mmol) in anhydrous THF (8 ml) at −78 °C and the mixture was stirred at −78 °C for 20 min. After the addition of $MgBr_2$ [1.00 M in Et_2O/toluene (1:1), 1.5 ml, 1.5 mmol], the mixture was further stirred at −78 °C for 30 min. A solution of aryl(oxo)-acetate (1.0 mmol) in anhydrous THF (2 ml) was added dropwise to the above mixture at −78 °C and the mixture was stirred at −78 °C for 3 h then refluxed for 2 h. After the addition of satd NH_4Cl aq, the mixture was extracted with AcOEt three times. The combined organic extracts were washed with H_2O and brine, dried over Na_2SO_4,

and concentrated in vacuo. The residue was purified by silica gel column chromatography (hexane–AcOEt or hexane–$CHCl_3$ system) to give the following products.

*4.3.1. Ethyl benzofuran-3-carboxylate (**3**).* See Ref. 3

*4.3.2. tert-Butyl benzofuran-3-carboxylate (**4**).* Yellow oil; yield 55%; ^{1}H NMR ($CDCl_3$) δ 1.63 (9H, s), 7.32–7.37 (2H, m), 7.49–7.53 (1H, m), 8.01–8.04 (1H, m), 8.18 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.4, 81.2, 111.5, 116.0, 121.9, 123.8, 124.7, 124.9, 150.5, 155.4, 162.6; IR (neat) 1716 cm^{-1}; EIMS *m*/*z*: 218 (M^+, 22.4), 162 (100). HRMS calcd for $C_{13}H_{14}O_3$: 218.0943. Found 218.0964.

*4.3.3. tert-Butyl 3-(2-methoxyphenyl)propiolate (**5**).* Red oil; yield 16%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 3.89 (3H, s), 6.87–6.95 (2H, m), 7.38 (1H, t, *J*=7.9 Hz), 7.51 (1H, t, *J*=7.9 Hz); ^{13}C NMR ($CDCl_3$) δ 28.1, 55.8, 80.7, 83.2, 85.9, 109.1, 110.7, 120.4, 131.8, 134.7, 153.1, 161.2; IR (neat) 2210, 1701 cm^{-1}; EIMS *m*/*z*: 232 (M^+, 34.0), 176 (100). HRMS calcd for $C_{14}H_{16}O_3$: 232.1099. Found 232.1105.

*4.3.4. tert-Butyl 3-(2-ethoxyphenyl)propiolate (**12**).* Brown solid (mp 73–75 °C); yield 6%; ^{1}H NMR ($CDCl_3$) δ 1.48 (3H, t, *J*=7.0 Hz), 1.54 (9H, s), 4.11 (2H, q, *J*=7.0 Hz), 6.87 (1H, d, *J*=8.4 Hz), 6.90 (1H, t, *J*=7.6 Hz), 7.35 (1H, dd, *J*=7.6, 8.4 Hz), 7.50 (1H, d, *J*=7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 14.70, 28.13, 64.39, 80.91, 83.10, 85.86, 109.39, 111.85, 120.23, 131.74, 134.65, 153.18, 160.76; IR (Nujol) 2208, 1697 cm^{-1}; EIMS *m*/*z*: 246 (M^+, 23.0), 144 (100). HRMS calcd for $C_{15}H_{18}O_3$: 246.1256. Found 246.1241.

*4.3.5. tert-Butyl 3-[2-(allyloxy)phenyl]propiolate (**13**).* Red oil; yield 9%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 4.63 (2H, d, *J*=4.9 Hz), 5.31 (1H, dd, *J*=1.6, 10 Hz), 5.54 (1H, dd, *J*=1.6, 17 Hz), 5.99–6.13 (1H, m), 6.86–6.95 (2H, m), 7.35 (1H, dt, *J*=1.6, 7.6 Hz), 7.52 (1H, dd, *J*=1.6, 7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 28.14, 69.08, 80.65, 83.13, 86.08, 109.64, 112.19, 117.23, 120.56, 131.68, 132.36, 134.60, 153.14, 160.38; IR (neat) 2212, 1630 cm^{-1}; EIMS *m*/*z*: 258 (M^+, 22.9), 144 (100). HRMS calcd for $C_{16}H_{18}O_3$: 258.1256. Found 258.1249.

*4.3.6. tert-Butyl 3-[2-(2-methoxyethoxy)phenyl]propiolate (**14**).* Red oil; yield 16%; ^{1}H NMR ($CDCl_3$) δ 1.53 (9H, s), 3.53 (3H, s), 3.83 (2H, t, *J*=4.9 Hz), 4.19 (2H, t, *J*=4.9 Hz), 6.90 (1H, d, *J*=8.1 Hz), 6.93 (1H, t, *J*=8.1 Hz), 7.36 (1H, td, *J*=1.9, 8.1 Hz), 7.51 (1H, dd, *J*=1.9, 8.1 Hz); ^{13}C NMR ($CDCl_3$) δ 28.12, 59.78, 68.89, 70.77, 80.71, 83.06, 85.99, 109.70, 112.17, 120.72, 131.76, 134.61, 153.13, 160.74; IR (neat) 2212, 1701 cm^{-1}; EIMS *m*/*z*: 276 (M^+, 46.7), 59 (100). HRMS calcd for $C_{16}H_{20}O_4$: 276.1362. Found 276.1348.

*4.3.7. tert-Butyl 3-[2-(methoxymethoxy)phenyl]propiolate (**15**).* Yellow oil; yield 14%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 3.53 (3H, s), 5.26 (2H, s), 6.99 (1H, t, *J*=8.4 Hz), 7.14 (1H, d, *J*=8.4 Hz), 7.36 (1H, t, *J*=8.4 Hz), 7.52 (1H, d, *J*=8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 28.11, 56.39, 80.58, 83.22, 85.71, 94.91, 110.46, 114.97, 121.67, 131.67, 134.50, 153.07, 159.04; IR (neat) 2212, 1701 cm^{-1}; EIMS *m*/*z*: 262 (M^+, 1.4), 144 (100). HRMS calcd for $C_{15}H_{18}O_4$: 262.1205. Found 262.1227.

*4.3.8. tert-Butyl 2-(methoxymethyl)benzofuran-3-carboxylate (**17**).* Yellow oil; yield 30%; ^{1}H NMR ($CDCl_3$) δ 1.66 (9H, s), 3.49 (3H, s), 4.96 (2H, s), 7.31–7.37 (2H, m), 7.49–7.53 (1H, m), 7.98–8.01 (1H, m); ^{13}C NMR ($CDCl_3$) δ 28.4, 58.7, 65.5, 81.6, 111.3, 112.6, 122.2, 123.7, 125.1, 125.5, 153.9, 159.8, 162.7; IR (neat) 1708 cm^{-1}; EIMS *m*/*z*: 262 (M^+, 4.7), 173 (100). HRMS calcd for $C_{15}H_{18}O_4$: 262.1205. Found 262.1205.

*4.3.9. tert-Butyl 3-[2-(tert-butyldimethylsilyloxy)phenyl]propiolate (**16**).* Yellow oil; yield 10%; ^{1}H NMR ($CDCl_3$) δ 0.25 (6H, s), 1.05 (9H, s), 1.53 (9H, s), 6.83 (1H, d, *J*=8.4 Hz), 6.93 (1H, t, *J*=7.2 Hz), 7.29 (1H, dd, *J*=7.2, 8.4 Hz), 7.48 (1H, d, *J*=7.2 Hz); ^{13}C NMR ($CDCl_3$) δ −4.26, 18.35, 25.78, 28.17, 81.58, 82.96, 85.66, 112.63, 119.74, 121.14, 131.54, 134.47, 153.11, 158.03; IR (neat) 2214, 1708, 1151 cm^{-1}; FABMS *m*/*z*: 333 (MH^+). HRMS calcd for $C_{19}H_{29}O_3Si$: 333.1886. Found 333.1877.

*4.3.10. tert-Butyl 2-(tert-butyldimethylsilyl)benzofuran-3-carboxylate (**18**).* Colorless oil; yield 28%; ^{1}H NMR ($CDCl_3$) δ 0.43 (6H, s), 1.02 (9H, s), 1.65 (9H, s), 7.24–7.33 (2H, m), 7.48–7.51 (1H, m), 7.94–7.97 (1H, m); ^{13}C NMR ($CDCl_3$) δ −5.44, 18.09, 26.89, 28.50, 81.03, 111.24, 122.11, 123.21, 124.72, 125.51, 125.84, 157.50, 163.58, 169.39; IR (neat) 1712, 1242 cm^{-1}; FABMS *m*/*z*: 333 (MH^+). HRMS calcd for $C_{19}H_{29}O_3Si$: 333.1886. Found 333.1871.

*4.3.11. 1-Methoxy-2-(prop-1-ynyl)benzene (**20**).* See Ref. 18

*4.3.12. tert-Butyl 5-methoxybenzofuran-3-carboxylate (**28**).* Colorless oil; yield 47%; ^{1}H NMR ($CDCl_3$) δ 1.63 (9H, s), 3.86 (3H, s), 6.92 (1H, dd, *J*=2.7, 9.2 Hz), 7.37 (1H, d, *J*=9.2 Hz), 7.50 (1H, d, *J*=2.7 Hz), 8.13 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.36, 55.70, 81.09, 103.53, 111.98, 114.23, 115.82, 125.35, 150.31, 151.05, 156.63, 162.62; IR (neat) 1713 cm^{-1}; EIMS *m*/*z*: 248 (M^+, 22.8), 192 (100). HRMS calcd for $C_{14}H_{16}O_4$: 248.1049. Found 248.1045.

*4.3.13. tert-Butyl 3-(2,5-dimethoxyphenyl)propiolate (**35**).* Yellow oil; yield 12%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 3.75 (3H, s), 3.85 (3H, s), 6.81 (1H, d, *J*=9.2 Hz), 6.94 (1H, dd, *J*=3.0, 9.2 Hz), 7.04 (1H, d, *J*=3.0 Hz); ^{13}C NMR ($CDCl_3$) δ 28.11, 55.83, 56.35, 80.58, 83.29, 85.72, 109.34, 112.05, 118.38, 118.63, 152.89, 153.01, 155.80; IR (neat) 2212, 1697 cm^{-1}; EIMS *m*/*z*: 262 (M^+, 24.7), 206 (100). HRMS calcd for $C_{15}H_{18}O_4$: 262.1205. Found 262.1207.

*4.3.14. tert-Butyl 5-methylbenzofuran-3-carboxylate (**29**).* Yellow solid (mp 46–47 °C); yield 42%; ^{1}H NMR ($CDCl_3$) δ 1.65 (9H, s), 2.48 (3H, s), 7.14 (1H, d, *J*=8.4 Hz), 7.38 (1H, d, *J*=8.4 Hz), 7.85 (1H, s), 8.14 (1H, s); ^{13}C NMR ($CDCl_3$) δ 21.42, 28.37, 81.09, 110.91, 115.56, 121.59, 124.73, 126.12, 133.38, 150.55, 153.89, 162.68; IR (Nujol) 1717 cm^{-1}; EIMS *m*/*z*: 232 (M^+, 40.3), 176 (100). HRMS calcd for $C_{14}H_{16}O_3$: 232.1099. Found 232.1096.

*4.3.15. tert-Butyl 3-(2-methoxy-5-methylphenyl)propiolate (**36**).* Yellow oil; yield 15%; ^{1}H NMR ($CDCl_3$) δ 1.53 (9H, s), 2.25 (3H, s), 3.85 (3H, s), 6.77 (1H, d, *J*=8.6 Hz), 7.17 (1H, dd, *J*=1.9, 8.6 Hz), 7.32 (1H, d, *J*=1.9 Hz); ^{13}C NMR ($CDCl_3$) δ 20.17, 28.12, 55.88, 80.97, 83.11, 85.65, 108.68, 110.61, 129.66, 132.43, 134.96, 153.12, 159.25; IR (neat) 2210, 1697 cm^{-1}; EIMS *m*/*z*: 246 (M^+, 34.8), 190 (100). HRMS calcd for $C_{15}H_{18}O_3$: 246.1256. Found 246.1257.

*4.3.16. tert-Butyl 5-chlorobenzofuran-3-carboxylate (**30**).* Red oil; yield 40%; ^{1}H NMR ($CDCl_3$) δ 1.63 (9H, s), 7.30 (1H, dd, *J*=2.2, 8.6 Hz), 7.43 (1H, d, *J*=8.6 Hz), 8.00 (1H, d, *J*=2.2 Hz), 8.18 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.42, 81.76, 112.56, 115.79, 121.73, 125.33, 126.11, 129.74, 151.60, 153.79, 162.05; IR (Nujol) 1714 cm^{-1}; EIMS *m*/*z*: 254 (M^+, 6.8), 252 (M^+, 20.9), 196 (100). HRMS calcd for $C_{13}H_{13}{}^{35}ClO_3$: 252.0553. Found 252.0546. Calcd for $C_{13}H_{13}{}^{37}ClO_3$: 254.0524. Found 254.0497.

*4.3.17. tert-Butyl 3-(5-chloro-2-methoxyphenyl)propiolate (**37**).* Brown oil; yield 13%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 3.87 (3H, s), 6.82 (1H, d, *J*=9.2 Hz), 7.32 (1H, dd, *J*=2.7, 9.2 Hz), 7.47 (1H, d, *J*=2.7 Hz); ^{13}C NMR ($CDCl_3$) δ 28.10, 56.18, 78.91, 83.54, 86.53, 110.70, 111.93, 125.13, 131.56, 133.85, 152.72, 159.84; IR (neat) 2217, 1705 cm^{-1}; EIMS *m*/*z*: 268 (M^+, 10.8), 266 (M^+, 32.8), 210 (100). HRMS calcd for $C_{14}H_{15}{}^{35}ClO_3$: 266.0710. Found 266.0722. Calcd for $C_{14}H_{15}{}^{37}ClO_3$: 268.0680. Found 268.0679.

*4.3.18. tert-Butyl 6-methoxybenzofuran-3-carboxylate (**31**).* Yellow oil; yield 62%; ^{1}H NMR ($CDCl_3$) δ 1.62 (9H, s), 3.85 (3H, s), 6.97 (1H,

dd, J=8.6, 2.2 Hz), 7.02 (1H, d, J=2.2 Hz), 7.86 (1H, d, J=8.6 Hz), 8.08 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 28.45, 55.73, 81.20, 95.93, 113.00, 115.99, 117.99, 122.01, 149.59, 156.47, 158.30, 162.72; IR (neat) 1712 cm^{-1}; EIMS m/z: 248 (M^+, 35.1), 192 (100). HRMS calcd for $C_{14}H_{16}O_4$: 248.1049. Found 248.1057.

*4.3.19. tert-Butyl 3-(2,4-dimethoxyphenyl)propiolate (**38**).* Yellow oil; yield 9%; ^{1}H NMR ($CDCl_3$) δ 1.53 (9H, s), 3.83 (3H, s), 3.87 (3H, s), 6.41 (1H, d, J=2.2 Hz), 6.46 (1H, dd, J=2.2, 8.6 Hz), 7.45 (1H, d, J=8.6 Hz); ^{13}C NMR ($CDCl_3$) δ 28.17, 55.53, 55.85, 81.55, 82.93, 85.27, 98.24, 101.52, 105.19, 136.00, 153.39, 162.80, 162.86; IR (neat) 2202, 1697 cm^{-1}; EIMS m/z: 262 (M^+, 24.0), 206 (100). HRMS calcd for $C_{15}H_{18}O_4$: 262.1205. Found 262.1199.

*4.3.20. tert-Butyl 6-chlorobenzofuran-3-carboxylate (**32**).* Yellow oil; yield 49%; ^{1}H NMR ($CDCl_3$) δ 1.52 (9H, s), 7.19 (1H, d, J=8.6 Hz), 7.38 (1H, s), 7.81 (1H, d, J=8.6 Hz), 8.03 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.35, 81.52, 111.98, 115.94, 122.47, 123.39, 124.61, 130.90, 150.86, 155.31, 162.00; IR (neat) 1714 cm^{-1}; FABMS: 252 (M^+), 254 (M^+). HRMS calcd for $C_{13}H_{13}{}^{35}ClO_3$: 252.0553. Found, 252.0556. Calcd for $C_{13}H_{13}{}^{37}ClO_3$: 254.0524. Found 254.0543.

*4.3.21. tert-Butyl 3-(4-chloro-2-methoxyphenyl)propiolate (**39**).* Brown oil; yield 17%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 3.89 (1H, s), 6.88 (1H, d, J=1.9 Hz), 6.91 (1H, dd, J=1.9, 8.4 Hz), 7.42 (1H, d, J=8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 28.11, 56.14, 79.53, 83.43, 86.50, 107.86, 111.66, 120.78, 135.22, 137.61, 152.88, 161.66; IR (neat) 2212, 1697 cm^{-1}; EIMS m/z: 268 (M^+, 13.2), 266 (M^+, 39.3), 210 (100). HRMS calcd for $C_{14}H_{15}{}^{35}ClO_3$: 266.0710. Found 266.0713. Calcd for $C_{14}H_{15}{}^{37}ClO_3$: 268.0680. Found 268.0679.

*4.3.22. tert-Butyl naphtho[2,3-b]furan-3-carboxylate (**33**).* Yellow solid (mp 95–96 °C); yield 33%; ^{1}H NMR ($CDCl_3$) δ 1.56 (9H, s), 7.29–7.38 (2H, m), 7.77–7.89 (3H, m), 8.15 (1H, s), 8.40 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.45, 81.41, 107.30, 115.41, 120.38, 124.41, 125.01, 125.31, 127.67, 128.37, 130.84, 131.29, 153.01, 154.15, 162.46; IR (Nujol) 1714 cm^{-1}; EIMS m/z: 268 (M^+, 16.8), 212 (100). HRMS calcd for $C_{17}H_{16}O_3$: 268.1099. Found 268.1101.

*4.3.23. tert-Butyl 3-(3-methoxynaphthalen-2-yl)propiolate (**40**).* Red oil; yield 29%; ^{1}H NMR ($CDCl_3$) δ 1.57 (9H, s), 3.97 (3H, s), 7.10 (1H, s), 7.35 (1H, t, J=8.1 Hz), 7.48 (1H, t, J=8.1 Hz), 7.70 (1H, d, J=8.1 Hz), 7.71 (1H, d, J=8.1 Hz), 8.07 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.10, 55.81, 80.66, 83.27, 85.64, 105.47, 110.85, 124.31, 126.48, 127.65, 127.81, 128.01, 135.09, 135.98, 152.94, 157.03; IR (neat) 2212, 1693 cm^{-1}; EIMS m/z: 282 (M^+, 41.1), 226 (100). HRMS calcd for $C_{18}H_{18}O_3$: 282.1256. Found 282.1259.

*4.3.24. tert-Butyl 7-methylbenzofuran-3-carboxylate (**34**).* Yellow oil; yield 32%; ^{1}H NMR ($CDCl_3$) δ 1.53 (9H, s), 2.41 (3H, s) 7.01 (1H, d, J=7.3 Hz), 7.12 (1H, t, J=7.3 Hz), 7.75 (1H, d, J=7.3 Hz), 8.07 (1H, s); ^{13}C NMR ($CDCl_3$) δ 14.87, 28.41, 81.12, 116.20, 119.29, 121.66, 123.89, 124.18, 125.77, 150.25, 154.55, 162.72; IR (neat) 1712 cm^{-1}; EIMS m/z: 232 (M^+, 12.9), 57 (100). HRMS calcd for $C_{14}H_{16}O_3$: 232.1099. Found 232.1091.

*4.3.25. tert-Butyl 3-(2-methoxy-3-methylphenyl)propiolate (**41**).* Yellow oil; yield 19%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 2.26 (3H, s), 3.95 (3H, s) 6.96 (1H, t, J=7.6 Hz), 7.22 (1H, d, J=7.6 Hz), 7.34 (1H, d, J=7.6 Hz); ^{13}C NMR ($CDCl_3$) δ 16.07, 28.11, 60.99, 80.93, 83.20, 85.88, 113.10, 123.31, 131.38, 132.33, 133.38, 153.02, 160.87; IR (neat) 2214, 1701 cm^{-1}; EIMS m/z: 246 (M^+, 51.1), 145 (100). HRMS calcd for $C_{15}H_{18}O_3$: 246.1256. Found 246.1256.

*4.3.26. tert-Butyl 3-(2-methoxypyridin-3-yl)propiolate (**45**).* Colorless oil; yield 6%; ^{1}H NMR ($CDCl_3$) δ 1.55 (9H, s), 4.02 (3H, s), 6.89 (1H, dd, J=5.1, 7.6 Hz), 7.79 (1H, dd, J=1.9, 7.6 Hz), 8.20 (1H, dd, J=1.9, 5.1 Hz); ^{13}C NMR ($CDCl_3$) δ 28.13, 54.17, 78.71, 83.66, 86.78, 104.21, 116.27, 143.12, 148.33, 152.72, 164.32; IR (neat) 2216, 1699 cm^{-1}; EIMS m/z: 233 (M^+, 68.3), 177 (100). HRMS calcd for $C_{13}H_{15}NO_3$: 233.1052. Found 233.1046.

*4.3.27. tert-Butyl 3-(2,4-dimethoxypyrimidin-5-yl)propiolate (**46**).* White solid (mp 89–91 °C); yield 39%; ^{1}H NMR ($CDCl_3$) δ 1.54 (9H, s), 4.01 (3H, s), 4.06 (3H, s), 8.45 (1H, s); ^{13}C NMR ($CDCl_3$) δ 28.01, 54.62, 55.28, 76.02, 83.52, 88.12, 96.94, 152.49, 163.24, 164.97, 171.11; IR (Nujol) 2219, 1712 cm^{-1}; EIMS m/z: 264 (M^+, 25.8), 208 (100). HRMS calcd for $C_{13}H_{16}N_2O_4$: 264.1110. Found 264.1106.

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