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# Nickel-catalyzed intermolecular codimerization of acrylates and alkynes†

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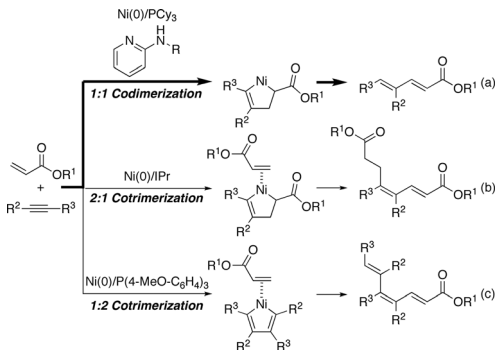
**The linear codimerization of acrylates and alkynes to produce 1,3-dienes is successfully demonstrated using a nickel catalyst in association with 2-aminopyridine as an additive.**

Transition-metal-catalyzed cooligomerizations of alkynes and alkenes that involves an σ–π isomerization are powerful methodologies for an efficient construction of complex molecules from readily accessible starting materials.[1] Therefore, development of cooligomerization has been a research topic of great interest.[2–5] Recently, we reported an intermolecular cotrimerization of alkenes and alkynes by tuning the nickel catalyst allowing access to 1,3-dienes and 1,3,5-trienes. It was found that sterically hindered *N*-heterocyclic carbene ligands (IPr) give 1,3-dienes (Scheme 1b), while P(4-MeO–$C_6H_4$)$_3$ gives 1,3,5-trienes (Scheme 1c).[6] Herein, we wish to report an unprecedented nickel-catalyzed codimerization, which incorporates an acrylate and an alkyne into a 1,3-diene (Scheme 1a).[7–10]

During the exploration of different cooligomerization conditions, we found that on addition of 2-aminopyridine, the reaction of methyl acrylate (**1a**) and 4-octyne (**2a**) affords 1,3-diene **4aa** as a preferred product. The reaction of **1a** and **2a** in the presence of *N*-methyl-2-aminopyridine **3a** (20 mol%) gave **4aa** in 56% yield along with **5aa** in 25% yield (Table 1,




**Scheme 1** Nickel-catalyzed cooligomerization of acrylates and alkynes.

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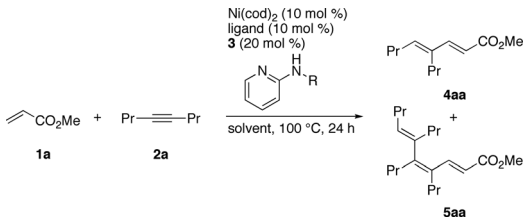
† Electronic supplementary information (ESI) available: Experimental details and NMR spectra. See DOI: 10.1039/c0cc04061d

**Table 1** Codimerization between a methyl acrylate **1a** and an 4-octyne **2a** to afford a 1,3-diene **4aa**[a]



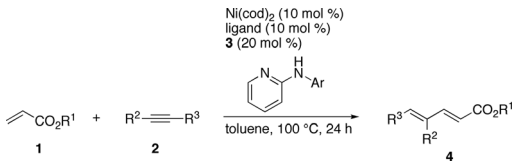

| Entry | R (**3**) | Ligand | Solvent | **4aa**[b]/**5aa**[c] yield (%) |
|---|---|---|---|---|
| 1 | Me (**3a**) | $PCy_3$ | Toluene | 56/25 |
| 2 | —[d] | $PCy_3$ | Toluene | <5/39 |
| 3 | Me (**3a**) | $PBu_3$ | Toluene | 42/36 |
| 4 | Me (**3a**) | $PPh_3$ | Toluene | 52/27 |
| 5 | Me (**3a**) | IPr | Toluene | 41/(24)[e] |
| 6 | Ph (**3b**) | $PCy_3$ | Toluene | 95/<5 |
| 7 | 3-$CF_3$–$C_6H_4$ (**3c**) | $PCy_3$ | Toluene | 95/<5 |
| 8 | 4-MeO–$C_6H_4$ (**3d**) | $PCy_3$ | Toluene | 91/<5 |
| 9 | 2-Me–$C_6H_4$ (**3e**) | $PCy_3$ | Toluene | 91/<5 |
| 10 | Ph (**3b**) | $PCy_3$ | 1,4-Dioxane | 87/<5 |
| 11 | Ph (**3b**) | $PCy_3$ | MeCN | 80/<5 |
| 12 | Ph (**3b**) | $PCy_3$ | Pyridine | <5/<5 |

[a] Reactions were carried out using $Ni(cod)_2$ (10 mol%), ligand (10 mol%), 2-aminopyridine **3** (20 mol%), **1** (0.6 mmol, 1.2 equiv.), and **2** (0.5 mmol) in 5 mL of solvent at 100 °C for 24 h. [b] NMR yields based on **2** (0.5 mmol). [c] NMR yields based on **2** (0.25 mmol). [d] The reaction was carried out without an addition of 2-aminopyridine **3**. [e] (2*E*,4*Z*)-Dimethyl-4,5-dipropylocta-2,4-dienedioate was obtained in 24% yield as a minor product. For details, see ref. 6.

entry 1). While in the absence of 2-aminopyridine, the reaction afforded **5aa** in 39% yield as a sole product (entry 2). Among phosphine ligands examined, $PCy_3$ gave the best yield of **4aa** (entries 3 and 4). IPr (1,3-bis(2,6-diisopropylphenyl)imidazol-2-ylidene) afford **4aa** in 41% yield (entry 5). It was found after thorough screening that a *N*-aryl-2-aminopyridine is the most effective for the selective codimerization to give 1,3-diene **4aa** (entry 6). Almost same results were obtained when trifluoromethyl-, methoxy- or methyl-substituted *N*-phenyl-2-aminopyridine was employed as an additive (entries 7–9). In other solvents, such as 1,4-dioxane, MeCN, or pyridine, yields and selectivity were even lower (entries 10–12).

The scope of the codimerization of various alkenes with alkynes is briefly examined and summarized in Table 2. Under the optimized reaction conditions, *tert*-butyl acrylate (**1b**) also provides 1,3-diene **4ba** in 92% yield (entry 2). The reaction with unsymmetrical alkynes, such as 3-octyne and 2-octyne,

**Table 2** Codimerization of acrylate **1** and alkyne **2**[a]



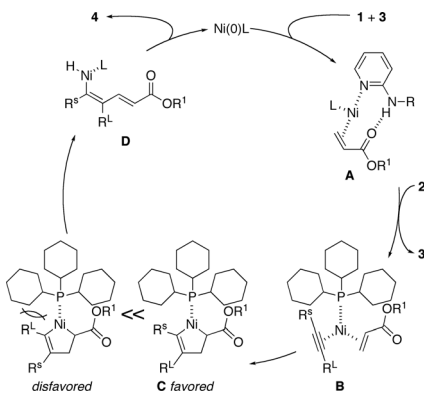

1 2 4

| Entry | 1 | $R^1$ (equiv.) | 2 | $R^2$ | $R^3$ | 3 | 4 | Yield[b] (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | **1a** | Me (1.2) | **2a** | Pr | Pr | **3b** | **4aa** | 95 |
| 2 | **1b** | *t*Bu (1.2) | **2a** | Pr | Pr | **3b** | **4ba** | 92 |
| 3 | **1a** | Me (1.2) | **2b** | $C_5H_{11}$ | $C_5H_{11}$ | **3b** | **4ab** | 90 |
| 4 | **1a** | Me (1.2) | **2c** | Bu | Et | **3b** | **4ac** | 82 (1/1)[c] |
| 5 | **1a** | Me (1.2) | **2d** | $C_5H_{11}$ | Me | **3b** | **4ad** | 76 (5/1)[c] |
| 6 | **1a** | Me (1.2) | **2d** | $C_5H_{11}$ | Me | **3e** | **4ad** | 79 (5/1)[c] |
| 7 | **1a** | Me (1.2) | **2e** | *i*Pr | Me | **3b** | **4ae** | 64 (10/1)[c] |
| 8 | **1a** | Me (1.2) | **2e** | *i*Pr | Me | **3e** | **4ae** | 69 (10/1)[c] |
| 9 | **1a** | Me (2.0) | **2f** | Pr | Ph | **3b** | **4af** | 58 |
| 10 | **1a** | Me (2.0) | **2f** | Pr | Ph | **3c** | **4af** | 62 |
| 11 | **1a** | Me (2.0) | **2g** | $C_5H_{11}$ | 4-MeO–$C_6H_4$– | **3c** | **4ag** | 87 |
| 12 | **1a** | Me (2.0) | **2h** | $C_5H_{11}$ | 4-F–$C_6H_4$– | **3c** | **4ah** | 67 |
| 13 | **1a** | Me (2.0) | **2i** | *c*Pr | Ph | **3c** | **4ai** | 53 |

[a] Reactions were carried out using $Ni(cod)_2$ (10 mol%), $PCy_3$ (10 mol%), **3** (20 mol%), **1** (0.6 mmol, 1.2 equiv.), and **2** (0.5 mmol) in 5 mL of toluene at 100 °C for 24 h. [b] Isolated yields based on alkyne **2** (0.5 mmol). [c] Ratio of isomers.

gave the 1,3-dienes consisting of regioisomers in a range of 1/1 to 5/1 ratio (entries 4–6), whereas the reaction of 4-methyl-2-pentyne (**2e**) gave **4ae** regioselectively (entries 7 and 8). The codimerization reaction is also compatible with aryl-substituted alkyne and afforded the corresponding 1,3-dienes in good yields with excellent regioselectivities (entries 9–12). Cyclopropyl-substituted alkyne **2i** also reacted with **1a** to furnish 1,3-diene **4ai** in 53% yield regioselectively (entry 13). However, terminal alkynes, such as 1-octyne and phenylacetylene, failed to participate in the reaction.

A reaction pathway to account for the formation of 1,3-diene **4** based on the observed results is outlined in Scheme 2. In view of the effects of 2-aminopyridine **3** on the reaction, it is reasonable to consider that the catalytic cycle of the present reaction may involve assembly of 2-aminopyridine and acrylate **1** in the coordination sphere of a nickel metal center through hydrogen bonding to form Ni(0) intermediate **A**.[11,12] Subsequent coordination of alkyne and dissociation of 2-aminopyridine affords Ni(0) intermediate **B**. Oxidative cyclization of nickel(0) with an alkyne and an acrylate provides




**Scheme 2** Plausible reaction pathway.

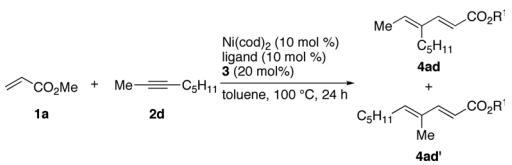
nickelacyclopentene complex **C**, in which the steric repulsive interaction is minimal between the bulkier $R^L$ and the $PCy_3$ ligand on the nickel. β-Hydride elimination and reductive elimination would afford **4** and regenerate the starting nickel(0).

It should be noted that 2-aminopyridines have lesser effects on the regioselectivity of the reaction. The reaction of **1a** and **2d** with various derivatives of aminopyridine in place of *N*-phenyl-2-aminopyridine **3b** was examined, and it was found that the reaction afforded 1,3-diene **4ad** consisting of regioisomers in 5/1 ratio (Table 3, entries 1–4). The phosphine ligands have more influence on the regioselectivity of the reaction (entry 5). Therefore, it might be reasonable to presume that *N*-phenyl-2-aminopyridine has effects on the formation of intermediate **A**, but not on the formation of intermediate **B** or intermediate **C**.

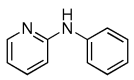
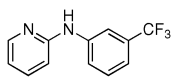
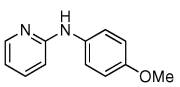
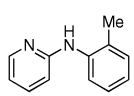
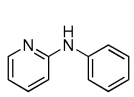
We next speculated that an assembly of two molecules of acrylamide **6a** in the coordination sphere of a nickel metal center through hydrogen bonding (*vide infra* Scheme 3, **A′**), also reacted with alkyne to provide a nickelacyclopentene complex **C′**, and this led to selective codimerization of acrylamide **6a** and alkyne **2a** to furnish 1,3-diene **7aa**. To test our hypothesis, we examined a reaction of *N*-phenylacrylamide (**6a**) and 4-octyne (**2a**) with $Ni(cod)_2/PCy_3$ catalyst, and found that the reaction gave 1,3-diene **7aa** in 77% yield (Scheme 4). Considering that the reaction of *N*-methyl-*N*-phenylacrylamide (**6b**) with **2a** gave 1,3,5-triene **8ba** exclusively *via* cotrimerization, we suggest that the proton on the nitrogen atom of **6a** may contribute to form intermediate **A′**.

Indeed, a stoichiometric reaction of *N*-phenylacrylamide (**6a**) with $Ni(cod)_2$ and $PCy_3$ gave an pseudodiene nickel

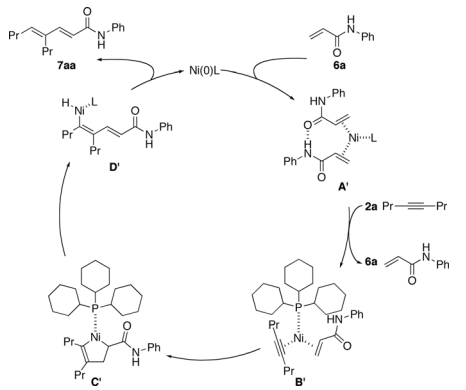
**Table 3** Regioselectivity of the codimerization of **1a** and **2d**[a]



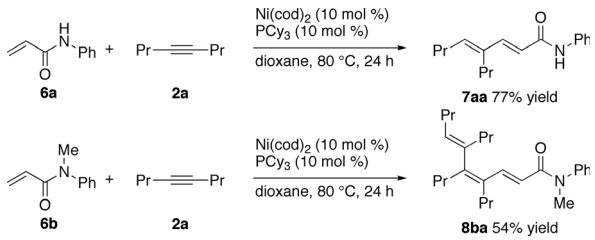

1a 2d

| Entry | Ligand | 3 | | Yield[b] (%) (**4ad**/**4ad′**)[c] |
|---|---|---|---|---|
| 1 | $PCy_3$ |  | **3b** | 76 (5/1) |
| 2 | $PCy_3$ |  | **3c** | 76 (5/1) |
| 3 | $PCy_3$ |  | **3d** | 73 (5/1) |
| 4 | $PCy_3$ |  | **3e** | 79 (5/1) |
| 5 | $PPh_3$ |  | **3f** | 40 (3/2) |

[a] Reactions were carried out using $Ni(cod)_2$ (10 mol%), ligand (10 mol%), additive (20 mol%), **1** (0.6 mmol, 1.2 equiv.), and **2d** (0.5 mmol) in 5 mL of solvent at 100 °C for 24 h. [b] Isolated yields based on **2d** (0.5 mmol). [c] Ratio of regioisomers.




**Scheme 3** Plausible reaction pathway.




**Scheme 4** Cooligomerization of acrylamide and alkyne.

complex **A′** quantitatively. The molecular structure of **A′** was unambiguously confirmed by the X-ray crystal structure analysis, which showed that two amides and one phosphine ligand are coordinated to the nickel in a trigonal planar arrangement (Fig. 1). A short intermolecular N···O distance (2.816 Å) may indicate that two amides are intermolecularly NH···O=C hydrogen-bonded, forming a pseudodiene complex.[13] It was also found that a stoichiometric reaction of complex **A′** with an equivalent of **2a** in dioxane at 40 °C afforded 1,3-diene **7aa** in 43% yield.[14]

In summary, we have developed a new nickel-catalyzed codimerization of an acrylate and an alkyne to provide 1,3-diene. We demonstrated for the first time that 2-aminopyridine acts as a ligand and contributes for selective formation of 1,3-dienes *via* codimerization of an acrylate and an alkyne. Furthermore, we discovered that two molecules of acrylamides are able to form a pseudodiene complex with nickel(0); such a complex allows exclusive intermolecular codimerization of an acrylamide and an alkyne.

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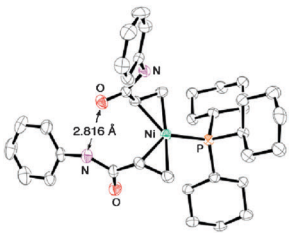


**Fig. 1** ORTEP drawing of **A′**.

## Notes and references


1 For pioneering works of ruthenium-catalyzed codimerization of alkynes and alkenes, see: B. M. Trost and A. F. Indolese, *J. Am. Chem. Soc.*, 1993, **115**, 4361. For reviews, see: (*a*) B. M. Trost, F. D. Toste and A. B. Pinkerton, *Chem. Rev.*, 2001, **101**, 2067; (*b*) B. M. Trost, M. U. Frederiksen and M. T. Rudd, *Angew. Chem., Int. Ed.*, 2005, **44**, 6630.

2 For ruthenium-catalyzed codimerization of alkynes and alkenes to provide 1,3-dienes, see: (*a*) T. Mitsudo, S.-W. Zhang, M. Nagao and Y. Watanabe, *J. Chem. Soc., Chem. Commun.*, 1991, 598; (*b*) M. Murakami, M. Ubukata and Y. Ito, *Tetrahedron Lett.*, 1998, **39**, 7361; (*c*) T. Nishimura, Y. Washitake and S. Uemura, *Adv. Synth. Catal.*, 2007, **349**, 2563; (*d*) N. M. Neisius and B. Plietker, *Angew. Chem., Int. Ed.*, 2009, **48**, 5752.

3 For palladium-catalyzed codimerization and cotrimerization of alkynes and alkenes to provide 1,3-dienes, see: (*a*) N. Tsukada, H. Setoguchi, T. Mitsuboshi and Y. Inoue, *Chem. Lett.*, 2006, 1164; (*b*) A. T. Lindhardt, M. L. H. Mantel and T. Skrydstrup, *Angew. Chem., Int. Ed.*, 2008, **47**, 2668; (*c*) K. Itoh, K. Hirai, M. Sasaki, Y. Nakamura and H. Nishiyama, *Chem. Lett.*, 1981, 865; (*d*) L. Zhao and X. Lu, *Org. Lett.*, 2002, **4**, 3903; (*e*) H. Horiguchi, K. Hirano, T. Satoh and M. Miura, *Adv. Synth. Catal.*, 2009, **351**, 1431.

4 For rhodium-catalyzed codimerization of alkynes and alkenes to provide 1,3-dienes, see: Y. Shibata, M. Hirano and K. Tanaka, *Org. Lett.*, 2008, **10**, 2829.

5 For cobalt-catalyzed codimerization of alkynes and alkenes, see: S. Mannathan and C.-H. Cheng, *Chem. Commun.*, 2010, **46**, 1923.

6 H. Horie, T. Kurahashi and S. Matsubara, *Chem. Commun.*, 2010, **46**, 7229.

7 For related Ni-catalyzed addition reaction of alkynes to carbon–carbon unsaturated bonds, see: (*a*) M. Shirakura and M. Suginome, *J. Am. Chem. Soc.*, 2008, **130**, 5410; (*b*) K. Ogata, H. Murayama, J. Sugasawa, N. Suzuki and S. Fukuzawa, *J. Am. Chem. Soc.*, 2009, **131**, 3176; (*c*) M. Shirakura and M. Suginome, *J. Am. Chem. Soc.*, 2009, **131**, 5060; (*d*) K. Ogata, J. Sugasawa and S. Fukuzawa, *Angew. Chem., Int. Ed.*, 2009, **48**, 6078; (*e*) M. Shirakura and M. Suginome, *Org. Lett.*, 2009, **11**, 523; (*f*) K. Ogata, J. Sugasawa, Y. Atsuumi and S. Fukuzawa, *Org. Lett.*, 2010, **12**, 148; (*g*) M. Shirakura and M. Suginome, *Angew. Chem., Int. Ed.*, 2010, **49**, 3827.

8 For Ni-catalyzed intramolecular codimerization, see: T. N. Tekavec and J. Louie, *Tetrahedron*, 2008, **64**, 6870.

9 For related Ni-catalyzed cyclo-oligomerization, see: (*a*) S.-i. Ikeda, N. Mori and Y. Sato, *J. Am. Chem. Soc.*, 1997, **119**, 4779; (*b*) N. Mori, S.-i. Ikeda and Y. Sato, *J. Am. Chem. Soc.*, 1999, **121**, 2722; (*c*) J. Seo, H. M. P. Chui, M. J. Heeg and J. Montgomery, *J. Am. Chem. Soc.*, 1999, **121**, 476; (*d*) S. Ogoshi, A. Nishimura and M. Ohashi, *Org. Lett.*, 2010, **12**, 3450.

10 (*a*) T. Sambaiah, L.-P. Li, D.-J. Huang, C.-H. Lin, D. K. Rayabarapu and C.-H. Cheng, *J. Org. Chem.*, 1999, **64**, 3663; (*b*) A. Herath, W. Li and J. Montgomery, *J. Am. Chem. Soc.*, 2008, **130**, 469; (*c*) S. Ogoshi, T. Haba and M. Ohashi, *J. Am. Chem. Soc.*, 2009, **131**, 10350; (*d*) Y. Nakao, H. Idei, K. S. Kaniva and T. Hiyama, *J. Am. Chem. Soc.*, 2009, **131**, 15996; (*e*) S. Ogoshi, A. Nishimura, T. Haba and M. Ohashi, *Chem. Lett.*, 2009, 1166.

11 (*a*) B. Breit and W. Seiche, *J. Am. Chem. Soc.*, 2003, **125**, 6608; (*b*) M. Weis, C. Waloch, W. Seiche and B. Breit, *J. Am. Chem. Soc.*, 2006, **128**, 4188; (*c*) I. Usui, S. Schmidt, M. Keller and B. Breit, *Org. Lett.*, 2008, **10**, 1207.

12 (*a*) T. Yamamoto, K. Igarashi, J. Ishizu and A. Yamamoto, *J. Chem. Soc., Chem. Commun.*, 1979, 554; (*b*) T. Yamamoto, K. Igarashi, S. Komiya and A. Yamamoto, *J. Am. Chem. Soc.*, 1980, **102**, 7448; (*c*) H. Hoberg, A. Ballesteros, A. Sigan, C. Jégat, D. Bärhausen and A. Milchereit, *J. Organomet. Chem.*, 1991, **407**, C23.

13 (*a*) I. M. Klotz and J. S. Franzen, *J. Am. Chem. Soc.*, 1962, **84**, 3461; (*b*) I. M. Klotz and S. B. Farnham, *Biochemistry*, 1968, **7**, 3879; (*c*) R. Taylor, O. Kennard and W. Versichel, *J. Am. Chem. Soc.*, 1983, **105**, 5761.

14 The reaction of **6a** (0.40 mmol) and **2a** (0.60 mmol) in the presence of catalytic amount of the nickel complex **A′** (0.05 mmol) in dioxane (80 °C) also afforded **7aa** in 77% yield.


 