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COMMUNICATIONS

Published on Web 08/03/2002

Novel Catalytic CO_2 Incorporation Reaction: Nickel-Catalyzed Regio- and Stereoselective Ring-Closing Carboxylation of Bis-1,3-dienes

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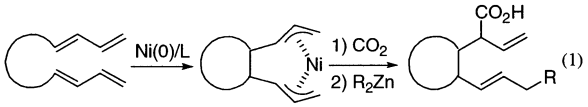
Received April 21, 2002

Development of transition-metal-catalyzed carbon dioxide (CO_2) incorporation reactions into organic molecules is an attractive subject in synthetic organic chemistry.[1] However, only a few catalytic synthetic reactions have been reported.[2] Among the reported reactions, palladium- or nickel-catalyzed co-oligomerization of 1,3-dienes with CO_2, which proceeds via a bis-π-allyl intermediate, is one of the first and most extensively studied transition-metal-catalyzed CO_2 fixation process.[3−7] Despite the potential usefulness of this reaction, it has rarely been used for the synthesis of complex organic molecules, due in part to the low selectivity. One practical solution to this problem might be to conduct the reaction in intramolecular form.[8] On the basis of this concept, we have studied a nickel-promoted co-oligomerization of bis-1,3-diene and CO_2 and have found an efficient methodology that utilizes an organozinc compound as a supplemental reagent and enables a catalytic process with extra carbon−carbon bond formation to be realized. In this communication, we report this novel reaction, i.e., a highly regio- and stereoselective ring-closing carboxylation of bis-1,3-dienes (eq 1).

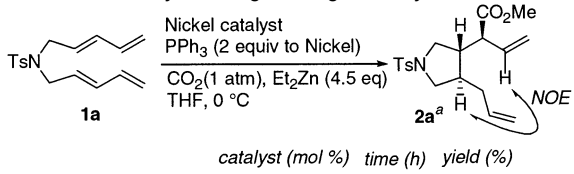


(1)

A reaction of symmetrical bis-1,3-diene **1a** in the presence of a nickel catalyst and Et_2Zn was examined first (Scheme 1). To a solution of $Ni(cod)_2$ (20 mol %) and PPh_3 (40 mol %) in THF were added **1a** and Et_2Zn (4.5 equiv), and the mixture was stirred at 0 °C for 3 h under an atmosphere of CO_2 (1 atm). Hydrolysis of the resulting mixture followed by treatment with diazomethane afforded **2a** in 75% yield as a sole product. The results of an NOE experiment for **2a** showed that the configuration of two side chains on the five-membered ring was trans. The stereochemistry, which is concerned with a methoxycarbonyl moiety, was determined by the coupling constants of Ha in a ^1H NMR spectrum of **3** that was prepared from **2a** by the procedures shown in Scheme 2. In this reaction, an air-stable Ni(II) complex also can be used as a catalyst precursor in place of $Ni(cod)_2$. By using 5 mol % of $Ni(acac)_2$ and 10 mol % of PPh_3, **2a** was obtained in 72% yield (Scheme 1).

A possible reaction mechanism is shown in Scheme 3. The reaction seems to start with oxidative cycloaddition of bis-diene **1a** to an Ni(0) complex[10] to produce bis-π-allylnickel complex **4**, and subsequent insertion of CO_2 into the nickel−carbon bond affords carboxylate **5**.[11] The role of Et_2Zn in this reaction is probably regeneration of a Ni(0) complex via a transmetalation process.[12−15] Thus, complex **5** reacts with Et_2Zn to provide ethylnickel complex **6**, which can then easily undergo β-hydride elimination to afford

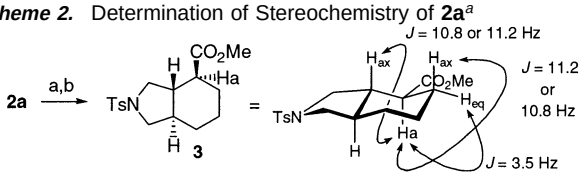
Scheme 1. Ni-Catalyzed Ring-Closing Carboxylation of **1a**



catalyst (mol %)	*time (h)*	*yield (%)*
$Ni(cod)_2$ (20)	3.5	75
$Ni(acac)_2$ (5)	24	72

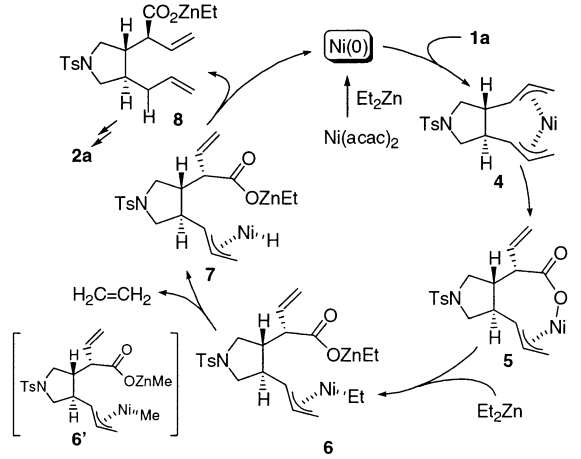
[a] The product was isolated and characterized after treatment with diazomethane.

Scheme 2. Determination of Stereochemistry of **2a**[a]



[a] Reagents and conditions: (a) $RuCl_2(=CHPh)(PCy_3)_2$ (5 mol %), CH_2Cl_2, 6 h, 80%; (b) H_2, Pd/C, AcOEt, rt, 6 h, 94%.

Scheme 3. Possible Reaction Mechanism



complex **7**. Reductive elimination from **7** reproduces a Ni(0) complex and provides carboxylate **8**, which corresponds to ester **2a**. In this case, the β-hydride elimination process (**6** to **7**) seems to restrict the transfer of an ethyl group from Et_2Zn to the product. This possibility prompted us to examine organozinc reagents having no β-hydrogen atom on their alkyl ligand.

The reaction of **1a** with Me_2Zn (4.5 equiv) and CO_2 (1 atm) in the presence of a nickel catalyst (10 mol %) afforded **9a** in 94% yield (Table 1, entry 1). The formation of **9a** can be explained by the reductive elimination from methylnickel complex **6′**, which was produced via a reaction course similar to that shown in Scheme 3. Bis-diene **1b** also underwent methylative carboxylation to afford ester **9b** in high yield (entry 2). Furthermore, phenylative ring-

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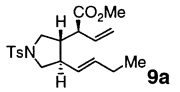
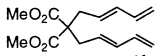
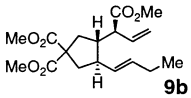
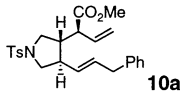
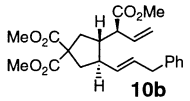
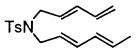
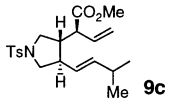
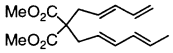
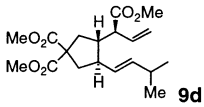
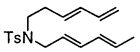
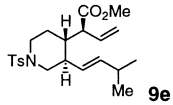
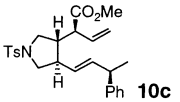
10.1021/ja026620c CCC: $22.00

Table 1. Methylative or Phenylative Ring-Closing Carboxylation[a]

entry	substrate	R_2Zn/ temp/ time (°C) (h)	product [b]	yiled (%)
1	**1a**	Me_2Zn/rt /19	 **9a**	94
2	 **1b**	Me_2Zn/40/21	 **9b**	91
3	**1a**	Ph_2Zn/rt/20	 **10a**	90
4	**1b**	Ph_2Zn/40/22	 **10b**	82
5	 **1c**	Me_2Zn/ 38/13	 **9c**	77
6	 **1d**	Me_2Zn/45/33	 **9d**	71
7	 **1e**	Me_2Zn/50/30	 **9e**	56
8	**1c**	Ph_2Zn/30/24	 **10c**	64

[a] All reactions were carried out in the presence of $Ni(acac)_2$ (10 mol % for entries 1 and 15 mol % for the other cases), PPh_3 (2 equiv to nickel), and organozinc (4.9 equiv for entry 3 and 4.5 equiv for the other cases) under an atmosphere of CO_2 (1 atm). [b] All products were isolated as methyl esters after treatment with diazomethane.

closing carboxylation could be carried out in a regio- and stereoselective manner by the use of Ph_2Zn instead of Me_2Zn (entries 3 and 4).

It is notable that this reaction was applicable to the reaction of unsymmetrical bis-1,3-dienes with high selectivities. Methylative carboxylation of bis-diene **1c** or **1d**, which possessed a methyl group on a terminal carbon of one diene moiety, proceeded with regioselective introduction of CO_2 into the unsubstituted diene moiety (not into the methyl-substituted one) to afford **9c** or **9d** (Table 1, entries 5 and 6). The same selectivity was also found in the reaction of **1e**, which resulted in regio- and stereoselective construction of a heterocyclic six-memberd ring (entry 7). Furthermore, the addition of a phenyl group also occurred in a stereoselective manner to afford **10c** as a single diastereomer when carboxylation of **1c** was carried out with Ph_2Zn (entry 8).[16]

In conclusion, we have developed a nickel-catalyzed ring-closing carboxylation of bis-1,3-dienes, which proceeds via insertion of CO_2 into a bis-π-allylnickel intermediate followed by a transmetalation process of the resulting cyclic nickel carboxylate with an organozinc reagent. This reaction can be carried out easily under mild conditions, and the yields and regio- and stereoselectivities are generally high. Efforts to expand the scope of this reaction are underway.

Acknowledgment. This work was supported in part by a Grant-in-Aid for Scientific Research (No. 14771235) from the Ministry of Education, Culture, Sports, Science and Technology, Japan, which is gratefully acknowledged.

Supporting Information Available: Information on typical procedures for carboxylations, procedures for determination of the stereochemistry, and spectral data for all new compounds (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) Reviews: Arakawa, H.; Aresta, M.; Armor, J. N.; Barteau, M. A.; Beckman, E. J.; Bell, A. T.; Bercaw, J. E.; Creutz, C.; Dinjus, E.; Dixon, D. A.; Domen, K.; DuBois, D. L.; Eckert, J.; Fujita, E.; Gibson, D. H.; Goddard, W. A.; Goodman, W.; Keller, J.; Kubas, G. J.; Kung, H. H.; Lyons, J. E.; Manzer, L. E.; Marks, T. J.; Morokuma, K.; Nicholas, K. M.; Periana, R.; Que, L.; Rostrup-Nielson, J.; Sachtler, W. M. H.; Schmidt, L. D.; Sen, A.; Somorjai, G. A.; Stair, P.; Stults, B. R.; Tumas, W. *Chem. Rev.* **2001**, *101*, 953.

(2) Reviews: (a) Behr, A. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 661. (b) Braunstein, P.; Matt, D.; Nobel, D. *Chem. Rev.* **1988**, *88*, 747. (c) Leitner, W. *Coord. Chem. Rev.* **1996**, *153*, 257. (d) Yin, X.; Moss, J. R. *Coord. Chem. Rev.* **1999**, *181*, 27. (e) Walther, D.; Ruben, M.; Rau, S. *Coord. Chem. Rev.* **1999**, *182*, 67.

(3) (a) Sasaki, Y.; Inoue, Y.; Hashimoto, H. *J. Chem. Soc., Chem. Commun.* **1976**, 605. (b) Inoue, Y.; Sasaki, Y.; Hashimoto, H. *Bull. Chem. Soc. Jpn.* **1978**, *51*, 2375.

(4) (a) Musco, A.; Perego, C.; Tartiari, V. *Inorg. Chim. Acta* **1978**, *28*, L147. (b) Musco, A. *J. Chem. Soc., Perkin Trans. 1* **1980**. 693.

(5) (a) Behr, A.; Juszak, K.-D.; Keim, W. *Synthesis* **1983**, 574. (b) Behr, A.; Juszak, K.-D. *J. Organomet. Chem.* **1983**, *255*, 263. (c) Behr, A.; He, R. *J. Organomet. Chem.* **1984**, *276*, C69. (d) Behr, A. *Bull. Soc. Chim. Belg.* **1985**, *94*, 671. (e) Behr, A.; He, R.; Juszak, K.-D.; Krüger, C.; Tsay, Y.-H. *Chem. Ber.* **1986**, *119*, 991. (f) Behr, A.; Kanne, U. *J. Organomet. Chem.* **1986**, *309*, 215.

(6) Braunstein, P.; Matt, D.; Nobel, D. *J. Am. Chem. Soc.* **1988**, *110*, 3207.

(7) (a) Hoberg, H.; Gross, S.; Milchereit, A. *Angew. Chem., Int. Ed. Engl.* **1987**, *26*, 571. (b) Hoberg, H.; Peres, Y.; Milchereit, A.; Gross, S. *J. Organomet. Chem.* **1988**, *345*, C17. (c) Hoberg, H.; Minato, M. *J. Organomet. Chem.* **1991**, *406*, C25.

(8) For typical examples based on similar concepts, see: (a) Wender, P. A.; Tebbe, M. J. *Synthesis* **1991**, 1089 and references therein. (b) Takacs, J. M.; Clement, F.; Zhu, J.; Chandramouli, S. V.; Gong, X. *J. Am. Chem. Soc.* **1997**, *119*, 5804−5817 and references therein.

(9) The signal of Ha appears as a double double doublet (ddd, J = 11.2, 10.8, 3.5 Hz) at 2.28 ppm. For the procedures to determine the stereochemistry of other ring-closing carboxylation products, see Supporting Information.

(10) (a) Jolly, P. W.; Wilke, G. *The Organic Chemistry of Nickel*; Academic: New York, 1975; Vol. II, pp 133−161. (b) Jolly, P. W. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, F. G. A., Abel, E. W., Eds.; Pergamon: New York, 1970; Vol. 8, pp 671−679. (c) Wilke, G. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 185.

(11) (a) Jolly, P. W.; Stobbe, S.; Wilke, G.; Goddard, R.; Krüger, C.; Sektowski, J. C.; Tsay, Y.-H. *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 124. (b) Jolly, P. W. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 283. (c) Benn, R.; Jolly, P. W.; Mynott, R.; Raspel, B.; Schenker, G.; Schick, K. P.; Schoroth, G. *Organometallics* **1985**, *4*, 1945.

(12) (a) Montgomery, J. *Acc. Chem. Res.* **2000**, *33*, 467. (b) Lozanov, M.; Montgomery, J. *J. Am. Chem. Soc.* **2002**, *124*, 2106.

(13) Shibata, K.; Kimura, M.; Shimizu, M.; Tamaru, Y. *Org. Lett.* **2001**, *3*, 2181.

(14) Bercot, E. A.; Rovis, T. *J. Am. Chem. Soc.* **2002**, *124*, 174.

(15) (a) Sato, Y.; Takanashi, T.; Mori, M. *Organometallics* **1999**, *18*, 4819. (b) Takimoto, M.; Mori, M. *J. Am. Chem. Soc.* **2001**, *123*, 2895. (c) Takimoto, M.; Shimizu, K.; Mori, M. *Org. Lett.* **2001**, *3*, 3345.

(16) The ^{13}C NMR spectrum of **10c** indicated that **10c** was obtained as a single isomer (see Supporting Information). For detailed procedures to determine the stereochemistry, see Supporting Information.

JA026620C