ELSEVIER

Journal of Molecular Catalysis A: Chemical 96 (1995) 197–201

JOURNAL OF MOLECULAR CATALYSIS A: CHEMICAL

Regioselective palladium(II) catalyzed hydroesterification of alkynes and alkynols using formate esters

Bassam El Ali, Howard Alper*

Department of Chemistry, University of Ottawa, 10 Marie Curie, Ottawa, Ontario, Canada K1N 6N5

Received 20 May 1994; accepted 24 October 1994

Abstract

The catalytic system $Pd(OAc)_2$/dppb/PPh_3/*p*-TsOH catalyzes the hydroesterification of alkynes and alkynols with formate esters to give unsaturated esters in good yields and selectivities.

Keywords: Alkynes; Alkynols; Formate esters; Hydroesterification; Palladium; Regioselectivity

1. Introduction

It is well known that palladium(II) complexes can catalyze the hydroesterification of olefins in acidic alcohol under mild conditions [1]. The selective mono- and dicarbonylation of terminal olefins can occur using Pd–C and Cu(II) or Cu(I) chloride in alcohol [2]. Arylalkynes undergo regioselective carbonylation catalyzed by palladium complexes in the presence of iodide promoters in methanol to form methyl-2 arylpropenoates [3]. The hydroaminocarbonylation of terminal alkynes proceeds regioselectively in the presence of palladium complexes and iodide promoters in diethylamine [4]. In contrast, hydrocarboxylation of alkynes and alkenes occurs selectively in the presence of formic acid under mild conditions [5]. The metal-catalyzed reaction of unsaturated substrates and formate esters has been the subject of a number of publications and patents. Catalysts based on ruthenium [6], iridium [7] or palladium [8–10] have usually been used in the case of olefins and alkynes. We have found now that palladium acetate, in the presence of suitable phosphine ligands [1,4-bis(diphenylphosphino) butane (dppb) and triphenylphosphine (PPh_3)] and *p*-toluene sulfonic acid (*p*-TsOH), catalyzes the regiospecific conversion of alkynes and formate esters into the corresponding 2-substituted-2-propenoate esters. The carbonylation of terminal and internal alkynes has been examined using the catalytic system.

2. Results and discussion

Phenylacetylene (**1**, R^1=Ph, R^2=H) (1.0 mmol) reacts with n-butyl formate (**2**, R^3=n-C_4H_9) (10.0 mmol) and a catalytic amount of palladium acetate (0.02 mmol) dppb (0.04 mmol), triphenylphosphine (PPh_3) (0.08 mmol), and *p*-toluenesulfonic acid (*p*-TsOH) (0.08 mmol) in tetrahydrofuran (THF) (2.5 ml)

*Corresponding author.

SSDI 1381-1169(94)00048-4

for 48 h at 100°C and 20.0 atm of carbon monoxide affording butyl-2-phenyl-2-propenoate (**3**) and butyl (*E*)-cinnamate (**4**) in a ratio of 94:6 (80% yield) as depicted in Scheme 1.

Only traces of products were obtained in the absence of *p*-TsOH, and no reaction occurred in the absence of carbon monoxide or both phosphine ligands (Table 1, entries 1, 3). The role of phosphine ligands in a related catalytic system was studied previously [5b], and it was found that the nature of the phosphine ligand is an important factor, with PPh_3 and dppb the most appropriate choices. The present findings confirm the previous results that a mixture of a monodentate and bidentate phosphine ligand (PPh_3 and dppb) (entries 4–6) is more effective in promoting the catalytic hydroestrification of alkynes than using either of the two phosphine ligands alone. Specifically, phenylacetylene undergoes hydroesterification with n-butyl formate using a 1:4 ratio of $Pd(OAc)_2$:PPh_3 (Table 1, entry 4) to give **3** and **4** in a total yield of 33%. Use of dppb (2:1 ratio of dppb: $Pd(OAc)_2$) instead of PPh_3 afforded the products in 55% yield (entry 5) while the presence of both phosphines increased the yield to 80% (entry 6). Note that the regioselectivity of the reaction is essentially unaffected by the nature or number of phosphine ligands.

The ratio of formate ester to alkyne significantly affects the product yields. When the ratio of butyl formate to phenylacetylene was reduced from 10:1 to 1:1, the yield of α,β-unsaturated esters decreased from 80% to 15%. At a 4:1 ratio of butyl formate to alkyne, the yield was 25%, which is less than that realized (45%) using a 4:1 ratio of butanol to phenylacetylene (conditions similar to Miura [3]).

The results for the reaction of a variety of formate esters are summarized in Table 1. The best

Table 1
Reaction of phenylacetylene with formate esters catalyzed by $Pd(OAc)_2$/dppb/PPh_3/*p*-TsOH[a]

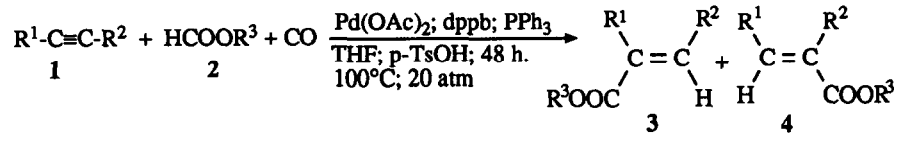
Entry	$HCOOR^3$, R^3 = **2**	dppb	PPh_3	CO	Yields[b] % (3+4)	Product distribution[c] %	
						3	**4**
1	$CH_2CH_2CH_2CH_3$	yes	yes	no	0	–	–
2	$CH_2CH_2CH_2CH_3$[d]	yes	yes	yes	traces	–	–
3	$CH_2CH_2CH_2CH_3$	no	no	yes	0	–	–
4	$CH_2CH_2CH_2CH_3$	no	yes	yes	33	94	6
5	$CH_2CH_2CH_2CH_3$	yes	no	yes	55	92	8
6	$CH_2CH_2CH_2CH_3$	yes	yes	yes	80	94	6
7	$CH_2CH_2CH_3$	yes	yes	yes	68	93	7
8	CH_3	yes	yes	yes	74	94	6
9	CH_2–$CH(CH_3)_2$	yes	yes	yes	54	93	7
10	$CH(CH_3)$–CH_2CH_3	yes	yes	yes	45	92	8
11	$C(CH_3)_3$	yes	yes	yes	32	92	8

[a]Conditions: Ph–C≡CH (1.0 mmol); $HCOOR^3$ (10.0 mmol); THF (2.5 ml); $Pd(OAc)_2$ (0.02 mmol); dppb (0.04 mmol); PPh_3 (0.08 mmol); *p*-TsOH (0.08 mmol); 20 atm, 100°C; 48 h.
[b]Isolated yield.
[c]Products were identified by comparison of spectral data (GC–MS), ^1H and ^{13}C NMR) with those for authentic materials.
[d]No *p*-TsOH was used.

results were obtained with n-butyl formate (entry 6) (80% yield); while methyl or n-propyl formate (entries 8, 7) gave esters in slightly lower yields (74% and 68%). The effective bulk of the alkyl groups in the formate ester can affect the yield of the reaction (entries 9–11). However, the regioselectivity of the products (**3** and **4**) was unaffected by using different formate esters.

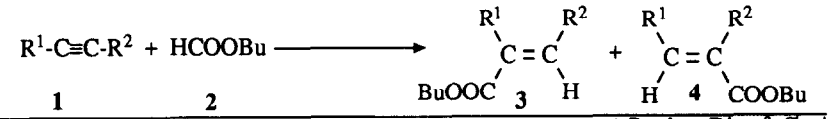
The catalytic system $Pd(OAc)_2$/dppb/PPh_3/CO/H^+ in presence of butyl formate was applied to a series of aromatic and aliphatic, terminal and internal alkynes (Table 2).

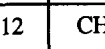
p-Methoxyphenylacetylene (entry 12) reacts with $HCOOC_4H_9$ to form unsaturated esters in good yield (76%) and selectivity for **3** (92%). The control of regioselectivity of the reaction



Scheme 1.

Table 2
Alkyne-n-butyl formate reactions catalyzed by $Pd(OAc)_2$/dppb/PPh_3/*p*-TsOH[a]



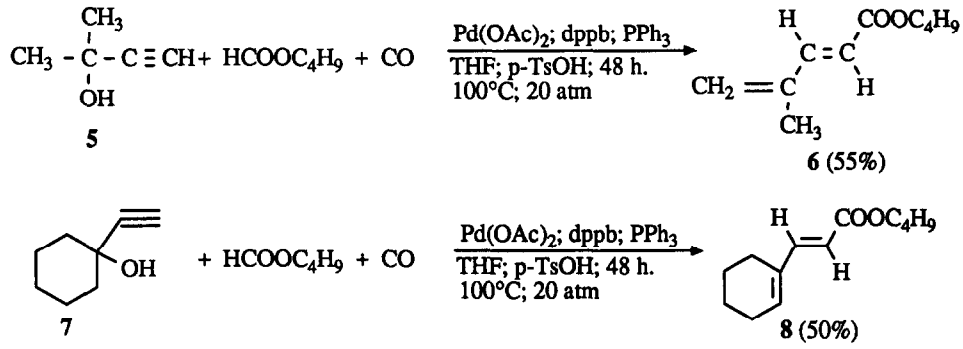
Entry	Alkyne, **1**	Yield,[b] % (3+4)	Product Distr.[c], % 3	4
12	CH_3O-  -C≡CH	76	92	8
13	Ph-CH_2CH_2-C≡CH	70	84	16
14	$CH_3(CH_2)_7$-C≡CH	65	80	20
15	NC-$CH_2CH_2CH_2$-C≡CH	50	84	16
16	Cl-$CH_2CH_2CH_2$-C≡CH	51	85	15
17	CH_3-CH_2-CH(CH_3)-C≡CH	65	70	30
18	$(CH_3)_3$C-C≡CH	57	40	60
19	$(CH_3)_3$Si-C≡CH	55	0	100
20	CH_3-$(CH_2)_3$-C≡C-CH_3	68	45	55
21	CH_3-CH(CH_3)-C≡C-CH_3	59	34	66
22	Ph-C≡C-CH_3	50	44	56
23	$(CH_3)_2$C-$(CH_2)_2$-C≡C-$(CH_2)_2$-C$(CH_3)_2$	60	100	--
24	Ph-C≡C-Ph	51	100	--

[a,b,c]See Table 1 for experimental conditions.

depends in part on the substituent R^1 in the case of terminal alkynes (R^2 = H); for example, 4-phenyl-1-butyne (entry 13), 1-decyne (entry 14), 5-cyano-1-pentyne (entry 15), and 5-chloro-1-pentyne (entry 16) gave the corresponding unsaturated esters in good yields (50–70%) but the selectivity for **3** decreased a little (80–85%) in the latter cases. It appears that the steric effect is significant in determining the regioselectivity of terminal alkynes. For example, 3-methyl-1-pentyne (entry 17) gave an acceptable yield of **3** and **4**, but with decreased selectivity for **3** (70%). The 1,2 disubstituted isomer **4** is the preferred product for R^1 = t-butyl group (entry 18) and the exclusive product for R^1 = $SiMe_3$ (entry 19).

Internal alkynes also undergo catalytic hydroesterification under the same conditions as terminal alkynes (Table 2, entries 20–24). The yield and regioselectivity depend on the nature of the substituents; with internal unsymmetric alkynes (entries 20–22) being less regioselective than terminal alkynes. The reaction of symmetrical internal alkynes, of course, leads to one product in reasonable yields (51–60%) (entries 23, 24).

The metal-catalyzed carbonylation of unsaturated alcohols has been the subject of many investigations [11]. Recently we described a new method for the cyclocarbonylation of alkynols to 2(5*H*)-furanones in good yields [12].

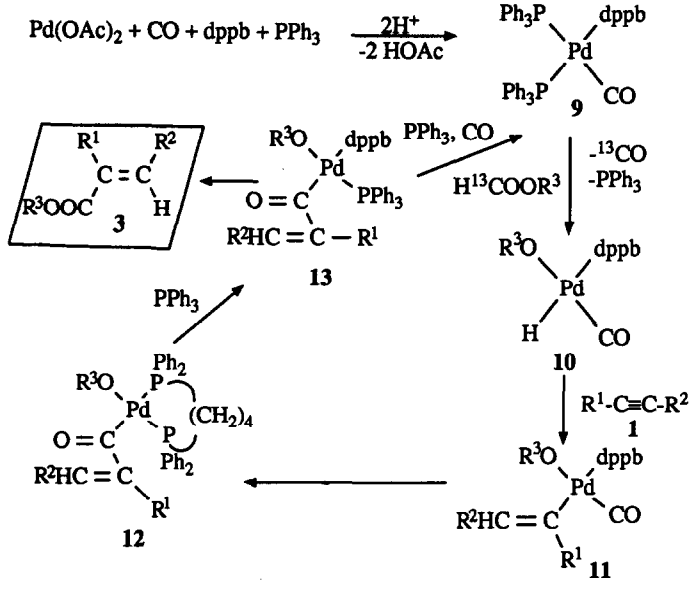


Scheme 2.

Alkynols are also reactive under the conditions of hydroesterification of alkynes described above. For example, 2-methyl-3-butyn-2-ol (**5**) and 1-ethynyl-1-cyclohexanol (**7**) reacts in a regio- and stereospecific manner with n-butylformate to give the *trans*-unsaturated ester **6** and **8** (Scheme 2), respectively, in good yields (50–55%) [13].

An experiment effected using $H^{13}COOCH_3$ with PhC≡CH and CO afforded the α,β-unsaturated ester containing only traces of the label. Taking this result into consideration, one can propose the mechanism, illustrated in Scheme 3, for the carbonylation of alkynes in the presence of dppb, PPh_3, *p*-TsOH, $HCOOR^3$ and CO. The reaction of palladium acetate with dppb, PPh_3 and CO in the presence of *p*-TsOH may give **9**. Reaction of the latter with the formate ester can generate a metal alkoxyhydride complex **10**. Addition of the hydride to the alkyne (**1**) may form **11**. Ligand migration to the carbonyl carbon, with dppb occupying the vacant coordination site would afford **12**. Reductive elimination in the presence of PPh_3 and CO (possibly via **13**) would give the product **3**, and regenerate **9**.

In conclusion, $Pd(OAc)_2$/dppb/PPh_3/*p*-TsOH catalyses the hydroesterfication of alkynes



Scheme 3.

and alkynols with formate esters to give the corresponding unsaturated esters in good yields and in most cases high regioselectivity.

3. Experimental section

3.1. General

The solvents and formate esters were distilled from an appropriate drying agent under N_2. The alkynes and alkynols (Farchan) were dried and distilled before use.

^1H-^{13}C-NMR spectra were recorded on Varian Gemini 200 MHz and XL 300 MHz spectrometers at ambient temperature.

3.1.1. General procedure for the catalytic reactions

A mixture of the alkyne (or alkynol) (1.0 mmol), formate ester (10.0 mmol), THF (2.5 ml), $Pd(OAc)_2$ (0.02 mmol), dppb (0.04 mmol), PPh_3 (0.08 mmol) and *p*-toluenesulfonic acid (0.08 mmol) were placed in a 45 ml autoclave. The mixture was stirred under 20 atm of carbon monoxide at 100°C for 48 h. The reactor was cooled to room temperature and the pressure was released. The solution was filtered through Celite and GC–MS analyses confirmed the formation of products. The unsaturated esters were isolated by column chromatography on silica gel and identified by comparison of GC–MS, ^1H and ^{13}C NMR results with literature data or authentic samples of **3**, **4**, **6**, **8** prepared previously [5b,12].

Acknowledgements

We are grateful to the Natural Sciences and Engineering Research Council of Canada, and to British Petroleum, for financial support.

References

[1] B. Despeyroux and H. Alper, Ann. N.Y. Acad. Sci., 415 (1983) 148; S.B. Fergusson and H. Alper, J. Chem. Soc., Chem. Commun., (1984) 1349.
[2] K. Inomata, S. Toda and H. Kinoshita, Chem. Lett., (1990) 1567.
[3] Y. Kushino, K. Itoh, M. Miura and M. Nomura, J. Mol. Catal., 89 (1994) 151; T. Hiyama, N. Wakasa, T. Ueda and T. Kusumoto, Bull. Chem. Soc. Jpn., 63 (1990) 640.
[4] S. Torii, H. Okumoto, M. Sadakane and L.H. Xu, Chem. Lett., 1991, 1673.
[5] (a) B. El Ali and H. Alper, J. Mol. Catal., 77 (1992) 7; (b) D. Zargarian and H. Alper, Organometallics, 12 (1992) 712.
[6] N. El Mostafa and G. Jenner, J. Mol. Catal., 59 (1990) L15; W. Keim and E. Becker, J. Mol. Catal., 84 (1989) 95.
[7] D.J. Drury and P.S. Williams, Eur. Pat. Appl. 106656 (1984).
[8] M. Mlekuz, F. Joo and H. Alper, Organometallics, 6 (1987) 1591.
[9] I.J.B. Lin and H. Alper, J. Chem. Soc., Chem. Commun., (1989) 248.
[10] H. Alper, M. Saldana-Maldonado and I.J.B. Lin, J. Mol. Catal., 49 (1988) L27.
[11] I. Tkatchenko, in G. Wilkinson (Ed.), Comprehensive Organometallic Chemistry, Vol. 8, Pergamon Press, New York, 1982, p. 101–223.
[12] B. El Ali and H. Alper, J. Org. Chem., 56 (1991) 5357.
[13] K.T. Huh, A. Orita and H. Alper, J. Org. Chem., 58 (1993) 6956.
[14] B. El Ali and H. Alper, J. Mol. Catal., 67 (1991) 29.