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Inter- and Intramolecular Palladium-Catalyzed Hydrocarbonation of Methylenecyclopropanes with Carbon Pronucleophiles†

Naofumi Tsukada, Akinori Shibuya, Itaru Nakamura, Haruo Kitahara‡ and Yoshinori Yamamoto*

Department of Chemistry, Graduate School of Science
Tohoku University, Sendai 980-8578, Japan

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Abstract

The inter- and intramolecular additions of pronucleophiles to methylenecyclopropanes proceeded smoothly in the presence of catalytic amounts of $Pd(PPh_3)_4$, affording hydrocarbonation products in good to high yields. The ring opening of methylenecyclopropanes mainly occurred at the distal position to the exomethylene. In some cases, proximal bond cleavage also took place. The mode of ring opening depended upon both the structure of the pronucleophile and the substituent at the exomethylene carbon.

keywords: hydrocarbonation; palladium catalyzed reaction; pronucleophile; methylenecyclopropane.

The addition of a carbon nucleophile to a carbon-carbon multiple bond is one of the most important methods for carbon-carbon bond formation. The addition of carbanionic organometallics to active olefins such as Michael acceptors is a classical and well-known reaction among these methods, wherein anionic organometallics react with an activated alkene bearing an electron-withdrawing group[1]. Transition metal catalysts have opened the door to a new field, enabling the addition of organometallics to an unactivated alkene[2] and the addition of an active methyne and methylene to an activated alkene (Michael acceptor) under neutral conditions[3]. More recently, "hydrocarbonation" of an unactivated C=C double bond with

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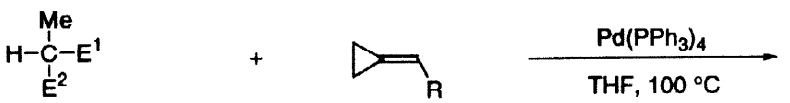
certain pronucleophiles has been reported[4-10], which presumably proceeds through the transition metal-catalyzed activation of a C-H bond of pronucleophiles such as an active methyne and methylene[4-7], a terminal alkyne[8], an aldehyde[9], and an aromatic ring[10]. 1,3-Dienes[4], allenes[5], 1,3-enynes[6], and propargyl compounds[7] can be used as the unactivated alkene for the addition of an active methyne and methylene. However, the addition of an active methyne and methylene to nonconjugated alkenes has not been known until now. Previously, we communicated the palladium-catalyzed *intermolecular* hydrocarbonation of methylenecyclopropanes, which are regarded as a nonconjugated alkene, with pronucleophiles[11]. Now, we report the detailed study of the *intermolecular* hydrocarbonation of methylenecyclopropanes together with the palladium-catalyzed *intramolecular* hydrocarbonation[12] of methylenecyclopropanes.

Results and Discussion

Intermolecular Hydrocarbonation

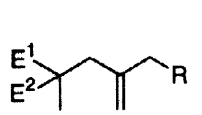
The palladium-catalyzed reaction of certain pronucleophiles (**1**) with methylenecyclopropanes (**2**) gave the hydrocarbonation products (**3**) in good to high yields, and afforded **4** in certain cases either exclusively or as a byproduct in a mixture with **3** (eq 1).



1a ; $E^1 = E^2 = CN$
1b ; $E^1 = CN$, $E^2 = CO_2Et$
1c ; $E^1 = E^2 = CO_2Et$

2a ; $R = (CH_2)_3Ph$
2b ; $R = C_6H_{11}$
2c ; $R = (CH_2)_2Ph$
2d ; $R = CH_2Ph$
2e ; $R = Ph$
2f ; $R = p\text{-}CF_3\text{-}C_6H_4$
2g ; $R = p\text{-}MeO\text{-}C_6H_4$

(1)



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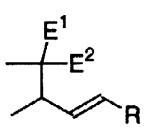


3a ; $E^1 = E^2 = CN$, $R = (CH_2)_3Ph$
3b ; $E^1 = CN$, $E^2 = CO_2Et$, $R = (CH_2)_3Ph$
3c ; $E^1 = E^2 = CN$, $R = C_6H_{11}$
3d ; $E^1 = CN$, $E^2 = CO_2Et$, $R = (CH_2)_2Ph$
3e ; $E^1 = E^2 = CO_2Et$, $R = (CH_2)_2Ph$
3f ; $E^1 = E^2 = CN$, $R = (CH_2)_2Ph$
3g ; $E^1 = E^2 = CN$, $R = CH_2Ph$
3h ; $E^1 = E^2 = CO_2Et$, $R = Ph$

4a ; $E^1 = E^2 = CN$, $R = (CH_2)_2Ph$
4b ; $E^1 = E^2 = CN$, $R = CH_2Ph$
4c ; $E^1 = E^2 = CN$, $R = Ph$
4d ; $E^1 = CN$, $E^2 = CO_2Et$, $R = Ph$
4e ; $E^1 = E^2 = CN$, $R = p\text{-}CF_3\text{-}C_6H_4$
4f ; $E^1 = E^2 = CN$, $R = P\text{-}MeO\text{-}C_6H_4$

The results are summarized in Table 1. The addition of methylmalononitrile **1a** to 4-phenyl-1-butenylidenecyclopropane **2a** proceeded smoothly in the presence of catalytic amounts of $Pd(PPh_3)_4$ in THF at 100 °C to give **3a** in 82% yield (entry 1). Other palladium catalysts, such as $PdCl_2(PPh_3)_2$ and $Pd_2(dba)_3 \cdot CHCl_3$–PPh_3, gave the addition product in lower yields. The reaction of ethyl 2-cyanopropionate **1b** with **2a** gave **3b** in 95% yield (entry 2). Cyclohexylmethylenecyclopropane **2b** also reacted with **1a** very smoothly (entry 3). Similarly, the ring opening of 3-phenyl-1-propylidenecyclopropane **2c** with **1b** or **1c** afforded **3d** or **3e**, respectively, in good yields (entries 4 and 5). The reaction of **1a** with **2c** gave **3f** in 75% yield along with small amounts (10%) of **4a** (entry 6). With 2-phenylethylidenecyclopropane **2d**, the reaction of **1a** afforded **3g** in 57% yield together with 31% yield of **4b** (entry 7). The reaction of benzylidenecyclopropane **2e** with **1a** or **1b** produced only **4c** or **4d** in 88% or 83% yield, respectively (entries 8 and 9). In the reactions of the *para*-substituted benzylidenecyclopropanes **2f** and **2g** with **1a**, **4e** and **4f** were formed exclusively and none of the isomers (derivatives of **3**) were obtained, indicating that the electronic effect of the *para*-substituents did not exert a significant influence upon the product distribution (entries 10 and 11). On the other hand, the reaction of **2e** with ethyl methylmalonate **1c** gave **3h** in 55% yield (entry 12). Accordingly, the mode of ring opening of methylenecyclopropanes depends upon both the structure of the pronucleophiles and the substituent at the exomethylene carbon.

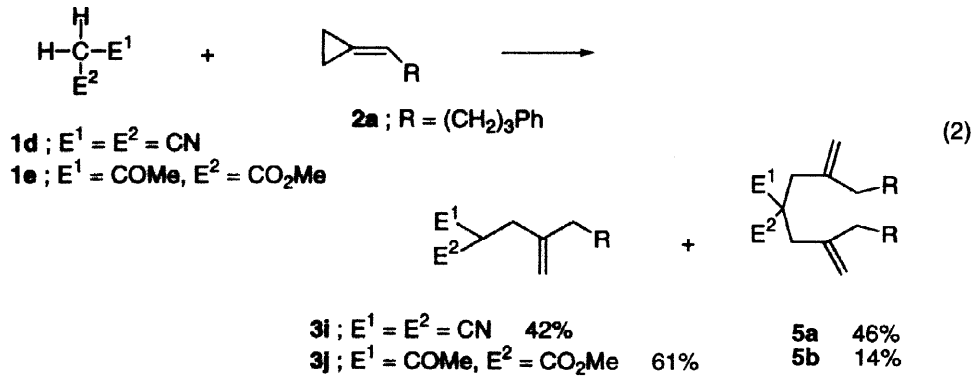
Table 1. Palladium Catalyzed Addition of **1** to **2**[a]

Entry	1	2	Yield of 3/%	Yield of 4/%
1	**1a**	**2a**	**3a**, 82	-
2	**1b**	**2a**	**3b**, 95	-
3	**1a**	**2b**	**3c**, 94	-
4	**1b**	**2c**	**3d**, 67	-
5	**1c**	**2c**	**3e**, 70	-
6	**1a**	**2c**	**3f**, 75	**4a**, 10
7	**1a**	**2d**	**3g**, 57	**4b**, 31
8	**1a**	**2e**	-	**4c**, 88
9	**1b**	**2e**	-	**4d**, 83
10	**1a**	**2f**	-	**4e**, 94
11	**1a**	**2g**	-	**4f**, 72
12	**1c**	**2e**	**3h**, 55	-

[a] The reaction of **1** (0.5 mmol) and **2** (1.0 mmol) was carried out in the presence of $Pd(PPh_3)_4$ (10 mol%) in THF at 100 °C for 2-3 days. All yields are of pure product isolated by column chromatography. The configuration of the double bond of **4** was confirmed by the coupling constant of the olefin protons (15.2-15.8 Hz).

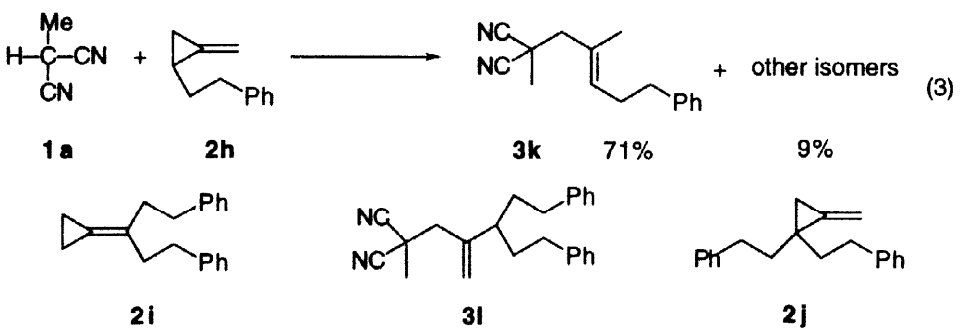
In the reaction of active methylenes, both monoalkylation and dialkylation products were

obtained (eq 2). The addition of malononitrile **1d** to **2a** gave ca. 1:1 mixture of the monoalkylation **3i** (42%) and the dialkylation product **5a** (46%), while the ketoester **1e** gave the corresponding monoalkylation product **3j** predominantly.



(2)

Our interest was then directed to the ring opening of methylenecyclopropanes **2h-j** which are mono-substituted at the cyclopropane ring or gem-disubstituted both at the exocyclic vinylic carbon and the cyclopropane ring. The cyclopropane ring of **2h** opened at the distal position in the reaction with **1a** to yield **3k**[13] in 71% yield along with small amounts of other isomers (eq 3). In this reaction, **3f** was not obtained at all, while it was produced in the reaction of **2c** having a 2-phenylethyl substituent at the exomethylene carbon. The reaction of **1a** with **2i** gave **3l** in 85% yield, but the reaction with **2j** did not give the desired hydrocarbonation product at all.



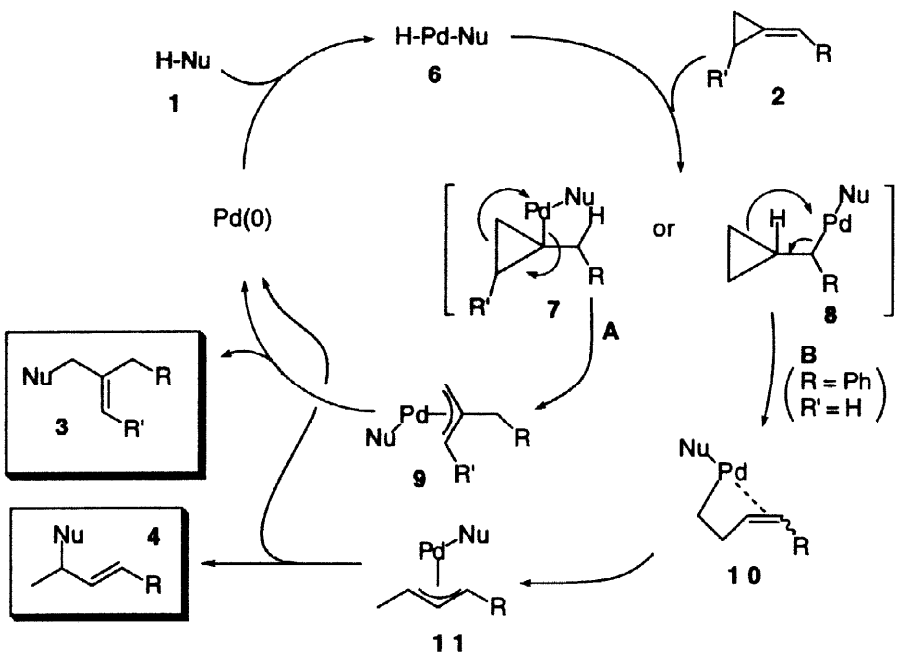
(3)

Mechanism

A plausible mechanism for the ring opening of **2** with pronucleophiles **1** is shown in Scheme 1. Oxidative addition of Pd(0) into the C-H bond of pronucleophiles **1** would generate the palladium hydride complex **6**. The hydropalladation of methylenecyclopropanes **2** with **6** would afford the alkylpalladium complexes **7** and/or **8**. The complex **7** would undergo

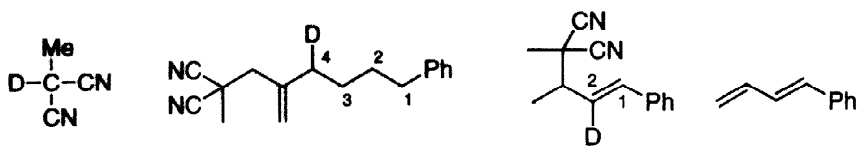
rearrangement to the π-allylpalladium **9** (route **A**). The reductive elimination of Pd(0) from **9** would produce **3**. The palladium complex **8** would isomerize to the π-allylpalladium complex **11** *via* **10** (route **B**). The reductive elimination would give **4** and Pd(0). Presumably, the reaction of **2e** with **1a** took route **B**, whereas the reaction of **2a** with **1a** proceeded through route **A**[14].

Scheme 1



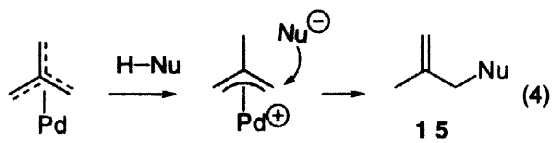
We carried out the reaction with deuterated methylmalononitrile **1f** to help clarify the hydrocarbonation mechanism. The reaction of **1f** with **2a** under the same conditions as above gave **3a**-*d* in 82% yield in which the d-content at the C-4 position was 85%. On the other hand, the reaction of **1f** with **2e** afforded **4c**-*d* in 86% yield in which the d-content at the C-2 position was 27% and the other protons were not deuterated at all. The former observation is in good agreement with the proposed route **A**. The latter result supports the proposed route **B**, but the very low deuterium content at the C-2 position could not be accounted for. We monitored the reaction of **2e** by using ^{1}H-NMR and found that 1-phenyl-1,3-butadiene **12** was produced as an intermediate, its production reached a maximum after 25 h, and decreased along with the reaction progress. No 1,3-butadiene formation was observed in the reaction of **2a**! The result clearly indicates that **12** is produced via the β-H-Pd elimination of **10** and the elimination-addition process occurs on the way from **10** to **11** in which loss of deuterium takes

place.



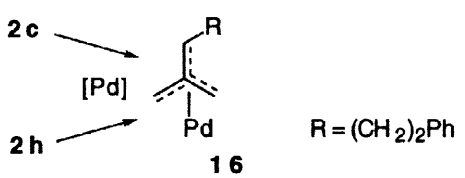
1f **3a-*d*** **4c-*d*** **12**

Trost and Chan reported that the addition of pronucleophiles to the trimethylene-methane (TMM) palladium complex **13** derived from 2-acetoxymethyl-3-allyltrimethylsilane afforded the adduct **15** via **14** (eq 4)[15].



13 **14** **15** (4)

On the other hand, it was proposed that the TMM-palladium complex **13** would be involved as an intermediate in the palladium-catalyzed [3+2] cycloaddition of methylenecyclopropanes with olefins[16]. If the present hydrocarbonation reaction proceeds through a TMM-palladium complex **16**, the same product (or product ratio) should be obtained from **2c** and **2h** (eq 5).



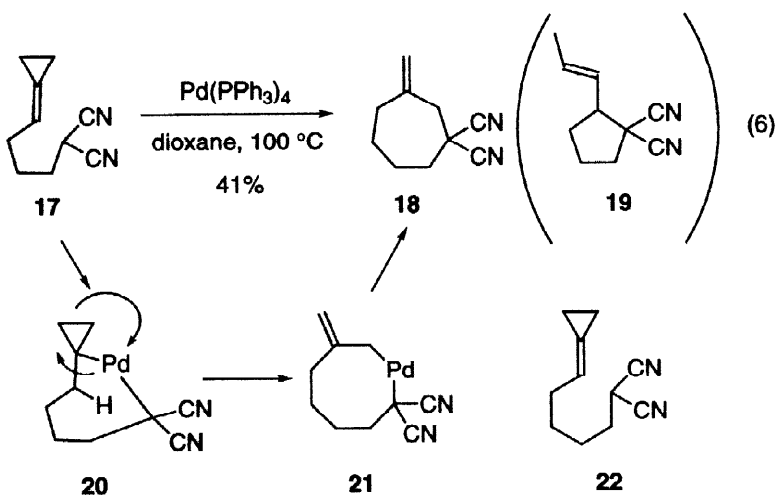
16 $R = (CH_2)_2Ph$ (5)

However, the actual reactions afforded totally different results; only **3f** was obtained from the reaction of **2c**, whereas **3k** was produced predominantly from **2h**. Accordingly, it is not likely that the TMM-palladium complex **16** is an intermediate in the addition reactions of **1a** to **2c** and **2h**. Ring opening mainly occurred at the distal position, which is different from the hydrostannation[14a], hydrosilylation[14b] and the Heck reaction[14c,d] of methylene-cyclopropanes, although in some cases the proximal bond of cyclopropanes was cleaved

exclusively or as a side reaction.

Intramolecular Hydrocarbonation

We carried out the intramolecular hydrocarbonation reaction of ω-cyclopropylidene-alkylmalononitrile **17**. In the presence of a catalytic amount (10 mol%) of $Pd(PPh_3)_4$, the reaction of **17** produced the corresponding intramolecular hydrocarbonation product, 7-membered carbocycle, **18** in 41% yield (eq 6)[17]. The chemical yield of **18** was not necessarily good, but other products such as 5-membered carbocycle **19** was not produced under the reaction conditions. The formation of **18** can be explained by the hydropalladation pathway (route **A**) mentioned in Scheme 1; the hydropalladation of **17** would produce the intermediate **20**, which would undergo the rearrangement (as shown in Scheme 1) to **21** and subsequent reductive elimination of Pd(0) would produce **18**. Since **17** is an exomethylenecyclopropane substituted with an aliphatic group, the direction of the intramolecular hydropalladation is in good agreement with that of the intermolecular hydropalladation. We also attempted the intramolecular cyclization of **22**. However, neither 6-membered nor 8-membered cyclized product was obtained under the reaction condition mentioned above: the starting material was recovered even after a prolonged reaction at 100 °C.



Experimental Section

General. Spectroscopic measurements were carried out with the following instruments: JEOL GSX-270 and JEOL LA-300 (^{1}H NMR), SHMADZU FTIR-8200A (FT-IR). Dehydrated tetrahydrofuran was purchased

from KANTO CHEMICAL Co. All other dehydrated solvents were purchased from Wako Pure Chemical Inc.

General procedure of the addition of pronucleophiles 1 to methylenecyclopropanes 2. To a mixture of pronucleophile **1** (0.5 mmol), methylenecyclopropane **2** (1.0 mmol) and $Pd(PPh_3)_4$ (58mg, 0.05 mmol) was added THF (1 ml) under Ar atmosphere in a pressure vial. After heating at 100 ℃ for 2-3 days, the mixture was filtered through a short silica gel column using ethyl acetate as an eluent. Concentration and purification by passing through a silica gel column (hexane/ethyl acetate as an eluent) afforded adducts **3** and/or **4**.

2-Cyano-2-methyl-4-methylene-8-phenyloctanenitrile (3a): IR (neat) 3100-2800, 2249, 1643, 1603, 1497, 1454, 912, 748, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.58-1.74 (m, 4 H), 1.77 (s, 3 H) 2.21 (t, J = 7.4 Hz, 2 H), 2.56 (s, 2 H), 2.60 (t, J = 7.5 Hz, 2 H), 5.10 (s, 1 H), 5.12 (s, 1 H), 7.08-7.34 (m, 5 H); Anal. Cald for $C_{16}H_{18}N_2$ (238.34): C, 80.63; H, 7.61; N, 11.75. Found: C, 80.73; H, 7.60; N, 11.63.

Ethyl 2-Cyano-2-methyl-4-methylene-8-phenyloctanoate (3b): IR (neat) 3100-2800, 2245, 1744 1242, 1223, 748, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.30 (t, J = 7.1 Hz, 3 H), 1.58 (s, 3 H), 1.42-1.69 (m, 4 H), 2.12 (t, J = 7.5 Hz, 2 H), 2.43 (d, J = 14.1 Hz, 1 H), 2.61 (t, J = 7.5 Hz, 2 H), 2.65 (d, J = 14.0 Hz, 1 H), 4.24 (q, J = 7.2 Hz, 2 H), 4.90 (s, 1 H), 7.12-7.32 (m, 5 H).

2-Cyano-2-methyl-4-methylene-5-cyclohexylpentanenitrile (3c): IR (neat) 3080, 2924, 2249, 1448 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 0.80-1,76 (m, 11 H), 1.82 (s, 3 H), 2,12 (d, J = 7.1 Hz, 2 H), 2.61 (s, 3 H), 5.13 (s, 1 H), 5.16 (s, 1 H) ^{13}C NMR ($CDCl_3$) δ 25.2, 26.1, 26.4, 30.9, 32.9, 35.7, 43.97, 44.04, 116.2, 118.5, 139.7; HRMS (EI) Calcd for $C_{14}H_{20}N_2$: m/z 216.1625. Found: m/z 216.1628.

Ethyl 2-Cyano-2-methyl-4-methylene-7-phenylheptanoate (3d): IR (neat) 3100-2800, 2243, 1744, 1454, 1244, 1167, 1018, 750, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.30 (t, J = 7.1 Hz, 3 H), 1.61 (s, 3 H), 1.72-1.84 (m, 2 H), 2.16 (t, J = 7.7 Hz, 2 H), 2.47 (d, J = 13.8 Hz, 1 H), 2.62 (t, J = 7.8 Hz, 2 H), 2.68 (d, J = 13.8 Hz, 1 H), 4.22 (q, J = 7.2 Hz, 2 H), 4.95 (s, 1 H), 5.00 (s, 1 H), 7.14-7.32 (m, 5 H); Anal. Cald for $C_{18}H_{23}NO_2$ (285.39): C, 75.76; H, 8.12; N, 4.91. Found: C, 75.81; H, 7.80; N, 5.23.

Ethyl 2-Ethoxycarbonyl-2-methyl-4-methylene-7-phenylheptanoate (3e): IR (neat) 3100-2800, 2245, 1732, 1641, 1242, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.21 (t, J = 7.9 Hz, 6 H), 1.37 (s, 3 H), 1.69-1.79 (m, 2 H), 1.94 (t, J = 7.8 Hz, 2 H), 2.56 (t, J = 7.6 Hz, 2 H), 2.67 (s, 2 H), 4.06-4.19 (m, 4 H), 4.76 (s, 1 H), 4.87 (s, 1 H), 7.01-7.32 (m, 5 H).

2-Cyano-2-methyl-4-methylene-7-phenylheptanenitrile (3f): IR (neat) 3100-2800, 2249, 1643, 1603, 1497, 1454, 912, 752, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.76-1.88 (m, 5 H), 2.27 (t, J =7.7 Hz, 2 H), 2.63 (s, 2 H), 2.65 (t, J = 7.7 Hz, 2 H), 5.17 (s, 1 H), 5.19 (s, 1 H), 7.16-7.32 (m, 5 H); Anal. Cald for $C_{16}H_{18}N_2$ (238.34): C, 80.63; H, 7.61; N, 11.75. Found: C, 80.73; H, 7.60; N, 11.63.

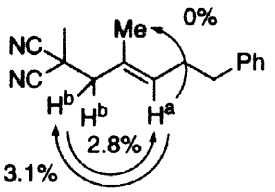
2-Cyano-2-methyl-4-methylene-6-phenylhexanenitrile (3g): IR (neat) 3100-2800, 2249, 1497, 1454, 914, 750, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.80 (s, 3 H), 2.53 (t, J = 7.9 Hz, 2 H), 2.61 (s, 2 H), 2.79 (t, J = 7.9 Hz, 2 H), 5.19 (s, 1 H), 5.22 (s, 1 H), 7.14-7.32 (m, 5 H); Anal. Cald for $C_{15}H_{16}N_2$ (224.31): C, 80.32; H, 7.19; N, 12.49. Found: C, 79.82; H, 7.41; N, 12.26.

Ethyl 2-Ethoxycarbonyl-2-methyl-4-methylene-5-phenylpentanoate (3h): IR (neat) 3100-2820

1732, 1643, 1643, 1495, 1454, 1379, 1300, 1244, 1192, 1109, 1024, 910, 862, 735, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.13–1.20 (m, 6 H), 1.38 (s, 2 H), 2.60 (s, 2 H), 3.19, (s, 2 H), 4.02-4.18 (m, 4 H), 4.75 (s, 1 H), 4.81 (s, 1 H), 7.04-7.26 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 13.96, 20.02, 40.28, 43.44, 53.30, 61.28, 116.57, 126.14, 128.27, 129.06, 139.13, 143.89, 172.26; HRMS (EI) Calcd for $C_{18}H_{24}O_4$: m/z 304.1675. Found: m/z 304.1672.

(*E*)-2-Cyano-2,4-dimethyl-7-phenyl-4-heptenenitrile (3k): IR (neat) 3100-2800, 2249, 1603, 1497, 1454, 748, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.72 (d, J = 1.3 Hz, 3 H), 1.77 (s, 3 H), 2.41 (q, J = 7.5 Hz, 2 H), 2.58 (s, 2 H), 2.71 (t, J = 7.3 Hz, 2 H), 5.56 (t, J = 7.2 Hz, 1 H), 7.15-7.32 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 17.00, 24.81, 29.96, 31.21, 35.20, 48.09, 116.38, 125.89, 127.77, 128.30, 128.39, 133.14, 141.39; HRMS (EI) Calcd for $C_{16}H_{18}N_2$: m/z 238.1470. Found: m/z 238.1452.

The geometry of the double bond of **3k** was determined by NOE experiments. A 2.8% increment was observed on the H^a proton upon irradiation of the H^b protons. Irradiation of the H^a proton also showed a 3.1% increment on the H^b protons, whereas no increment was observed on the methyl group, indicating the *E* geometry of the double bond of **3k**.



2-Cyano-2-methyl-4-methylene-7-phenyl-5-(2-phenylethyl)-heptano-nitrile (3l): IR (neat) 3086-2777, 2249, 1726, 1645, 1602, 1497, 1454, 1383, 1284, 1149, 1117, 1072, 1029, 910, 750, 700; ^1H NMR (300 MHz, $CDCl_3$) δ 1.69-1.88 (m, 7 H), 2.28 (m, 1 H), 2.56 (s, 2 H), 2.61 (m, 4 H), 5.29 (s, 1 H), 5.43 (s, 1 H), 7.15-7.31 (m, 10 H); ^{13}C NMR ($CDCl_3$) δ 25.61, 30.49, 33.20, 35.51, 42.83, 44.68, 115.91, 116.10, 125.77, 128.22, 128.29, 141.87, 143.60; HRMS (EI) Calcd for $C_{24}H_{26}N_2$: m/z 342.2094. Found: m/z 342.2094.

(*E*)-2-Cyano-2,3-dimethyl-7-phenyl-4-heptenenitrile (4a): IR (neat) 3100-2800, 2249, 1665, 1603, 1497, 1454, 1383, 972, 748, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.32 (d, J = 6.8 Hz, 3 H), 1.55 (s, 3 H), 2.42 (q, J = 7.0 Hz, 2 H), 2.52 (m, 1 H), 2.73 (t, J = 7.5 Hz, 2 H), 5.31 (dd, J = 8.8, 15.2 Hz, 1 H), 5.71 (dt, J = 6.9, 15.2 Hz, 1 H), 7.14-7.32 (m, 5 H); Anal. Cald for $C_{16}H_{18}N_2$ (238.34): C, 80.63; H, 7.61; N, 11.75. Found: C, 80.34; H, 7.42; N, 11.36.

(*E*)-2-Cyano-2,3-dimethyl-6-phenyl-4-hexenenitrile (4b): IR (neat) 3100-2800, 2249, 1495, 1454, 1385, 974, 752, 700, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.36 (d, J = 6.8 Hz, 3 H), 1.70 (s, 3 H), 2.60 (m, 1 H), 3.42 (d, J = 6.8 Hz, 2 H), 5.45 (dd, J = 8.8, 15.2 Hz, 1 H), 5.87 (dt, J = 6.8, 15.3 Hz, 1 H), 7.12-7.36 (m, 5 H); Anal. Cald for $C_{15}H_{16}N_2$ (224.31): C, 80.32; H, 7.19; N, 12.49. Found: C, 79.92; H, 7.36; N, 12.09.

(*E*)-2-Cyano-2,3-dimethyl-5-phenyl-4-pentenenitrile (4c): IR (neat) 3100-2800, 2249, 1495, 1450, 1385, 970, 752, 696, 665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.47 (d, J = 6.9 Hz, 3 H), 1.79 (s, 3 H),

2.76 (m, 1 H), 6.05 (dd, J = 8.9, 15.8 Hz, 1 H), 6.60 (d, J = 15.8 Hz, 1 H), 7.20-7.42 (m, 5 H); Anal. Cald for $C_{14}H_{14}N_2$ (210.28): C, 79.97; H, 6.71; N, 13.32. Found: C, 80.25; H, 6.98; N, 13.05.

(*E*)-2-Cyano-2,3-dimethyl-5-(4-trifluoromethylphenyl)-4-pentenenitrile (4d): IR (neat) 2939 2249, 1327, 1124, 1069 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.50 (d, J = 6.8 Hz, 3 H), 1.80 (s, 3 H), 2.76-2.90 (m, 1 H), 6.19 (dd, J = 8.9, 15.8 Hz, 1 H), 6.67 (d, J = 15.8 Hz, 1 H), 7.50 (d, J = 8.3 Hz, 2 H) 7.61 (d, J = 8.3 Hz, 2 H); Anal. Cald for $C_{15}H_{13}N_2F_3$ (278.28): C, 64.74; H, 4.71; N, 10.07. Found: C, 64.75; H, 4.64; N, 9.73.

(*E*)-2-Cyano-2,3-dimethyl-5-(4-methoxyphenyl)-4-pentenenitrile (4e): IR (neat) 2957, 2249, 1510, 1244 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.48 (d, J = 6.8 Hz, 3 H), 2.69-2.82 (m, 1 H),. 3.82 (s, 3 H) 5.91 (dd, J = 9.0, 15.8 Hz, 1 H), 6.55 (d, J = 15.8 Hz, 1 H), 6.87 (d, J = 8.8 Hz, 2 H), 7.33 (d, J = 8.8 Hz, 2 H); ^{13}C NMR ($CDCl_3$) δ 17.2, 23.1, 36.9, 45.6, 55.3, 114.1, 115.3, 116.0, 122.8, 127.9, 128.3, 134.9, 159.8; HRMS (EI) Calcd for $C_{15}H_{16}N_2O$: m/z 240.1263. Found: m/z 240.1278.

(*E*)-Ethyl 2-Cyano-2,3-dimethyl-5-phenyl-4-pentenoate (4f): IR (neat) 3090-2862, 2245, 1742, 1495, 1450, 1385, 1259, 1113, 1028, 970, 856, 752, 694 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.18 (t, J = 7.2 Hz, 3 H, diastereomer A), 1.21 (d, J = 7.0 Hz, 3 H, diastereomer B), 1.25 (t, J = 6.8 Hz, 3 H, diastereomer A), 1.31 (t, J = 7.2 Hz, 3 H, diastereomer B), 1.57 (s, 3 H), 2.72-2.83 (m, 1 H), 4.11-4.19 (m, 2 H, diastereomer A), 4.22-4.30 (m, 2 H, diastereomer B), 6.05 (dd, J = 9.4 Hz, 15.0 Hz, 1 H, diastereomer B), 6.10 (dd, J = 9.0 Hz, 15.8 Hz, 1 H, diastereomer A), 6.42 (d, J = 15.8 Hz, 1 H, diastereomer A), 6.49 (d, J = 15.6 Hz, 1 H, diastereomer B), 7.17-7.37 (m, 5 H); Anal. Cald for $C_{16}H_{19}NO_2$ (257.33): C, 63.14; H, 6.29; N, 4.60. Found: C, 63.56; H, 6.60; N, 4.85.

2-Cyano-6-cyclopropylidenehexanenitrile (17): IR (neat) 3055, 2920, 2257, 1458 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.00-1.12 (m, 4 H), 1.74-1.86 (m, 2 H),. 2.00-2.10 (m, 2 H), 2.24-2.34 (m, 2 H) 3.72 (t, J = 7.0 Hz, 1 H), 5.69-5.78 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 1.9, 2.3, 22.4, 25.9, 30.19, 30.24, 112.6 115.8, 123.4; HRMS (EI) Calcd for $C_{10}H_{12}N_2$: m/z 160.1000. Found: m/z 160.1014.

1,1-Dicyano-3-methylenecycloheptane (18): IR (neat) 3080, 2941, 2247, 1447 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.66-1.81 (m, 4 H), 2.24-2.27 (m, 2 H), 2.40 (t, J = 6.5 Hz, 2 H), 2.85 (m, 2H), 5.15 (m 2 H); ^{13}C NMR ($CDCl_3$) δ 23.3, 26.3, 34.9, 35.7, 38.9, 43.4, 116.1, 119.8, 140.1; HRMS (EI) Calcd for $C_{10}H_{12}N_2$: m/z 160.1000. Found: m/z 160.1001.

2-Cyano-7-cyclopropylideneheptanenitrile (22): IR (neat) 3053, 2930, 2257, 1462 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 0.98-1.10 (m, 4 H), 1.50-1.71 (m, 4 H),. 2.00-2.10 (m, 2 H), 2.18-2.28 (m, 2 H) 3.71 (t, J = 6.9 Hz, 1 H), 5.68-5.78 (m, 1 H); Anal. Cald for $C_{11}H_{14}N_2$ (174.25): C, 75.83; H, 8.10; N, 16.08. Found: C, 75.66; H, 8.11; N, 15.82.

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‡Department of Natural Scienece, Faculty of Education, Hirosaki University, Hirosaki 036-8560

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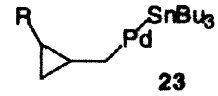

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