Lithiation of 1-alkynyl-1-chlorocyclopropanes and subsequent reactions with electrophilic reagents: synthesis of functionalized alkynyl- and vinylidenecyclopropanes

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1-Alkynyl-1-chlorocyclopropanes undergo chlorine-lithium exchange on treatment with Bu^nLi in THF at −40—0 °C. Thus generated organolithium species react with carbon dioxide (dry ice) and acetone to give selectively hitherto unknown 1-alkynylcyclopropanecarboxylic acids and the corresponding alcohols in up to 74% yields. Similar reactions involving methyl chloroformate result in the mixtures of cyclopropylacetylenic and vinylidenecyclopropanic esters, while the use of aliphatic aldehydes as electrophiles provides secondary allenic alcohols in up to 64% yields.

Key words: 1-alkynyl-1-chlorocyclopropanes, *n*-butyllithium, lithiation, electrophilic reactions, regioselectivity, functionalized alkynylcyclopropanes, functionalized vinylidenecyclopropanes.

At present, alkynylcyclopropanes bearing functional groups at the three-membered cycle attract great attention of the researchers. These compounds are widely used in various chemical transformations[1—15] and exhibit valuable pharmacological activities.[16—18] Vinylidenecyclopropanes that are isomeric to alkynylcyclopropanes are the important building blocks extensively used in organic synthesis.[19] One of the types of alkynylcyclopropanes promising from a synthetic viewpoint is 1-alkynyl-1-chlorocyclopropanes that can be readily and efficiently accessed by [1+2] cycloaddition of alkynylchlorocarbenes to the alkene double bonds.[20,21] 1-Alkynyl-1-chlorocyclopropanes bearing such highly reactive moieties as the triple bond, cyclopropane ring, and the chlorine atom at the propargylic position were earlier subjected to hydrogenation,[22,23] dehydrochlorination to give conjugated alkynylcyclopropenes,[24] cycloaddition to the triple bond,[25] and cross-coupling with organozinc reagents.[26] A numerous examples of their transformation involving oxygen-,[27] nitrogen-,[9,24] and sulfur-centered nucleophiles[28] that proceed following elimination—addition mechanism are known. An unusual domino-reaction between alkynylchlorocycloprpanes and lithium derivatives of diaminoalkanes involving all the three reaction centers of the former to produce nitrogen-containing bicyclic systems was also reported.[10,29]

Another approach for functionalization of 1-alkynyl-1-chlorocyclopropanes is the chlorine-lithium exchange followed by the reaction of the generated organolithium compounds with electrophilic reagents. Note that this approach was approved only for 1-(trimethylsilylethynyl)-1-chlorocyclopropanes[30,31] and was not systematically studied to date. At the same time, it is known[32] that allenylpropargyllithium intermediates generated upon these reactions are complex equilibrium mixtures of different structures, therefore, depending on the reaction conditions their reactions with electrophiles can result in either cyclopropylacetylenic or vinylidenecyclopropanic products.

Therefore, it would be interesting to study in-depth peculiarities of lithiation of different 1-alkynyl-1-chlorocyclopropanes and regioselectivity of the reactions of thus generated lithium species with a variety of electrophilic reagents.

Results and Discussion

Our study revealed that addition of small excess (1.1 equiv.) of Bu^nLi solution in hexane to a solution of chlorocyclopropane **1a** in THF at −40÷−30 °C followed by treatment of the reaction mixture with dry ice results in previously unknown cyclopropanecarboxylic acid **2a** in 74% yield (Scheme 1). This compound was isolated pure by the conventional aqueous workup of the reaction mixture, acidification of the aqueous layer, and subsequent extraction. It is of note that performing the reaction at lower temperatures dramatically decreases the yield of acid **2a** due to low conversion of the starting compound. Thus,

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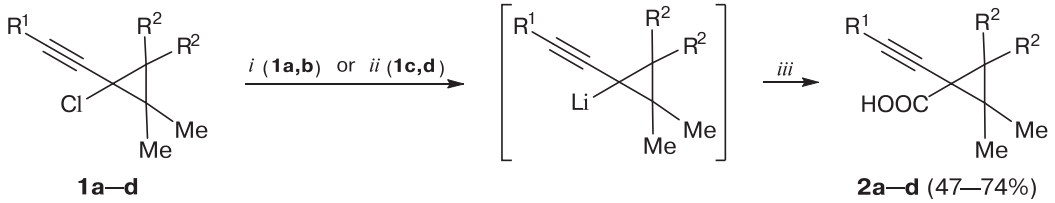
Scheme 1



1, 2: R^1 = Ph, R^2 = H (**a**), Me (**b**); R^1 = Bu^t, R^2 = Me (**c**); R^1 = Bu^n, R^2 = Me (**d**)

Reagents and conditions: *i*. THF, Bu^nLi (1 equiv.), −40÷−30 °C; *ii*. THF, Bu^nLi (1 equiv.), 0 °C; *iii*. 1) CO_2, 2) HCl, H_2O.

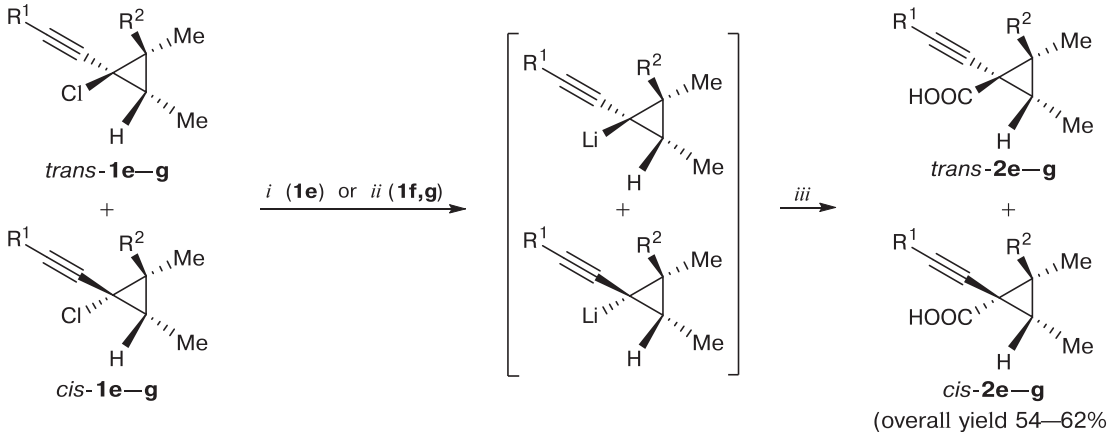
lithiation of cyclopropane **1a** with Bu^nLi at −70÷−60 °C for 5 h followed by addition of CO_2 gives acid **2a** in only 30% yield and GC analysis of the reaction mixture reveals the presence of large amount of unreacted **1a**.

Similarly, cyclopropane **1b** bearing four methyl groups at the cyclopropane ring was converted to the corresponding acid **2b** in 68% yield. In contrast, cyclopropanes **1c**,**d** react with Bu^nLi at −30 °C very slowly (CG analysis data) and their transformation into acids **2c**,**d** requires elevation of the reaction temperature to 0 °C (see Scheme 1). Apparently, the chlorine-lithium exchange in cyclopropanes **1c**,**d** is hindered since electronegativity of the alkylethynyl groups is lower than that of the phenylethynyl one.

When the isomeric mixtures of unsymmetrically substituted chlorocyclopropanes **1e**—**g** were used as the starting materials, the corresponding acids **2e**—**g** were prepared (Scheme 2). In all the cases, the isomeric compositions of products **2e—g** were close to those of the starting chlorides. For instance, chlorocyclopropane **1e** (*trans*-**1e** : *cis*-**1e** = = 1.12 : 1) produces a 1.2 : 1 mixture of acids *trans*-**2e** and *cis*-**2e** in 54% overall yield. Similarly, reactions of the isomeric mixtures of cyclopropanes **1f** and **1g** (*trans* : *cis* ratio of 1.2 : 1 and 1.4 : 1, respectively) give the corresponding acids **2f** and **2g** with *trans* : *cis* ratios of 1.1 : 1 and 1.5 : 1, respectively. Thus, the efficiency of metalation and subsequent carboxylation of both isomers of cyclopropanes **1e**—**g** is nearly equal.

We demonstrated that functionalization of alkynylchlorocyclopropanes **1** by lithiation and subsequent reactions with electrophilic reagents is of general character; however, the composition of the products dramatically depends on the nature of the compounds used. Thus, lithiation of cyclopropane **1a** in THF followed by addition of anhydrous acetone produces the corresponding tertiary alcohol **3** in 38% yield (Scheme 3). The low yield of compound **3** is apparently due to the side deprotonation of acetone to give hydrocarbon **4** in approximately the same amount as compound **3**. The formation of compound **4** was confirmed by the presence of the three characteristic doublets of doublets of the cyclopropane protons in the NMR ^1H spectrum of

Scheme 2

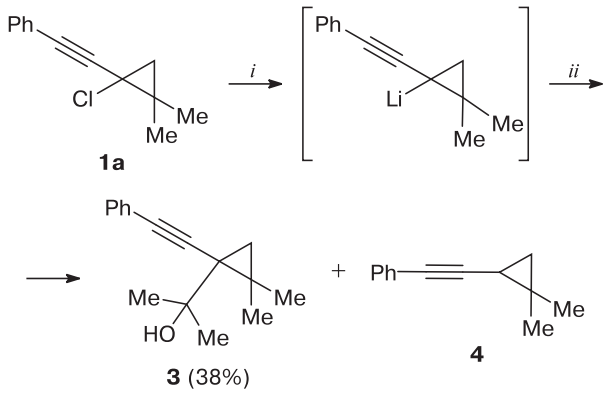


1, 2: R^1 = Ph, R^2 = Me (**e**); R^1 = Bu^t, R^2 = Me (**f**), H (**g**)

Reagents and conditions: *i*. THF, Bu^nLi (1 equiv.), −40÷−30 °C; *ii*. THF, Bu^nLi (1 equiv.), 0 °C; *iii*. 1) CO_2, 2) HCl, H_2O.

the reaction mixture and the peak with *m/z* 170 corresponding to the molecular ion of **4** in the mass spectrum.

Scheme 3



Reagents and conditions: *i*. THF, Bu^nLi (1 eqiuv.), −40÷−30 °C; *ii*. 1) Me_2CO, 2) H_2O.

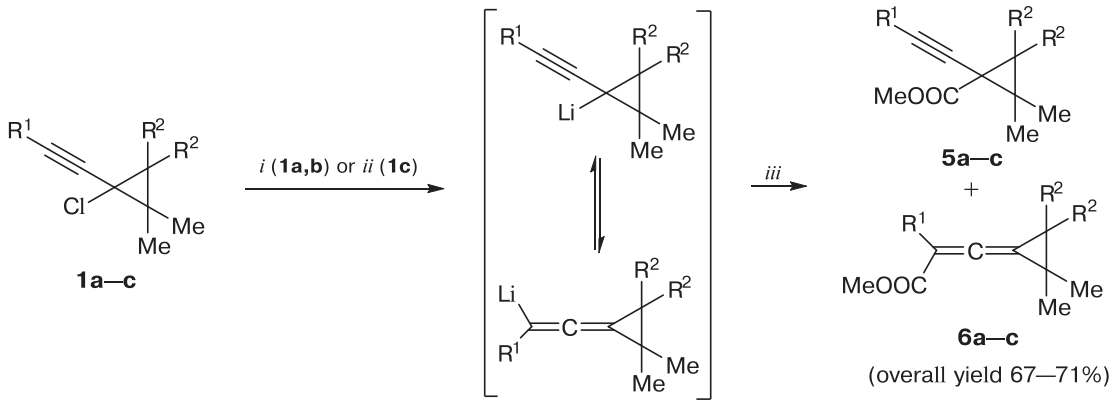
When methyl chloroformate was used as an electrophile, all the reactions give the mixtures of two products in 67—71% overall yields. According to the spectroscopy data, these products were identified as isomeric acetylenic (**5a—c**) and allenic (**6a—c**) esters (Scheme 4). The ratios of isomers **5** and **6** determined from NMR spectra of the reaction mixtures do not depend on the cyclopropane ring substitution pattern and were equal to 2 : 1 for both dimethyl-substituted cyclopropane **1a** and its tetramethyl-substituted analog **1b**. The reaction of cyclopropane **1c** with Bu^nLi and methyl chloroformate results in a 2.6 : 1 mixture of compounds **5c** and **6c** in the overall yield of 68%. Thus, the regioselectivity of introduction of the methoxycarbonyl group is only weakly affected by the replacement of the phenyl group at the triple bond by the bulkier electron-donating *tert*-butyl substituent.

Pure compounds **5** and **6** were easily isolated from the obtained product mixtures by silica gel column chromatography. This result allows us to consider the studied reaction as a convenient method to access both cyclopropylacetylenic esters **5** and their hitherto unknown vinylidenecyclopropanic isomers **6**.

The formation of vinylidenecyclopropanic derivatives was most pronounced when aliphatic aldehydes were used as the electrophiles. Thus, the reaction of cyclopropane **1a** with Bu^nLi at −30 °C in THF followed by addition of excess acetaldehyde gives allenic alcohol **7a** isolated by silica gel column chromatography in 58% yield. According to NMR spectroscopy of the reaction mixture, cyclopropylacetylenic derivative isomeric to alcohol **7a** was formed only in the trace amounts (<5%). Lithium species generated from cyclopropanes **1a** and **1b** react with butyraldehyde equally selectively to give the corresponding alcohols **7b** and **7c** in the 55—64% yields (Scheme 5). It is of note that owing to two stereogenic moieties (the allenic moiety with four different substituents and the carbon atom bearing the hydroxy group) compounds **7a** and **7b** are the 1 : 1 mixtures of two diastereomers. This fact agrees well with earlier described[33] formation of allenic alcohols upon the reaction of lithium derivatives generated by deprotonation of (arylethynyl)cyclopropanes with aromatic and aliphatic aldehydes.

In summary, in the present work we demonstrated that lithiation of alkynylchlorocyclopropanes **1** followed by the reactions of generated species with electrophilic reagents is of general character and can be considered as an efficient synthetic approach to functionalized alkynyl- and vinylidenecyclopropanes. The regioselectivity of the reactions substantially depends on the nature of the electrophile used.

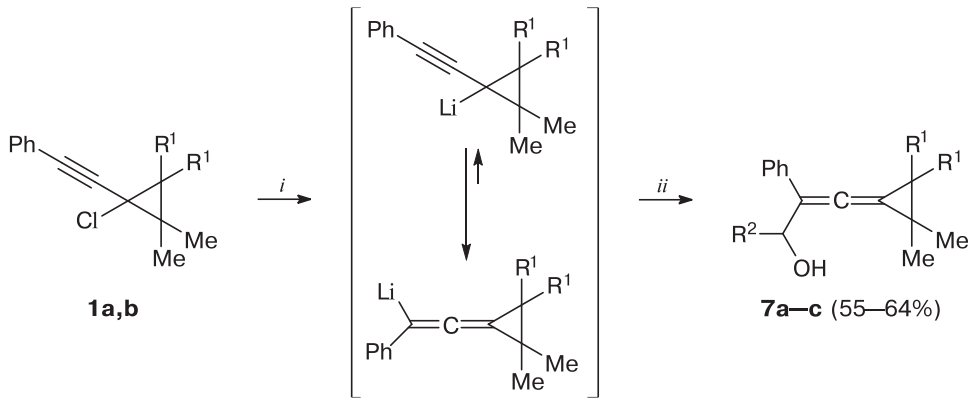
Scheme 4



1, 5, 6: R^1 = Ph, R^2 = H (**a**), Me (**b**); R^1 = Bu^t, R^2 = Me (**c**)

Reagents and conditions: *i*. THF, Bu^nLi (1 equiv.), −40÷−30 °C; *ii*. THF, Bu^nLi (1 equiv.), 0 °C; *iii*. 1) ClCOOMe, 2) H_2O.

Scheme 5



1: R^1 = H (**a**), Me (**b**)
7: R^1 = H, R^2 = Me (**a**), Pr (**b**); R^1 = Me, R^2 = Pr (**c**)

Reagents and conditions: *i*. THF, Bu^nLi (1 equiv.), −40÷−30 °C; *ii*. 1) R^2CHO, 2) H_2O.

Experimental

The starting compounds and the synthesized products were analyzed by GC using a Hewlett—Packard 5890 Series II system equipped with an HP-1 capillary column (30 m×0.153 mm) and a Hewlett—Packard 3396A series II integrator. ^1H and ^{13}C NMR spectra were run on a Bruker AC-200p spectrometer in $CDCl_3$; the chemical shifts are given in the δ scale relative to $SiMe_4$ as an internal standard.

High resolution electrospray ionization (ESI) mass spectrometry was performed with a Bruker micrOTOF II instrument operating in a positive ion mode (capillary voltage of −4500 V). Masses were scanned in the range from *m/z* 50 Da to *m/z* 3000 Da, external or internal calibrations were performed with an Electrospray Calibrant Solution (Fluka). The samples were prepared in MeCN and injected into the mass spectrometer *via* syringe inlet at a flow rate of 3 μL min^{-1}. The nebulizer gas was nitrogen (4 L min^{-1}), the capillary temperature was set at 180 °C.

Tetrahydrofuran was dried by distillation over $LiAlH_4$ immediately prior to use. The starting cyclopropane **1a** was synthesized from 1,3,3,3-tetrachloropropylbenzene and 2-methylpropene according to our previous work.[21] Cyclopropanes **1b—g** were synthesized from the corresponding 1,1-dichloroalk-2-ynes and alkenes as described earlier.[20]

Synthesis of 1-alkynylcyclopropanecarboxylic acids 2a—g from 1-alkynyl-1-chlorocyclopropanes 1a—g (general procedure). To a solution of chlorocyclopropane **1a—g** (1 mmol) in anhydrous THF (5 mL), a 1.6 *M* solution of in hexane (0.69 mL, 1.1 mmol of Bu^nLi) was added at either −30÷−40 °C (compounds **1a—c**) or 0 °C (compounds **1d—g**) under dry argon. The resulting mixture was stirred at this temperature for 30 min and excess of dry ice was added. After warming up to room temperature, water (10 mL) and Et_2O (30 mL) were added and the organic layer was separated. The aqueous layer was acidified with diluted HCl and the precipitated product was extracted with CH_2Cl_2 (2×10 mL). The combined organic layers were dried with anhydrous Na_2SO_4. Removal of the volatiles *in vacuo* afforded acids **2a—g**, which were purified by recrystallization from hexane or vacuum microdistillation if necessary.

2,2-Dimethyl-1-(phenylethynyl)cyclopropanecarboxylic acid (2a) was synthesized in the 74% yield from cyclopropane **1a**. Found (%): C, 78.28; H, 6.71. $C_{14}H_{14}O_2$. Calculated (%): C, 78.48; H, 6.59. ^1H NMR, δ: 1.28 (d, 1 H, C<u>H</u>H, *J* = 4.6 Hz); 1.36 (s, 3 H, CH_3); 1.49 (s, 3 H, CH_3); 1.84 (d, 1 H, C<u>H</u>H, *J* = 4.6 Hz); 7.24—7.35 (m, 3 H, H_m, H_p, Ph); 7.38—7.51 (m, 2 H, H_o, Ph); 9.60 (br.s, 1 H, COOH). ^{13}C NMR, δ: 19.6 (CH_3), 24.3 (CH_3), 27.7 (<u>C</u>COOH), 32.0 (CH_2), 33.2 (<u>C</u>$(CH_3)_2$), 81.7, 87.3 (C≡C), 123.3 (C(1), Ph), 127.9 (C(4), Ph), 128.2, 131.7 (C(2), C(3), C(5), C(6), Ph), 176.9 (COOH).

2,2,3,3-Tetramethyl-1-(phenylethynyl)cyclopropanecarboxylic acid (2b) was synthesized in the 68% yield from cyclopropane **1b**. Found (%): C, 79.16; H, 7.58. $C_{16}H_{18}O_2$. Calculated (%): C, 79.31; H, 7.49. ^1H NMR, δ: 1.38 (s, 6 H, 2 CH_3); 1.40 (s, 6 H, 2 CH_3); 7.25—7.36 (m, 3 H, H_m, H_p, Ph); 7.37—7.50 (m, 2 H, H_o, Ph); 9.32 (br.s, 1 H, COOH). ^{13}C NMR, δ: 17.9 (2 CH_3), 20.8 (2 CH_3), 33.6 (<u>C</u>COOH), 37.5 (2 <u>C</u>$(CH_3)_2$), 83.4, 87.2 (C≡C), 123.6 (C(1), Ph), 127.9 (C(4), Ph), 128.3, 131.8 (C(2), C(3), C(5), C(6), Ph), 175.7 (COOH).

1-(3,3-Dimethylbut-1-ynyl)-2,2,3,3-tetramethylcyclopropanecarboxylic acid (2c) was synthesized in the 66% yield from cyclopropane **1c**. Product **2c** was purified by recrystallization from hexane. Found (%): C, 77.85; H, 9.79. $C_{14}H_{22}O_2$. Calculated (%): C, 75.63; H, 9.97. ^1H NMR, δ: 1.17 (s, 9 H, $C(CH_3)_3$); 1.18 (s, 6 H, 2 CH_3); 1.23 (s, 6 H, 2 CH_3); 10.63 (br.s, 1 H, COOH). ^{13}C NMR, δ: 17.8 (2 CH_3), 20.5 (2 CH_3), 27.7 (<u>C</u>$(CH_3)_3$), 31.2 (C(<u>C</u>$H_3)_3$), 33.1 (<u>C</u>COOH), 35.6 (2 <u>C</u>$(CH_3)_2$), 75.5, 92.6 (C≡C), 175.7 (COOH).

1-(Hex-1-ynyl)-2,2,3,3-tetramethylcyclopropanecarboxylic acid (2d) was synthesized in the 47% yield from cyclopropane **1d**. The pure product was isolated by vacuum microdistillation (bath temperature of 150—170 °C, 1 Torr). Found (%): C, 77.72; H, 10.06. $C_{14}H_{22}O_2$. Calculated (%): C, 75.63; H, 9.97. ^1H NMR, δ: 0.90 (t, 3 H, CH_3 of Bu, *J* = 7.0 Hz); 1.25 (s, 6 H, 2 CH_3); 1.30 (s, 6 H, 2 CH_3); 1.36—1.55 (m, 4 H, $CH_3CH_2CH_2$); 2.26 (t, 2 H, C≡C<u>C</u>H_2, *J* = 6.9 Hz); 10.35 (br.s, 1 H, COOH). ^{13}C NMR, δ: 13.6 (CH_3 of Bu), 17.9 (2 CH_3), 18.7 (C≡C<u>C</u>H_2), 20.7 (2 CH_3), 22.1 (CH_2), 31.1 (CH_2), 33.4 (<u>C</u>COOH), 35.7 (2 <u>C</u>$(CH_3)_2$), 76.9, 84.0 (C≡C), 175.6 (COOH).

2,2,3-Trimethyl-1-(phenylethynyl)cyclopropanecarboxylic acid (2e) was synthesized in the 54% yield from cyclopentane **1e** as a mixture of two stereoisomers (*trans*-**2e** : *cis*-**2e** = 1.2 : 1). Product **2e** was isolated by recrystallization from hexane. Found (%): C, 79.06; H, 6.89. $C_{15}H_{16}O_2$. Calculated (%): C, 78.92; H, 7.06.

(1*R**,3*S**)-Isomer (*trans*-**2e**). ^{1}H NMR, δ: 1.34 (s, 3 H, CH_3); 1.35 (s, 3 H, CH_3); 1.37 (d, 3 H, $CHC\underline{H}_3$, J = 6.4 Hz); 2.03 (q, 1 H, $C\underline{H}CH_3$, J = 6.4 Hz); 7.26—7.37 (m, 3 H, H_m, H_p, Ph); 7.41—7.54 (m, 2 H, H_o, Ph); 11.60 (br.s, 1 H, COOH). ^{13}C NMR, δ: 9.6 ($CH\underline{C}H_3$), 18.2 (CH_3), 21.2 (CH_3), 32.1 ($\underline{C}COOH$), 33.8 ($\underline{C}HCH_3$), 36.6 ($\underline{C}(CH_3)_2$), 81.0, 84.2 (C≡C), 123.4 (C(1), Ph), 127.9 (C(4), Ph), 128.2, 131.8 (C(2), C(3), C(5), C(6), Ph), 177.4 (COOH).

(1*R**,3*R**)-Isomer (*cis*-**2e**). ^{1}H NMR, δ: 1.24 (d, 3 H, $CHC\underline{H}_3$, J = 6.4 Hz); 1.37 (s, 3 H, CH_3); 1.52 (s, 3 H, CH_3); 1.71 (q, 1 H, $C\underline{H}CH_3$, J = 6.4 Hz); 7.26—7.37 (m, 3 H, H_m, H_p, Ph); 7.41—7.54 (m, 2 H, H_o, Ph); 11.60 (br.s, 1 H, COOH). ^{13}C NMR, δ: 8.8 ($CH\underline{C}H_3$), 15.1 (CH_3), 26.1 (CH_3), 29.1 ($\underline{C}COOH$), 36.0 ($\underline{C}(CH_3)_2$), 40.5 ($\underline{C}HCH_3$), 84.9, 88.9 (C≡C), 123.4 (C(1), Ph), 127.8 (C(4), Ph), 128.2, 131.7 (C(2), C(3), C(5), C(6), Ph), 176.2 (COOH).

1-(3,3-Dimethylbut-1-ynyl)-2,2,3-trimethylcyclopropanecarboxylic acid (2f) was synthesized in the 62% yield from cyclopropane **1f** as a mixture of two stereoisomers (*trans*-**2f** : *cis*-**2f** = = 1.1 : 1). Found (%): C, 74.82; H, 9.83. $C_{13}H_{20}O_2$. Calculated (%): C, 74.96; H, 9.68.

(1*R**,3*S**)-Isomer (*trans*-**2f**). ^{1}H NMR, δ: 1.09 (d, 3 H, $CHC\underline{H}_3$, J = 6.3 Hz); 1.18 (s, 3 H, CH_3); 1.24 (s, 9 H, 3 CH_3); 1.25 (s, 3 H, CH_3); 1.79 (q, 1 H, $C\underline{H}CH_3$, J = 6.3 Hz); 10.65 (br.s, 1 H, COOH). ^{13}C NMR, δ: 9.6 ($CH\underline{C}H_3$), 18.0 (CH_3), 21.0 (CH_3), 27.6 ($\underline{C}(CH_3)_3$), 31.3 ($C(\underline{C}H_3)_3$), 31.6 ($\underline{C}COOH$), 32.3 ($\underline{C}HCH_3$), 34.7 ($\underline{C}(CH_3)_2$), 73.4, 93.2 (C≡C), 177.4 (COOH).

(1*R**,3*R**)-Isomer (*cis*-**2f**). ^{1}H NMR, δ: 1.21 (s, 9 H, 3 CH_3); 1.23 (s, 3 H, CH_3); 1.26 (d, 3 H, $CHC\underline{H}_3$, J = 6.3 Hz); 1.27 (s, 3 H, CH_3); 1.43 (q, 1 H, $C\underline{H}CH_3$, J = 6.3 Hz); 10.65 (br.s, 1 H, COOH). ^{13}C NMR, δ: 8.7 ($CH\underline{C}H_3$), 15.1 (CH_3), 25.9 (CH_3), 27.6 ($\underline{C}(CH_3)_3$), 28.6 ($\underline{C}COOH$), 31.3 ($C(\underline{C}H_3)_3$), 34.2 ($\underline{C}(CH_3)_2$), 39.5 ($\underline{C}HCH_3$), 77.5, 89.8 (C≡C), 176.0 (COOH).

1-(3,3-Dimethylbut-1-ynyl)-2,3-dimethylcyclopropanecarboxylic acid (2g) was synthesized in the 54% yield from cyclopropane **1g** as a mixture of two stereoisomers (*trans*-**2g** : *cis*-**2g** = = 1.5 : 1). Found (%): C, 74.36; H, 9.24. $C_{12}H_{18}O_2$. Calculated (%): C, 74.19; H, 9.34.

(1*r**,2*R**,3*S**)-Isomer (*trans*-**2g**). ^{1}H NMR, δ: 1.07—1.12 (m, 6 H, 2 $CHC\underline{H}_3$); 1.25 (s, 9 H, 3 CH_3); 1.78—1.90 (m, 2 H, 2 $C\underline{H}CH_3$); 10.33 (br.s, 1 H, COOH). ^{13}C NMR, δ: 8.8 (2 $CH\underline{C}H_3$), 26.6 ($\underline{C}COOH$), 27.8 ($\underline{C}(CH_3)_3$), 29.3 (2 $\underline{C}HCH_3$), 31.4 ($C(\underline{C}H_3)_3$), 71.7, 94.4 (C≡C), 179.2 (COOH).

(1s*,2*R**,3*S**)-Isomer (*cis*-**2g**). ^{1}H NMR, δ: 1.19 (s, 9 H, 3 CH_3); 1.20—1.25 (m, 6 H, 2 $CHC\underline{H}_3$); 1.78—1.90 (m, 2 H, 2 $C\underline{H}CH_3$); 10.33 (br.s, 1 H, COOH). ^{13}C NMR, δ: 7.5 (2 $CH\underline{C}H_3$), 22.8 ($\underline{C}COOH$), 27.4 ($\underline{C}(CH_3)_3$), 31.2 ($C(\underline{C}H_3)_3$), 33.5 (2 $\underline{C}HCH_3$), 79.9, 88.3 (C≡C), 175.5 (COOH).

Synthesis of esters 5a and 6a from cyclopropane 1a. To a solution of chlorocyclopropane **1a** (410 mg, 2 mmol) in anhydrous THF (5 mL), a 1.6 *M* solution of Bu^nLi in hexane (1.38 mL, 2.2 mmol of Bu^nLi) was added at −30÷−40 °C under dry argon. The resulting mixture was stirred at this temperature for 30 min and a solution of methyl chloroformate (208 mg, 2.2 mmol) in anhydrous THF (1 mL) was added. After warming up to room temperature, water (10 mL) and Et_2O (30 mL) were added and the organic layer was separated. The aqueous layer was extracted with Et_2O (10 mL) and the combined organic layers were dried with anhydrous Na_2SO_4. Removal of the volatiles *in vacuo* gave a yellow liquid residue containing ~80% of esters **5a** and **6a** in a 2.1 : 1 ratio (GC analysis data). Purification of this residue by silica gel column chromatography (elution with hexane—Et_2O, 20 : 1 → 10 : 1) afforded 205 mg (45%) of compound **5a** and 102 mg (22%) of compound **6a**.

Methyl 2,2-dimethyl-1-(phenylethynyl)cyclopropanecarboxylate (5a). MS (ESI), found: *m/z* 229.1228. Calculated for $C_{15}H_{16}O_2$, [M + H]: 229.1223. ^{1}H NMR, δ: 1.20 (d, 1 H, $C\underline{H}H$, J = 4.5 Hz); 1.28 (s, 3 H, CH_3); 1.47 (s, 3 H, CH_3); 1.81 (d, 1 H, $C\underline{H}H$, J = 4.5 Hz); 3.79 (s, 3 H, OCH_3); 7.26—7.36 (m, 3 H, H_m, H_p, Ph); 7.40—7.51 (m, 2 H, H_o, Ph). ^{13}C NMR, δ: 19.6 (CH_3), 24.0 (CH_2), 27.7 ($\underline{C}COOH$), 31.1 (CH_3), 31.6 ($\underline{C}(CH_3)_2$), 52.7 (OCH_3), 81.2, 88.0 (C≡C), 123.5 (C(1), Ph), 127.8 (C(4), Ph), 128.2, 131.7 (C(2), C(3), C(5), C(6), Ph), 170.7 ($\underline{C}OOCH_3$).

Methyl 3-(2,2-dimethylcyclopropylidene)-2-phenylacrylate (6a). MS (ESI), found: *m/z* 229.1226. Calculated for $C_{15}H_{16}O_2$, [M + H]: 229.1223. ^{1}H NMR, δ: 1.44 (s, 3 H, CH_3); 1.46 (s, 3 H, CH_3); 1.89 (d, 1 H, $C\underline{H}H$, J = 6.4 Hz); 1.94 (d, 1 H, $C\underline{H}H$, J = 6.4 Hz); 3.80 (s, 3 H, OCH_3); 7.23—7.59 (m, 5 H, Ph). ^{13}C NMR, δ: 24.3 (CH_3), 24.6 (CH_3), 27.1 (CH_2), 28.8 ($\underline{C}(CH_3)_2$), 52.0 (OCH_3), 89.5 (PhC=C=$\underline{C}$), 103.2 (Ph$\underline{C}$=C=C), 126.9, 128.1, 128.2 (C(2), C(3), C(4), C(5), C(6), Ph), 134.2 (C(1), Ph), 167.9 ($\underline{C}OOCH_3$), 194.3 (C=$\underline{C}$=C).

Similarly, a 2 : 1 mixture of esters **5b** and **6b** was synthesized from cyclopropane **1b**. Silica gel column chromatography (elution with hexane—Et_2O, 20 : 1 → 10 : 1) of this mixture afforded 261 mg (51%) of compound **5b** and 102 mg (20%) of compound **6b**.

Methyl 2,2,3,3-tetramethyl-1-(phenylethynyl)cyclopropanecarboxylate (5b). MS (ESI), found: *m/z* 257.1529. Calculated for $C_{17}H_{20}O_2$, [M + H]: 257.1536. ^{1}H NMR, δ: 1.35 (s, 12 H, 4 CH_3); 3.74 (s, 3 H, OCH_3); 7.21—7.34 (m, 3 H, H_m, H_p, Ph); 7.41—7.49 (m, 2 H, H_o, Ph). ^{13}C NMR, δ: 18.1 (2 CH_3), 20.4 (2 CH_3), 33.6 ($\underline{C}COOCH_3$), 35.1 (2 $\underline{C}(CH_3)_2$), 52.1 (OCH_3), 82.7, 87.6 (C≡C), 123.7 (C(1), Ph), 127.7 (C(4), Ph), 128.2, 131.7 (C(2), C(3), C(5), C(6), Ph), 169.7 ($\underline{C}OOCH_3$).

Methyl 3-(tetramethylcyclopropylidene)-2-phenylacrylate (6b). MS (ESI), found: *m/z* 257.1539. Calculated for $C_{17}H_{20}O_2$, [M + H]: 257.1536. ^{1}H NMR, δ: 1.43 (s, 6 H, 2 CH_3); 1.46 (s, 6 H, 2 CH_3); 3.78 (s, 3 H, OCH_3); 7.17—7.38 (m, 3 H, H_m, H_p, Ph); 7.52—7.60 (m, 2 H, H_o, Ph). ^{13}C NMR, δ: 21.5 (2 CH_3), 21.7 (2 CH_3), 36.6 (2 $\underline{C}(CH_3)_2$), 51.9 (OCH_3), 97.2 (PhC=C=$\underline{C}$), 102.5 (Ph$\underline{C}$=C=C), 126.6, 128.0, 128.1 (C(2), C(3), C(4), C(5), C(6), Ph), 134.7 (C(1), Ph), 168.2 ($\underline{C}OOCH_3$), 192.5 (C=$\underline{C}$=C).

Similarly, a 2.6 : 1 mixture of esters **5c** and **6c** was synthesized from cyclopropane **1c**. Silica gel column chromatography (elution with hexane—Et_2O, 30 : 1) of this mixture afforded 225 mg (48%) of compound **5c** and 94 mg (20%) of compound **6c**.

Methyl 1-(3,3-dimethylbut-1-ynyl)-2,2,3,3-tetramethylcyclopropanecarboxylate (5c). MS (ESI), found: *m/z* 237.1853. Calculated for $C_{15}H_{23}O_2$, [M + H]: 237.1849. ^{1}H NMR, δ: 1.17 (s, 6 H, 2 CH_3); 1.18 (s, 9 H, $C(CH_3)_3$); 1.20 (s, 6 H, 2 CH_3); 3.62 (s, 3 H, OCH_3). ^{13}C NMR, δ: 17.9 (2 CH_3), 19.9 (2 CH_3), 27.5 ($\underline{C}(CH_3)_3$), 31.0 ($C(\underline{C}H_3)_3$), 32.8 ($\underline{C}COOCH_3$), 33.1 (2 $\underline{C}(CH_3)_2$), 51.6 (OCH_3), 75.6, 91.0 (C≡C), 170.0 ($\underline{C}OOCH_3$).

Methyl 2-*tert*-butyl-3-(tetramethylcyclopropylidene)acrylate (6c). MS (ESI), found: *m/z* 237.1845. Calculated for $C_{15}H_{23}O_2$,

[M + H]: 237.1849. ^{1}H NMR, δ: 1.14 (s, 9 H, C(CH_3)$_3$); 1.28 (s, 6 H, 2 CH_3); 1.31 (s, 6 H, 2 CH_3); 3.59 (s, 3 H, OCH_3). ^{13}C NMR, δ: 20.9 (2 CH_3), 21.0 (2 CH_3), 29.5 (C($\underline{C}H_3$)$_3$), 33.0, 33.3 ($\underline{C}(CH_3)_3$, 2 $\underline{C}(CH_3)_2$), 50.8 (OCH_3), 96.8 (Bu^{t}C=C=$\underline{C}$), 109.3 (Bu$^t\underline{C}$=C=C), 167.8 ($\underline{C}OOCH_3$), 190.4 (C=$\underline{C}$=C).

Synthesis of alcohols 3 and 7a—c from 1-alkynyl-1-chlorocyclopropanes 1a,b (general procedure). To a solution of chlorocyclopropane **1a,b** (1 mmol) in anhydrous THF (5 mL), a 1.6 *M* solution of Bu^{n}Li in hexane (0.69 mL, 1.1 mmol of Bu^{n}Li) was added at −30÷−40 °C under dry argon. The resulting mixture was stirred at this temperature for 30 min and a solution of the corresponding carbonyl compound (acetaldehyde, acetone, butyraldehyde) (1.2 mmol) in anhydrous THF (1 mL) was added. After warming up to room temperature, water (10 mL) and CH_2Cl_2 (30 mL) were added, and the organic layer was separated. The aqueous layer was extracted with CH_2Cl_2 (3×10 mL), the combined organic layers were dried with anhydrous Na_2SO_4, and concentrated *in vacuo*. Purification of the residue by silica gel column chromatography afforded products **3** and **7a—c**.

2-[2,2-Dimethyl-1-(phenylethynyl)cyclopropyl]propan-2-ol (3) was synthesized in the 38% yield from cyclopropane **1a** and acetone. Product **3** was isolated by silica gel column chromatography (elution with hexane—Et_2O, 20 : 1). MS (ESI), found: *m/z* 229.1584. Calculated for $C_{16}H_{20}O$, [M + H]: 229.1587. ^{1}H NMR, δ: 0.74 (d, 1 H, C$\underline{H}$H, *J* = 4.2 Hz); 1.17 (d, 1 H, C$\underline{H}$H, *J* = 4.2 Hz); 1.29 (br.s, 1 H, OH); 1.40 (s, 3 H, CH_3); 1.45 (s, 3 H, CH_3); 1.51 (s, 3 H, CH_3); 1.61 (s, 3 H, CH_3); 7.23—7.34 (m, 3 H, H_m, H_p, Ph); 7.36—7.45 (m, 2 H, H_o, Ph). ^{13}C NMR, δ: 14.2 (C≡C$\underline{C}$), 20.4 (CH_3), 24.0 (CH_2), 24.5 ($\underline{C}(CH_3)_2$), 27.0 (CH_3), 27.8 (CH_3), 32.0 (CH_3), 72.2 ($\underline{C}(CH_3)_2OH$), 79.7, 94.8 (C≡C), 124.3 (C(1), Ph), 127.4 (C(4), Ph), 128.2, 131.4 (C(2), C(3), C(5), C(6), Ph).

4-(2,2-Dimethylcyclopropylidene)-3-phenylbut-3-en-2-ol (7a) was synthesized in the 58% yield from cyclopropane **1a** and acetaldehyde as a 1 : 1 mixture of two diastereomers. Product **7a** was isolated by silica gel column chromatography (elution with hexane—Et_2O, 20 : 1→10 : 1). MS (ESI), found: *m/z* 215.1436. Calculated for $C_{15}H_{18}O$, [M + H]: 215.1430. ^{1}H NMR, δ: 1.38 (s, 3 H, CH_3); 1.40 (s, 3 H, CH_3); 1.41 (s, 3 H, CH_3); 1.42 (s, 3 H, CH_3); 1.44 (d, 3 H, C$\underline{H}_3$CH, *J* = 6.2 Hz); 1.45 (d, 3 H, C$\underline{H}_3$CH, *J* = 6.2 Hz); 1.63 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.65 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.66 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.69 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.95 (br.s, 1 H, OH, for both diastereomers); 4.92 (q, 1 H, C$\underline{H}$OH, *J* = 6.2 Hz); 4.94 (q, 1 H, C$\underline{H}$OH, *J* = 6.2 Hz); 7.13—7.51 (m, 5 H, Ph, for both diastereomers). ^{13}C NMR, δ: 22.6, 23.0 (CH_3), 23.9, 24.1 (CH_2), 24.2, 24.5 ($\underline{C}(CH_3)_2$), 24.6, 24.65, 24.7, 24.75 (2 CH_3), 66.0, 66.2 (CHOH), 93.3, 93.5 (PhC=C=$\underline{C}$), 113.0, 113.1 (Ph$\underline{C}$=C=C), 126.2, 126.3, 126.4, 126.5, 128.5 (C(2), C(3), C(5), C(6), Ph), 136.5, 136.6 (C(1), Ph), 182.2 (C=$\underline{C}$=C, for both diastereomers).

1-(2,2-Dimethylcyclopropylidene)-2-phenylhex-1-en-3-ol (7b) was synthesized in the 64% yield form cyclopropane **1a** and butyraldehyde. Product **7b** was isolated as a 1 : 1 mixture of two diastereomers by silica gel column chromatography (elution with hexane—Et_2O, 20 : 1 → 10 : 1). MS (ESI), found: *m/z* 243.1747. Calculated for $C_{17}H_{22}O$, [M + H]: 243.1743. ^{1}H NMR, δ: 0.94 (t, 3 H, C$\underline{H}_3$$CH_2CH_2$, *J* = 7.2 Hz); 0.94 (t, 3 H, C$\underline{H}_3$$CH_2CH_2$, *J* = 7.2 Hz); 1.38 (s, 3 H, CH_3); 1.39 (s, 3 H, CH_3); 1.41 (s, 3 H, CH_3); 1.42 (s, 3 H, CH_3); 1.55—1.78 (m, 4 H, CH_3C$\underline{H}_2$C$\underline{H}_2$, for both diastereomers); 1.63 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.65 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.67 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 1.69 (d, 1 H, C$\underline{H}$H, *J* = 6.7 Hz); 2.03 (br.s, 1 H, OH, for both diastereomers); 4.70 (dd, 1 H, C$\underline{H}$OH, *J* = 7.0 Hz, *J* = 4.1 Hz); 4.73 (dd, 1 H, C$\underline{H}$OH, *J* = 7.0 Hz, *J* = 4.1 Hz); 7.13—7.50 (m, 5 H, Ph, for both diastereomers). ^{13}C NMR, δ: 14.0, 14.1 ($\underline{C}H_3CH_2CH_2$), 19.0, 19.1 ($CH_3\underline{C}H_2CH_2$), 23.8, 24.1 (CH_2), 24.2, 24.4 ($\underline{C}(CH_3)_2$), 24.5, 24.6, 24.65, 24.7 (2 CH_3), 38.7, 39.0 ($CH_3CH_2\underline{C}H_2$), 69.9, 70.0 (CHOH), 93.1, 93.3 (PhC=C=$\underline{C}$), 112.0 (Ph$\underline{C}$=C=C, for both diastereomers), 126.2, 126.3, 126.4, 128.5 (C(2), C(3), C(5), C(6), Ph), 136.6, 136.8 (C(1), Ph), 185.4, 185.5 (C=$\underline{C}$=C).

1-Tetramethylcyclopropylidene-2-phenylhex-1-en-3-ol (7c) was synthesized in the 55% yield from cyclopropane **1b** and butyraldehyde. Product **7c** was isolated by silica gel column chromatography (elution with hexane—Et_2O, 20 : 1 → 10 : 1). MS (ESI), found: *m/z* 271.2051. Calculated for $C_{19}H_{26}O$, [M + H]: 271.2056. ^{1}H NMR, δ: 0.95 (t, 3 H, C$\underline{H}_3$$CH_2CH_2$, *J* = 7.2 Hz); 1.37 (s, 3 H, CH_3); 1.38 (s, 3 H, CH_3); 1.40 (s, 3 H, CH_3); 1.41 (m, 3 H, CH_3); 1.39—1.79 (m, 4 H, CH_3C$\underline{H}_2$C$\underline{H}_2$); 2.15 (br.s, 1 H, OH); 4.69 (t, 1 H, C$\underline{H}$OH, *J* = 6.4 Hz); 7.13—7.50 (m, 5 H, Ph). ^{13}C NMR, δ: 14.1 ($\underline{C}H_3CH_2CH_2$), 19.2 ($CH_3\underline{C}H_2$-CH_2), 21.5 (CH_3), 21.6 (CH_3), 21.7 (CH_3), 21.8 (CH_3), 31.4 ($C(CH_3)_2$), 31.5 ($C(CH_3)_2$), 38.9 ($CH_3CH_2\underline{C}H_2$), 69.9 (CHOH), 101.63 (PhC=C=$\underline{C}$), 111.5 (Ph$\underline{C}$=C=C), 125.9, 126.2, 128.5 (C(2), C(3), C(5), C(6), Ph), 137.1 (C(1), Ph), 183.4 (C=$\underline{C}$=C).

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