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Article

Cyclization-Carbonylation-Cyclization Coupling Reaction of Propargyl Ureas with Palladium(II)-Bisoxazoline Catalyst

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Abstract: The cyclization-carbonylation-cyclization coupling reaction (CCC-coupling reaction) of propargyl ureas catalyzed by Pd^{II}(box) complexes afforded symmetrical ketones bearing two 2-amino-2-oxazoline groups in good to moderate yields.

Keywords: CCC-coupling; bisoxazoline; palladium; carbonylation; propargyl urea

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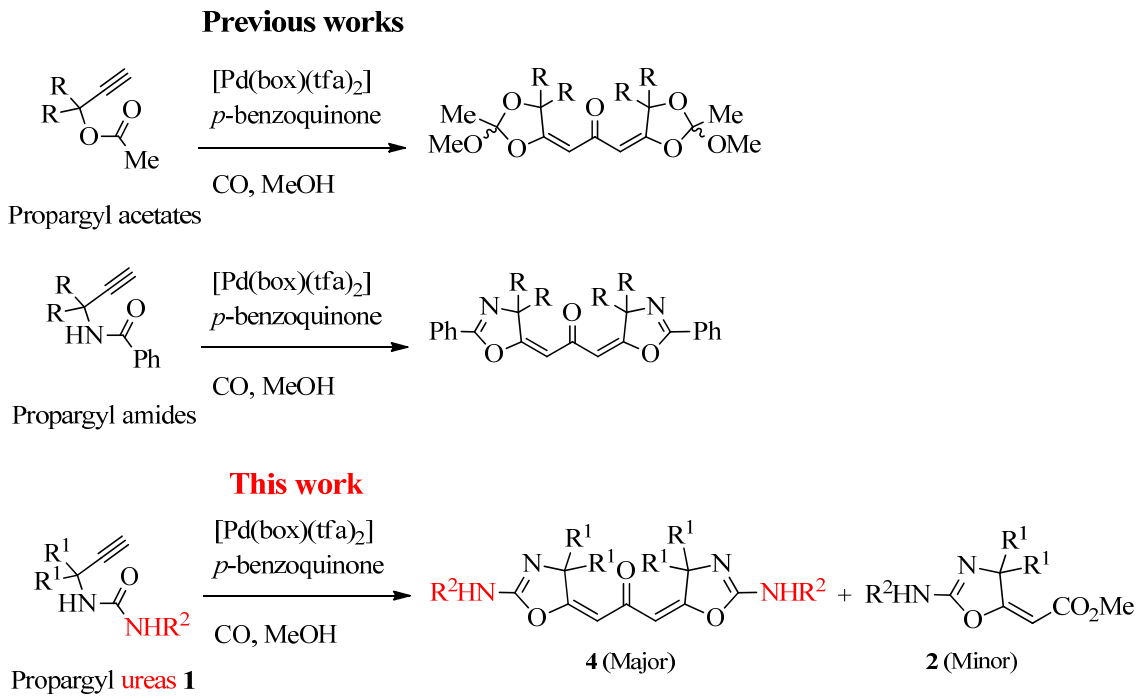
1. Introduction

Oxazolines appear in numerous medicinally active compounds and natural products [1–3]. Among them, 2-amino-2-oxazolines show various interesting pharmacological properties such as anti-hypertensive [4], antidepressant [5], appetite suppressant [6], nitric oxide synthase inhibitor [7] and central nervous system activity [8]. Diarylketones are also frequently found in natural products and pharmaceuticals [9,10]. In addition, they are good precursors for non-steroidal antiestrogen drugs (e.g., tamoxifen) and diarylmethyl compounds [11]. Cascade reactions are important tools for constructing a variety of heterocycles in one step starting from simple compounds [12,13]. Recently, we reported the cyclization-carbonylation-cyclization (CCC)-coupling reaction of propargylic acetates, amides, γ-propynyl-1,3-diketones, *N*-propargylanilines and *o*-alkynylphenols catalyzed by palladium(II)-bisoxazoline (box) complexes (Scheme 1). Symmetrical ketones bearing two cyclic

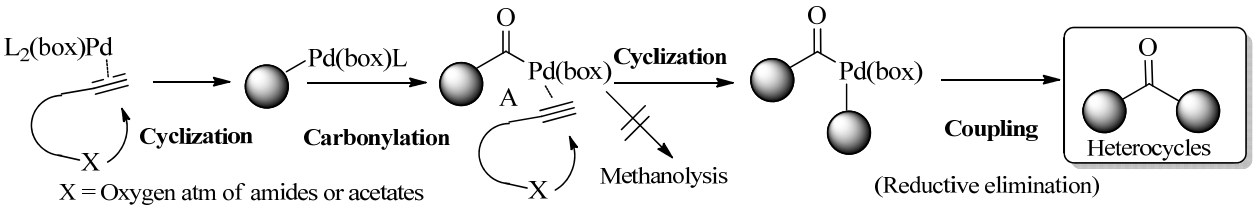
orthoesters [14], oxazolines [14], oxabicyclic groups [15], quinolines [16] and benzofurans [16] were obtained in a one-step reaction.

Scheme 1. Previous works and this work: CCC-coupling reaction of propargyl acetates, amides and ureas.

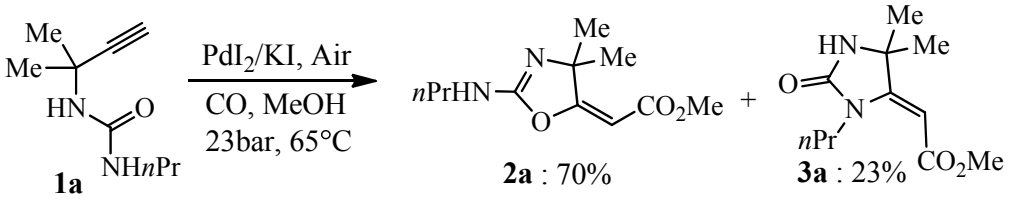


In these transformations, the triple bond of the substrate coordinates to palladium(II) and undergoes nucleophilic attack by the intramolecular nucleophile X, followed by CO insertion to produce the acyl palladium intermediate **A** (Scheme 2). Coordination of the triple bond of a second molecule induces the second cyclization. Reductive elimination then leads to formation of a ketone bearing two heterocyclic groups. We believe that the box ligand enhances the π-electrophilicity of palladium(II) [14–19], and thus promotes coordination of the second triple bond to the acyl palladium intermediate **A**, leading to dimerization. Previously, Bacchi *et al.* reported that the PdI_2-KI catalyzed cyclization-alkoxycarbonylation of propargyl urea **1a** afforded 2-amino-2-oxazoline derivative **2a** in 70% yield along with imidazoline derivative **3a** in 23% yield (Scheme 3) [20,21]. To extend our concept of the CCC-coupling reaction, we investigated the Pd^{II}(box) catalyzed carbonylation reaction of propargyl ureas **1** (Scheme 1).

Scheme 2. Our concept of a cyclization-carbonylation-cyclization coupling reaction (CCC coupling reaction) of propargylic compounds.



Scheme 3. Bacchi *et al*.: PdI_2-KI catalyzed cyclization-alkoxycarbonylation of **1** [20,21].

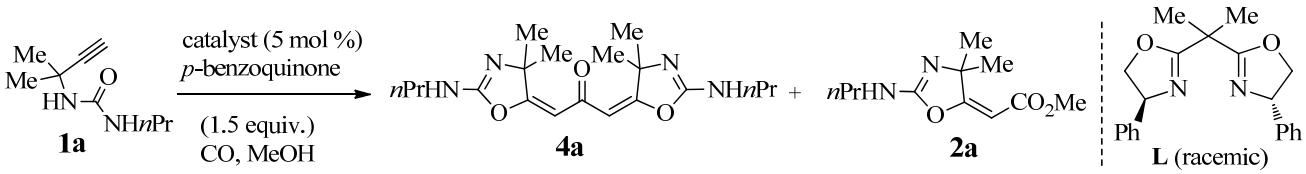


2. Results and Discussion

2.1. Optimization Studies

Initially, we selected **1a** as a standard substrate to search for potential catalysts (Table 1). The reaction of **1a** with $(CH_3CN)_2PdCl_2$ (5 mol %) in the presence of *p*-benzoquinone (1.5 equiv.) in methanol under a carbon monoxide atmosphere (balloon) generated the dimeric ketone **4a** in 46% yield, along with monomeric ester **2a** (36% yield) (Table 1, entry 1). These products were easily separated by chromatography on silica gel.

Table 1. Optimization of reaction condition.



Entry	Catalyst (5 mol %)	Conditions	Yield of 4a (%)	Yield of 2a (%)
1	$(CH_3CN)_2PdCl_2$	rt, 24 h	**4a**: 46	**2a**: 36
2	$Pd(tfa)_2$	−20 °C, 24 h	**4a**: 24	**2a**: 20
3	$[Pd(bipy)Cl_2]$	rt, 24 h	**4a**: 29	**2a**: 13
4	$(Ph_3P)_2PdCl_2$	rt, 19 h	**4a**: 16	**2a**: 61
5	$Pd(PPh_3)_4$	rt, 24 h	-	**2a**: 44
6	$[Pd(\mathbf{L})(tfa)_2]$	rt, 24 h	**4a**: 83	**2a**: 17
7	$[Pd(\mathbf{L})(tfa)_2]$	50 °C, 3 h	**4a**: 61	**2a**: 21
8	$[Pd(\mathbf{L})(tfa)_2]$	−20 °C, 24 h	**4a**: 30	**2a**: 29
9 [a]	$[Pd(\mathbf{L})(tfa)_2]$	rt, 24 h	N.R.	
10 [a]	$[Pd(\mathbf{L})(tfa)_2]$	rt, 24 h	N.R.	

[a] CH_2Cl_2 was used as solvent; [b] DMF was used as solvent.

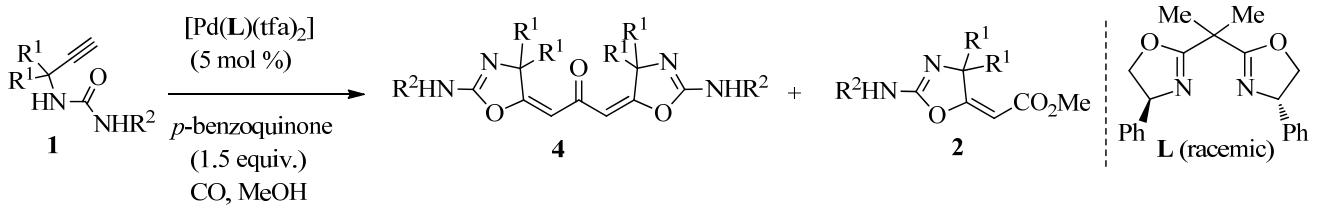
$Pd(tfa)_2$ and 2,2′-bipyridine complex also gave a mixture of products **4a** and **2a** in low yields (Table 1, entries 2–3). The use of phosphine complexes, $(Ph_3P)_2PdCl_2$ and $Pd(PPh_3)_4$, afforded monomeric ester **2a** as a major product (Table 1, entries 4–5). Next, an attempt was made to use the box complex $[Pd(\mathbf{L})(tfa)_2]$ according to our previous results [14–19]. As expected, the reaction occurred smoothly, and the yield of **4a** improved to 83% (Table 1, entry 6). Higher temperatures reduced both the reaction time and the dimer **4a**:monomer **2a** ratio (Table 1, entry 7). Lower temperatures reduced the yields of both products (Table 1, entry 8). Furthermore, CH_2Cl_2 and DMF were not suitable as solvents (Table 1,

entries 9–10). The structure of the dimeric ketone **4a** was confirmed by comparing the corresponding ^{1}H- and ^{13}C-NMR data with those of similar oxazolines [22].

2.2. Substrate Scope and Limitations

Having optimized the reaction conditions, we examined the reaction of various propargyl ureas **1b–j** with the box complex [Pd(**L**)(tfa)$_2$] (Table 2).

Table 2. CCC-coupling reaction of propargyl ureas **1**.



Entry	R^1	R^2	Conditions	Yield of 4 (%)	Yield of 2 (%)
1	Me	*n*Pr	rt, 24 h	**4a**: 83	**2a**: 17
2	Me	Bn	rt, 18 h	**4b**: 73	**2b**: 10
3	Me	*n*Bu	rt, 20 h	**4c**: 61	**2c**: 25
4	Me	Phenethyl	7 °C, 48 h	**4d**: 58	**2d**: 20
5	Me	Cyclohexyl	rt, 24 h	**4e**: 66	**2e**: 30
6	-(CH$_2$)$_5$-	Phenethyl	rt, 24 h	**4f**: 89	**2f**: 11
7	-(CH$_2$)$_5$-	Cyclohexyl	rt, 24 h	**4g**: 74	**2g**: 20
8	-(CH$_2$)$_5$-	Ph	rt, 40 h	**4h**: 24	**2h**: 23
9 [a]	-(CH$_2$)$_5$-	H	rt, 48 h	N.R.	
10	H	Phenethyl	rt, 24 h	N.R.	

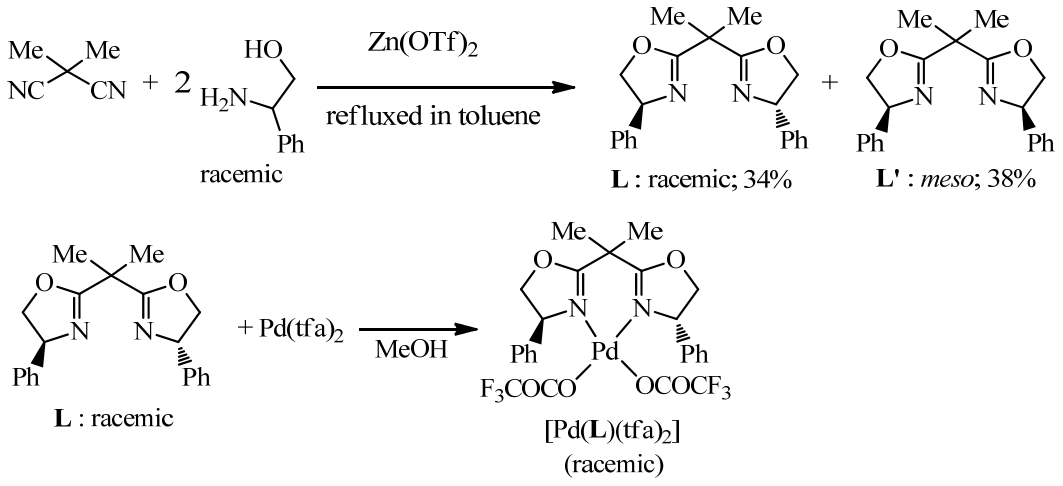
[a] **1i** was recovered (41%).

The reactions proceeded well for substrates **1a–g** bearing two methyl groups in the propargylic position (R^1 = Me) (Table 2, entries 1–5). The bulky cyclohexyl group in the propargylic position (R^1 = –(CH$_2$)$_5$–) did not affect the yields of **4f** and **4g** (Table 2, entries 6 and 7). The alkyl substituent of the terminal nitrogen (R^2) was found to be important for promoting the cyclization, lower yields were obtained for **1h** (R^2 = Ph) (Table 2, entry 8). The reaction of unsubstituted **1i** (R^2 = H) did not proceed (Table 2, entry 9). In addition, the *gem*-dialkyl effect [23] plays a fundamental role for the success of the reaction; the reaction of substrate **1j** having no substituent on the propargylic position did not proceed (Table 2, entry 10).

*2.3. Preparation of [Pd(**L**)(tfa)$_2$]*

Ligand **L** was prepared according to the previously reported procedure (Scheme 4) [24,25]. Condensation of 2,2-dimethyl-malononitrile with (±)-phenylglycinol using Zn(OTf)$_2$ in toluene afforded a mixture of **L** (racemic) and **L′** (*meso*) [18,26]. Chromatographic separation of the mixture gave the compounds in 34% and 38% yields, respectively. The key [Pd(**L**)(tfa)$_2$] [28] catalyst was easily obtained as a stable solid by simple filtration from a methanolic mixture of **L** and Pd(tfa)$_2$.

Scheme 4. Preparation of [Pd(**L**)(tfa)$_2$].



3. Experimental

3.1. General

All melting points were measured on a Yanaco MP-3S micro melting point apparatus and are uncorrected. ^{1}H-, ^{13}C-NMR and HMBC spectra were recorded on JEOL AL 400 and JEOL Lambda 500 spectrometer spectrometers in $CDCl_3$ with Me_4Si as an internal reference. ^{13}C-NMR spectra were recorded at 100 MHz. In the case of CD_2Cl_2, solvent peaks were used as a reference (5.32 ppm for ^{1}H, and 53.8 ppm for ^{13}C). High-resolution mass spectra (HR-MS) were obtained with JEOL GC Mate II, JMS-SX102 and JEOL JMS 600H spectrometer. IR spectra were recorded with JASCO FT/IR-300 spectrometer. All reagents were purchased from commercial sources and used without purification. All evaporations were performed under reduced pressure. For column chromatography, silica gel (Kieselgel 60) was employed.

3.2. Preparation of Substrates **1a–j**

The substrates **1a–j** were prepared according to the literature [27]. The substrates **1**, except for **1a** [20] and **1b** [20] are new compounds [22].

3.3. General Procedure for the CCC-Coupling Reaction of **1**

A 50-mL two-neck round-bottom flask containing a magnetic stirring bar, substrate **1** (0.5 mmol), *p*-benzoquinone (1.5 mmol) and MeOH (7 mL) was fitted with a rubber septum and a three-way stopcock connected to a balloon filled with carbon monoxide. The apparatus was purged with carbon monoxide by pump-filling via the three-way stopcock. A MeOH (1 mL) suspension of [Pd(**L**)(tfa)$_2$] (0.025 mmol) was added to the stirred solution at an appropriate temperature using a syringe. The remaining [Pd(**L**)(tfa)$_2$] was washed in MeOH (1 mL) twice. After stirring at the appropriate temperature for a period of time, the mixture was diluted with CH_2Cl_2 (50 mL) and washed with 3% NaOH (40 mL). The aqueous layer was extracted with CH_2Cl_2 (50 mL) twice and the combined organic layers were dried over $MgSO_4$ and concentrated *in vacuo*. The crude product was purified by

chromatography on silica gel. The fraction eluted with hexane-AcOEt (30/1–1/1) afforded the monomeric ester **2** and the dimeric ketone **4**. **4** was then precipitated from the reaction mixture and the resulting precipitate was collected by filtration and washed with cold MeOH (1 mL × 2). The filtrate was reprocessed via the above procedure to provide additional products after chromatography.

3.3.1. Dimeric Ketone **4a**

Hexane/AcOEt = 1/1. Colorless needles; mp 186–191 °C; ^{1}H-NMR ($CDCl_3$) δ 0.95 (6 H, t, *J* = 7.2 Hz), 1.55–1.65 (4 H, m), 1.63 (12 H, s), 3.20 (4 H, t, *J* = 7.2 Hz), 4.11 (2 H, br-s), 5.91 (2 H, s); ^{13}C-NMR ($CDCl_3$) δ 11.2 (2C), 22.9 (2C), 25.4 (4C), 44.6 (2C), 71.0 (2C), 103.2 (2C), 154.4 (2C), 177.2 (2C), 186.4; IR (KBr): 3203, 3114, 2963, 2877, 1724, 1629, 1370, 1183, 969, 930 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{19}H_{30}N_4O_3$: 362.2318; found: 362.2315.

3.3.2. (2*E*)-Methyl 2-[4,4-dimethyl-2-(propylamino)-5(4*H*)-oxazolylidene]acetate (**2a**)

Hexane/AcOEt = 4/1. Spectral data were identical to those described in the literature [20].

3.3.3. Dimeric Ketone **4b**

Hexane/AcOEt = 1/1. Colorless needles; mp 155–158 °C; ^{1}H-NMR ($CDCl_3$) δ 1.65 (12 H, s), 4.40 (2 H, s), 5.92 (2 H, s), 7.26–7.36 (10 H, m); ^{13}C-NMR ($CDCl_3$) δ 25.4 (4C), 46.8 (2C), 70.9 (2C), 103.5 (2C), 127.6 (4C), 127.7 (2C), 128.7 (4C), 137.8 (2C), 154.6 (2C), 176.9 (2C), 186.2; IR (KBr): 2930, 1730, 1630, 1182, 966, 933 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{27}H_{30}N_4O_3$: 458.2318; found: 458.2320.

3.3.4. *(2E)-Methyl 2-[4,4-dimethyl-2-(phenylmethylamino)-5(4H)-oxazolylidene]acetate* (**2b**)

Hexane/AcOEt = 4/1. Spectral data were identical to those described in the literature [20].

3.3.5. Dimeric Ketone **4c**

Hexane/AcOEt = 1/1. Colorless needles; mp 189–191 °C; ^{1}H-NMR ($CDCl_3$) δ 0.94 (6 H, t, *J* = 7.2 Hz), 1.33–1.59 (8 H, m), 1.63 (12 H, s), 3.23 (4 H, t, *J* = 7.2 Hz), 4.07 (2 H, br-s), 5.91 (2 H, s); ^{13}C-NMR ($CDCl_3$) δ 13.8 (2C), 19.9 (2C), 25.4 (4C), 31.7(2C), 42.6 (2C), 71.0 (2C), 103.2 (2C), 154.4 (2C), 177.1 (2C), 186.4; IR (KBr): 3206, 2965, 1725, 1627, 1184, 929 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{21}H_{34}N_4O_3$: 390.2631; found: 390.2632.

3.3.6. (2*E*)-Methyl 2-[4,4-dimethyl-2-(butylamino)-5(4*H*)-oxazolylidene]acetate (**2c**)

Hexane/AcOEt = 4/1. Colorless needles; mp 96–99 °C; ^{1}H-NMR ($CDCl_3$) δ 0.94 (3 H, t, *J* = 7.2 Hz), 1.35–1.43 (2 H, m), 1.52–1.62 (8 H, m), 3.23 (2 H, t, *J* = 7.2 Hz), 3.69 (3 H, s), 4.13 (1 H, br-s), 5.54 (1 H, s); ^{13}C-NMR ($CDCl_3$) δ 13.7, 19.9, 25.9 (2C), 31.7, 42.6, 51.1, 70.7, 92.6, 154.3, 166.6, 178.5; IR (KBr): 3179, 2967, 1723, 1708, 1689, 1656, 1172, 1095 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{12}H_{20}N_2O_3$: 240.1474; found: 240.1473.

3.3.7. Dimeric Ketone **4d**

Hexane/AcOEt = 1/1. Colorless needles; mp 180–182 °C; ^{1}H-NMR ($CDCl_3$) δ 1.63 (12 H, s), 2.89 (4 H, t, *J* = 6.8 Hz), 3.51 (4 H, t, *J* = 6.8 Hz), 4.01 (2 H, br-s), 5.87 (2 H, s), 7.19–7.33 (10 H, m); ^{13}C-NMR ($CDCl_3$) δ 25.4 (4C), 35.4 (2C), 43.7 (2C), 71.0 (2C), 103.3 (2C), 126.7 (2C), 128.7 (4C), 128.8 (4C), 138.4 (2C), 154.2 (2C), 177.0 (2C), 186.4; IR (KBr): 3211, 3108, 2942, 1736, 1626, 1180, 966, 931 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{29}H_{34}N_4O_3$: 486.2631; found: 486.2631.

3.3.8. (2*E*)-Methyl 2-[4,4-dimethyl-2-(phenylethylamino)-5(4*H*)-oxazolylidene]acetate (**2d**)

Hexane/AcOEt = 3/1. Brown oil; ^{1}H-NMR ($CDCl_3$) δ 1.62 (6 H, s), 2.89 (2 H, t, *J* = 6.8 Hz), 3.51 (2 H, t, *J* = 6.8 Hz), 3.68 (3 H, s), 4.35 (1 H, br-s), 5.52 (1 H, s), 7.19–7.31 (5 H, m); ^{13}C-NMR ($CDCl_3$) δ 25.9 (2C), 35.5, 43.6, 51.1, 70.7, 92.9, 126.7, 128.7 (2C), 128.8 (2C), 138.3, 154.3, 166.5, 178.2; IR (KBr): 3360, 3193, 2972, 1724, 1657, 1106, 1048 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{16}H_{20}N_2O_3$: 288.1474; found: 288.1471.

3.3.9. Dimeric Ketone **4e**

Hexane/AcOEt = 4/1. Colorless needles; mp 243–246 °C; ^{1}H-NMR ($CDCl_3$) δ 1.19–1.95 (22 H, m), 1.85 (12 H, s), 3.55 (2 H, m), 6.25 (2 H, s); ^{13}C-NMR ($CDCl_3$) δ 24.5 (4C), 24.7 (4C), 24.7 (2C), 32.7 (4C), 53.2 (2C), 64.9 (2C), 107.0 (2C), 156.4 (2C), 170.5 (2C), 184.1; IR (KBr): 3205, 2933, 2857, 1729, 1625, 1367, 1182, 990, 928 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{25}H_{38}N_4O_3$: 442.2944; found: 442.2943.

3.3.10. (2*E*)-Methyl 2-[4,4-dimethyl-2-(cyclohexylethylamino)-5(4*H*)-oxazolylidene]acetate (**2e**)

Hexane/AcOEt = 5/1. Colorless needles; mp 125–127 °C; ^{1}H-NMR ($CDCl_3$) δ 1.15–2.06 (10 H, m), 1.62 (6 H, s), 3.46 (1 H, m), 3.69 (3 H, s), 4.04 (1 H, br-s), 5.53 (1 H, s); ^{13}C-NMR ($CDCl_3$) δ 24.6, 25.5 (2C), 25.9 (2C), 33.3 (2C), 51.0, 51.3, 70.8, 92.4, 153.3, 166.6, 178.5; IR (KBr): 3206, 2934, 2856, 1717, 1658, 1538, 1102 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{14}H_{22}N_2O_3$: 266.1631; found: 266.1633.

3.3.11. Dimeric Ketone **4f**

Hexane/AcOEt = 10/1. Colorless needles; mp 186–190 °C; ^{1}H-NMR ($CDCl_3$) δ 1.32–1.80 (16 H, m), 2.65–2.72 (4 H, m), 2.89 (4 H, t, *J* = 6.8 Hz), 3.51 (4 H, t, *J* = 6.8 Hz), 4.06 (2 H, br-s), 5.88 (2 H, s), 7.19–7.31 (10 H, m); ^{13}C-NMR ($CDCl_3$) δ 22.3 (4C), 25.2 (2C), 32.9 (4C), 35.7 (2C), 43.9 (2C), 74.4 (2C), 103.6 (2C), 126.6 (2C), 128.7 (4C), 128.9 (4C), 138.6 (2C), 153.6 (2C), 177.3 (2C), 186.3; IR (KBr): 3418, 2930, 2860, 1720, 1625, 1014, 976, 931 cm^{-1}; HRMS-EI:*m/z* [M$^+$] calcd for $C_{35}H_{42}N_4O_3$: 566.3257; found: 566.3260.

3.3.12. Monomeric Ester **2f**

Hexane/AcOEt = 15/1. Colorless needles; mp 104–106 °C; ^{1}H-NMR ($CDCl_3$) δ 1.37–1.82 (8 H, m), 2.55–2.62 (2 H, m), 2.89 (2 H, t, *J* = 6.8 Hz), 3.51 (2 H, t, *J* = 6.8 Hz), 3.68 (3 H, s), 4.09 (1 H, br-s), 5.52 (1 H, s); ^{13}C-NMR ($CDCl_3$) δ 22.2 (2C), 25.1, 33.6 (2C), 35.6, 43.9, 51.1, 74.2, 92.6, 126.6,

128.7, 128.8, 138.6, 153.5, 166.7, 179.2; IR (KBr): 3111, 2969, 1732, 1655, 1127, 1065 cm^{-1}; HRMS-EI:*m/z* [M^+] calcd for $C_{19}H_{24}N_2O_3$: 328.1787; found: 328.1786.

3.3.13. Dimeric Ketone **4g**

Hexane/AcOEt = 15/1. Colorless needles; mp 189–191 °C; ^{1}H-NMR ($CDCl_3$) δ 1.11–1.79 (32 H, m), 2.00–2.03 (4 H, m), 2.65–2.72 (4 H, m), 3.40–3.47 (2 H, m), 3.94 (2 H, br-s), 5.91 (2 H, s); ^{13}C-NMR ($CDCl_3$) δ 22.3 (4C), 24.6 (4C), 25.1 (2C), 25.5 (2C), 32.8 (4C), 33.2 (4C), 51.3 (2C), 74.2 (2C), 103.4 (2C), 153.0 (2C), 177.3 (2C), 186.3; IR (KBr): 3430, 2928, 2855, 1710, 1624, 1498, 996, 927 cm^{-1}; HRMS-EI:*m/z* [M^+] calcd for $C_{31}H_{46}N_4O_3$: 522.3570; found: 522.3568.

3.3.14. Monomeric Estere **2g**

Hexane/AcOEt = 20/1. Colorless needles; mp 133–135 °C; ^{1}H-NMR ($CDCl_3$) δ 1.12–2.05 (18 H, m), 2.55–2.62 (2 H, m), 3.42–3.50 (1 H, m), 3.69 (3 H, s), 3.96 (1 H, br-s), 5.54 (1 H, s); ^{13}C-NMR ($CDCl_3$) δ 22.2 (2C), 24.6 (2C), 25.2, 25.6, 33.2 (2C), 33.4 (2C),51.1, 51.4, 74.2, 92.4, 152.8, 166.8, 179.3; IR (KBr): 3358, 2932, 2857, 1707, 1644, 1518, 1125, 1066 cm^{-1}; HRMS-EI:*m/z* [M^+] calcd for $C_{17}H_{26}N_2O_3$: 306.1944; found: 306.1945.

3.3.15. Dimeric Ketone **4h**

Hexane/AcOEt = 10/1. Colorless needles; mp 300 °C; ^{1}H-NMR ($CDCl_3$) δ 1.46–1.91 (16 H, m), 2.67–2.73 (4 H, m), 6.30 (2 H, s), 7.16–7.56 (10 H, m); ^{13}C-NMR ($CDCl_3$) δ 21.4 (4C), 23.9 (2C), 31.9 (4C), 69.4 (2C), 108.4 (2C), 122.5 (4C), 127.8 (2C), 129.8 (4C), 133.2 (2C), 155.9 (2C), 169.3 (2C), 183.7; IR (KBr): 3411, 2928, 2859, 1715, 1628, 1603, 1535, 996 cm^{-1}; HRMS-EI:*m/z* [M^+] calcd for $C_{31}H_{34}N_4O_3$: 510.2631; found: 510.2629.

3.3.16. Dimeric Ketone **2h**

Hexane/AcOEt = 30/1. Colorless needles; mp 121–124 °C; ^{1}H-NMR (CD_2Cl_2) δ 1.40–1.89 (8 H, m), 2.61–2.68 (2 H, m), 3.68 (3 H, s), 5.62 (1 H, s), 7.03 (1 H, t, J = 7.6 Hz), 7.32 (2 H, dd, J = 7.6, 8.0 Hz), 7.55 (2 H, d, J = 8.0 Hz); ^{13}C-NMR (CD_2Cl_2) δ 22.7 (2C), 25.6, 33.6 (2C), 51.4, 75.4, 93.4, 118.2 (2C), 122.9, 129.3 (2C), 139.1, 149.5, 166.7, 177.4; IR (KBr): 3298, 2929, 1688, 1605, 1552, 1315, 1151, 1064 cm^{-1}; HRMS-EI:*m/z* [M^+] calcd for $C_{17}H_{20}N_2O_3$: 300.1474; found: 300.1472.

*3.4. Preparation of Ligands and Racemic-[Pd(**L**)(tfa)$_2$]*

3.4.1. Preparation of **L** and **L′**

To a mixture of dimethylmalononitrile (681 mg, 7.23 mmol) and (±)-phenylglycinol (2.00 g, 14.5 mmol) in anhydrous toluene (160 mL) under Ar was added zinc triflate (2.63 g, 7.23 mmol), and the mixture was refluxed for 3 days. The mixture was allowed to cool, and was then diluted with a saturated $NaHCO_3$ aqueous solution (200 mL) and $CHCl_3$ (300 mL). After vigorously stirring for 1 h, the layers were separated. The aqueous layer was extracted with $CHCl_3$ (50 mL) twice. The combined organic layers were dried with $MgSO_4$ and concentrated *in vacuo*. The crude products were purified by

column chromatography on silica-gel (70 g). The fraction eluted with hexane/ethyl acetate (7/1) (containing 0.5% Et_3N) afforded **L′** (914 mg, 38%) [10] and **L** (818 mg, 34%) as pale yellow oils.

3.4.2. Preparation of [Pd(**L**)$(tfa)_2$]

To a stirring solution of **L** (307 mg, 0.92 mmol) in MeOH (4 mL) was added $Pd(tfa)_2$ (305 mg, 0.92 mmol) in MeOH (3 mL). The **[Pd(L)$(tfa)_2$]** was then precipitated from the reaction mixture, and the resulting precipitate was collected by filtration and washed with cold MeOH (1 mL) to give racemic-**[Pd(L)$(tfa)_2$]** [28] as a white powder (483 mg, 79%).

4. Conclusions

In conclusion, we have presented a cyclization-carbonylation-cyclization coupling reaction (CCC-coupling reaction) of propargyl ureas **1** catalyzed by Pd^{II}(box) complexes. Symmetrical ketones possessing two 2-amino-2-oxazoline groups were obtained in moderate to good yields. We believe that the box ligand enhances the π-electrophilicity of palladium(II), and thus promotes coordination of the triple bond (second molecule) to the acyl palladium intermediate **A**, leading to the dimerization reaction. We are currently investigating additional cascade reactions based on the cyclization-carbonylation-cyclization strategy for the synthesis of other types of ketones containing two hetero-cyclic groups.

Supplementary Materials

Supplementary materials can be accessed at: http://www.mdpi.com/1420-3049/17/8/9220/s1.

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