(*E*)-9-(2-Iodovinyl)-9*H*-carbazole: A New Coupling Reagent for the Synthesis of π-Conjugated Carbazoles
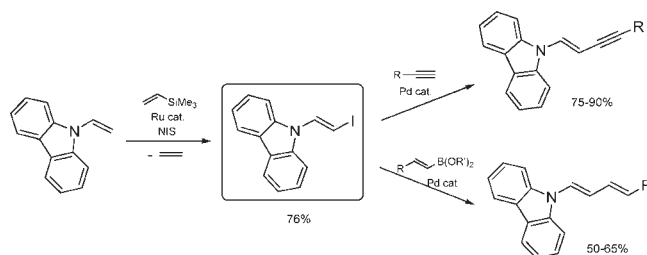
Piotr Pawluć,* Adrian Franczyk, Jędrzej Walkowiak, Grzegorz Hreczycho, Maciej Kubicki, and Bogdan Marciniec

Department of Organometallic Chemistry, Faculty of Chemistry, Adam Mickiewicz University, Grunwaldzka 6, 60-780 Poznan, Poland

piotrpaw@amu.edu.pl

ABSTRACT

The one-pot synthesis of (*E*)-9-(2-iodovinyl)-9*H*-carbazole *via* sequential ruthenium-catalyzed silylative coupling of *N*-vinylcarbazole with vinyltrimethylsilane and iododesilylation is reported. Its use as a new building block in the palladium-catalyzed Sonogashira and Suzuki−Miyaura coupling reactions to yield new carbazole-containing (*E*)-but-1-en-3-ynes and (*E,E*)-buta-1,3-dienes is demonstrated.

Carbazole has attracted considerable interest as a building block in material science for its known hole-transporting and electroluminescence properties.[1] The carbazole moiety can be easily functionalized or covalently linked to other molecules to enhance its π-conjugated system. Several new protocols for the synthesis of *N*-substituted π-conjugated carbazoles have been recently reported, based on the sequential catalytic carbazole *N*-arylation−Sonogashira coupling[2] or *N*-arylation−Wittig−Horner reaction;[3] however, the products were limited to those in which the nitrogen atom was substituted with arylethenyl- or arylethynyl groups.

Recently, carbazole-substituted aromatic enynes with excellent electroluminescence properties have also been prepared by catalytic dimerization of ethynylphenyl-substituted carbazole derivatives.[4]

On the other hand, *N*-vinylarylcarbazoles can be obtained via Heck arylation of *N*-vinylcarbazole;[5] however the main drawback of this reaction is the poor control of the α- and β-regioselectivity. Alternative approaches to *N*-vinylarylcarbazoles based on vinylation of carbazole by styryl halides[6] or sequential silylative coupling−Hiyama coupling of *N*-vinylcarbazole have been also reported.[7]

(1) For recent reviews see: (a) Grimsdale, A. C.; Chan, K. L.; Martin, R. E.; Jokisz, P. G.; Holmes, A. B. *Chem. Rev.* **2009**, *109*, 897. (b) Cheng, Y.-J.; Yang, S.-H.; Hsu, Ch.-S. *Chem. Rev.* **2009**, *109*, 5868. (c) Lo, S.-Ch; Burn, P. L. *Chem. Rev.* **2007**, *107*, 1097.

(2) (a) Adhikari, R. M.; Shah, B. K.; Palayangoda, S. S.; Neckers, D. C. *Langmuir* **2009**, *25*, 2402. (b) Adhikari, R. M.; Mondal, R.; Shah, B. K.; Neckers, D. C. *J. Org. Chem.* **2007**, *72*, 4727. (c) Panthi, K.; Adhikari, R. M.; Kinstle, T. H. *J. Phys. Chem. A* **2010**, *114*, 4550. (d) Wan, Y.; Yan, L.; Zhao, Z.; Ma, X.; Guo, Q.; Jia, M.; Lu, P.; Ramos-Ortiz, G.; Maldonado, J. L.; Rodriguez, M.; Xia, A. *J. Phys. Chem. B* **2010**, *114*, 11737.

(3) (a) Yang, Z.; Chi, Z.; Yu, T.; Zhang, X.; Chen, M.; Xu, B.; Liu, S.; Zhang, Y.; Xu, J. *J. Mater. Chem.* **2009**, *19*, 5541. (b) Yan, Y.-X.; Tao, X.-T.; Sun, Y.-H.; Yu, W.-T.; Xu, G.-B.; Wang, Ch.-K.; Zhao, H.-P.; Yang, J.-X.; Yu, X.-Q.; Zhao, X.; Jing, M.-H. *Bull. Chem. Soc. Jpn.* **2005**, *78*, 300.

(4) Liu, Y.; Nishiura, M.; Wang, Y.; Hou, Z. *J. Am. Chem. Soc.* **2006**, *128*, 5592.

(5) (a) He, Q.; Sun, Y.; Liu, W.; Xu, S.; Cao, Z.; Cheng, J.; Bai, F. *Tetrahedron Lett.* **2007**, *48*, 4249. (b) He, Q. G.; Cheng, J. G.; Bai, F. L. *Chin. Chem. Lett.* **2007**, *18*, 920. (c) Ma, W.; Wu, Y.; Han, J.; Gu, D.; Gan, F. *Chem. Phys. Lett.* **2005**, *403*, 405.

(6) Lebedev, A. Y.; Izmer, V. V.; Kazyulkin, D. N.; Beletskaya, I. P.; Voskoboynikov, A. Z. *Org. Lett.* **2002**, *4*, 623.

(7) (a) Marciniec, B.; Majchrzak, M.; Prukala, W.; Kubicki, M.; Chadyniak, D. *J. Org. Chem.* **2005**, *70*, 8550. (b) Prukala, W.; Marciniec, B.; Majchrzak, M.; Kubicki, M. *Tetrahedron* **2007**, *63*, 1107.

(8) To the best of our knowledge, only a single example of 4-substituted (*E,E*)-buta-1,3-dienylcarbazole: 9-((*E,E*)-4-nitrobuta-1,3-dien-1-yl)-9*H*-carbazole has been reported in the literature: Koike, T.; Hagiwara, M.; Takeuchi, N.; Tobinaga, S. *Heterocycles* **1997**, *45*, 1271.

Nevertheless, to the best of our knowledge, no examples of a general method for the synthesis of stereodefined (*E,E*)-dienes[8] and (*E*)-enynes[9] containing *N*-substituted carbazolyl groups has been given so far.

The design of differently functionalized building blocks and development of reaction sequences that would allow other key structural units are of intense ongoing synthetic interest. In this regard, stereodefined functionalized alkenyl halides suitable for cross-coupling reactions have been among the most successfully exploited for olefin motif elaboration. (*E*)-9-(2-Iodovinyl)-9*H*-carbazole would offer a synthetically versatile variant of *N*-vinylcarbazole which could be used as a coupling partner in palladium-catalyzed cross-coupling reactions allowing regio- and stereoselective construction of complex (*E*)-9-(but-1-en-3-yn-1-yl)-9*H*-carbazoles and (*E,E*)-9-(buta-1,3-dien-1-yl)-9*H*-carbazoles.

In this communication we report a one-pot synthesis of (*E*)-9-(2-iodovinyl)-9*H*-carbazole **1** from *N*-vinyl-carbazole by silylative coupling/iododesilylation sequence and its application as a new reagent in the palladium-catalyzed Sonogashira and Suzuki—Miyaura cross-coupling reactions (Scheme 1).

Scheme 1. New Synthetic Strategy to Highly π-Conjugated *N*-Substituted Carbazoles
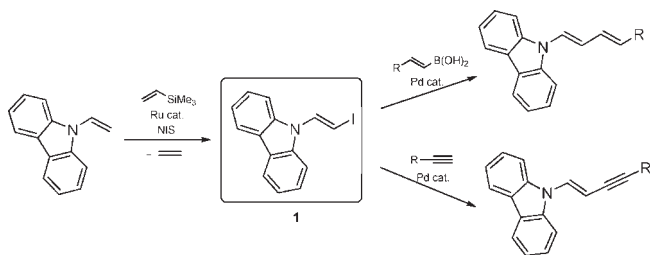
In the past two decades, we have developed the silylative coupling of olefins with vinyl-substituted organosilicon compounds occurring in the presence of complexes containing initially or generating in situ M—H and M—Si bonds.[10] The silylative coupling, in combination with subsequent desilylation reactions such as Hiyama cross-coupling and halodesilylation, appears to be a valuable step to provide highly conjugated π-electron compounds such as stilbenes, aryl-substituted polyenes, or styryl halides.[11]

As we have previously reported, the silylative coupling of *N*-vinylcarbazole with vinylsilanes catalyzed by a ruthenium—hydride complex occurred stereoselectively to give (*E*)-9-(2-silylvinyl)-9*H*-carbazoles in high yields.[7] On the basis of our recent results on the highly stereoselective

synthesis of (*E*)-β-aryl vinyl halides from styrenes,[12] we have envisaged that the ruthenium-catalyzed (*E*)-selective silylative coupling of *N*-vinylcarbazole with trimethylvinylsilane followed by *N*-iodosuccinimide-mediated iododesilylation could be a valuable synthetic method for the one-pot conversion of *N*-vinylcarbazole into (*E*)-9-(2-iodovinyl)-9*H*-carbazole. The resulting iodide could be used as a coupling partner for the stereoselective synthesis of carbazole-functionalized enynes and dienes.

The silylative coupling reaction of *N*-vinylcarbazole and trimethylvinylsilane (1.2 equiv) was conducted following the original procedure (RuHCl(CO)(PCy$_3$)$_2$ catalyst (2 mol %), toluene, 24 h, 100 °C, sealed ampule under Ar atmosphere)[7a] to give exclusively (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole (GC yield 95%). Treatment of (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole with 1.2 equiv of *N*-iodosuccinimide (NIS) in acetonitrile at room temperature allowed isolation of stereochemically pure (*E*)-9-(2-iodovinyl)-9*H*-carbazole **1** in 80% isolated yield (GC yield 98%). To the best of our knowledge, this is the first iododesilylation process disclosed for β-silylenamines.[13] Thus, by sequencing the highly (*E*)-selective silylative coupling of *N*-vinylcarbazole with a stereospecific iododesilylation, the stereochemical fidelity of the product is preserved.

During the course of our experiments, we have found that molecular iodine (1 equiv) in CH$_2$Cl$_2$ could also be employed for the iododesilylation of (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole at room temperature. However, it seemed to be less effective than NIS and gave the product with moderate yield and selectivity (GC yield 60%, *E/Z* = 8/2). In contrast, when iodine monochloride ICl (1 equiv) in CH$_2$Cl$_2$ was applied, no iodovinylcarbazole product was detected and decomposition of (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole to *N*-vinylcarbazole and vinyl iodide was observed.

After several attempts we found that iododesilylation of (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole in the presence of NIS occurred efficiently also when the 3:1 mixture of acetonitrile and toluene was employed as the solvent without affecting either the reaction yield and stereoselectivity. This result prompted us to attempt the iododesilylation step in one pot with silylative coupling without further purification of the (*E*)-9-(2-trimethylsilylvinyl)-9*H*-carbazole intermediate. In a typical procedure, *N*-vinylcarbazole, trimethylvinylsilane (1:1.2 ratio), and RuHCl(CO)(PCy$_3$)$_2$ catalyst (2 mol %) were dissolved in dry toluene (0.5 M concentration) and heated under an Ar atmosphere in a Schlenk bomb flask fitted with a plug valve at 110 °C for 24 h. Next, after cooling the reaction mixture to room temperature, a 3-fold excess of acetonitrile and 1.2 equiv of solid *N*-iodosuccinimide were added. Treatment of the silylative coupling product with NIS caused iododesilylation in a stereospecific manner, giving

(9) To the best of our knowledge, only a single example of carbazole-containing (*E*)-but-1-en-3-yne: (*E*)-9-(but-1-en-3-ynyl)-9*H*-carbazole has been reported: Wang, B. *Chin. J. Org. Chem.* **2005**, *1*, 81.
(10) For recent reviews, see: (a) Marciniec, B. *Acc. Chem. Res.* **2007**, *40*, 943. (b) Marciniec, B. *Coord. Chem. Rev.* **2005**, *249*, 2374.
(11) Pawluć, P.; Prukała, W.; Marciniec, B. *Eur. J. Org. Chem.* **2010**, *2*, 219.

(12) Pawluć, P.; Hreczycho, G.; Szudkowska, J.; Kubicki, M.; Marciniec, B. *Org. Lett.* **2009**, *11*, 3390.
(13) No report in the literature has been found on the halodesilylation of β-nitrogen-substituted vinylsilanes except the iododesilylation of β-silylvinyltoluenesulfonamides: Timbart, L.; Cintrat, J. Ch. *Chem.—Eur. J.* **2002**, *8*, 1637.

(*E*)-9-(2-iodovinyl)-9*H*-carbazole **1** in high geometrical purity (*E*/*Z* = 97/3) within 2 h (Scheme 2). Column chromatography of the resulting product (silica gel, eluent: hexane/ethyl acetate 50:2) afforded pure compound **1** in a 76% overall isolated yield.
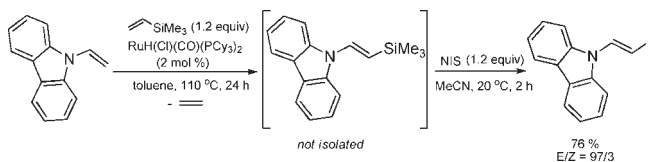
The *E*-configuration of the carbon−carbon double bond in **1** was determined on the basis of the ^{1}H and ^{13}C NMR spectra.[14] Moreover, compound **1** proved to be a solid and yielded a crystal amenable to X-ray structure determination (Figure 1). The non-hydrogen substituents of double bonds are in a *trans* disposition, as can be seen from the values of the torsion angle N12−C14−C15−I16− 176.5(3)°.[14]
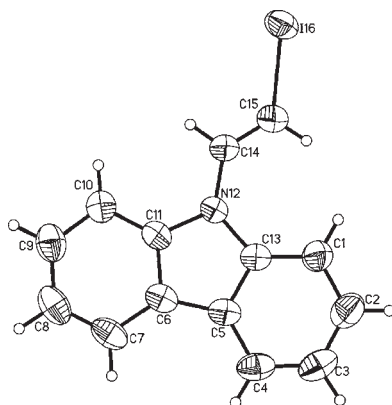
Figure 1. Perspective view of the molecule of **1**. Elipsoids are drawn at 50% probability level, hydrogen atoms are shown as spheres of arbitrary radii.

This approach to (*E*)-9-(2-iodovinyl)-9*H*-carbazole **1** provides a useful synthesis of various *β*-substituted vinyl-carbazoles *via* elaboration of the resulting iodide functionality into other substituents by using palladium-catalyzed cross-coupling processes. Thus, to demonstrate the synthetic usefulness of **1**, we investigated palladium-catalyzed Sonogashira[15] and Suzuki−Miyaura[16] coupling reactions.

The cross-coupling reactions of **1** with terminal alkynes were carried out under oxygen-free Sonogashira reaction conditions, which have been reported previously for haloenamides.[17] Sonogashira coupling of **1** with selected alkynes (Table 1) proceeded smoothly at room temperature in the presence of a Pd(PPh$_3$)$_4$/CuI catalytic system to give corresponding (*E*)-9-(but-1-en-3-yn-1-yl)-9*H*-carbazoles **2a**−**h** in good yields (75−90%). As terminal alkynes were used in excess, formation of a byproduct, symmetrical 1,3-diynes, was observed (10−20%) in the reaction mixture; however, they could be separated by column chromatography. In effort to explore the scope of the method, we have screened the coupling of **1** with alkyl-, aryl-, and silyl-substituted acetylenes (Table 1).

Table 1. Sonogashira Coupling of (*E*)-9-(2-Iodovinyl)-9*H*-carbazole **1** with Terminal Alkynes

compound	R	*E*/*Z*[a]	yield (%)[b]
2a	Ph	9/1	76
2b	4-PhC$_6$H$_4$	99/1	90
2c	4-*t*-BuC$_6$H$_4$	98/2	84
2d	SiMe$_3$	98/2	85
2e	*n*-C$_6$H$_{13}$	98/2	80
2f	C$_6$H$_{11}$	99/1	75
2g	Ph$_2$(OSiMe$_3$)C	99/1	88
2h	*t*-Bu	99/1	80
-	OEt	−	0

[a] *E*/*Z* ratio determined by ^{1}H NMR. [b] Yield of isolated products.

Unfortunately, no reaction took place with ethynyl ethyl ether. All the reactions were stereospecific, and in most cases, the (*E*)-double bond geometry was strongly favored, with an approximately 99:1−99:2 *E*/*Z* ratio as measured by ^{1}H NMR and GC-MS (Table 1).

Compounds **2a**−**h** were isolated and characterized spectroscopically.[14] The *E*-configuration of the double bond of (*E*)-9-(4-phenylbut-1-en-3-yn-1-yl)-9*H*-carbazole **2a** and (*E*)-9-(5,5-diphenyl-5-(trimethylsiloxy)pent-1-en-3-yn-1-yl)-9*H*-carbazole **2g** was further confirmed by single-crystal X-ray diffraction analysis.[14] We have also found that Suzuki−Miyaura coupling of **1** with 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane (2 equiv) in the presence of the Pd(PPh$_3$)$_4$ catalyst (10 mol %) under biphasic conditions (toluene (0.1 M), aqueous K$_2$CO$_3$ (3 equiv, 2 M), and ethanol (15 equiv)) gives (*E*)-9-(buta-1,3-dien-1-yl)-9*H*-carbazole **3a** in 65% isolated yield upon 24 h at 50 °C (Table 2). The reaction was highly stereospecific giving the product with retention of configuration (*E*/*Z* = 94:6); however, a side decomposition product, 9*H*-carbazole, was also isolated in 10% yield. The optimal conditions established for the reaction of compound **1** with vinylborane were applied to selected (*E*)-aryl vinyl boronic acids providing good yields (66−72% measured by GC) of

(14) For details see Supporting Information.

(15) For recent reviews, see: (a) Sonogashira, K. In *Metal-Catalyzed Cross-Coupling Reactions*; Stang, P. J.; Diederich, F., Eds.; Wiley-VCH: Weinheim, 1998; pp 203−229. (b) Viciu, M. S.; Nolan, S. P. In *Modern Arylation Methods*; Ackermann, L., Ed.; Wiley-VCH: Weinheim, 2009; Chapter 6, pp 183−220. (c) Chinchilla, R.; Najera, C. *Chem. Rev.* **2007**, *107*, 874.

(16) (a) Suzuki, A. In *Handbook of Organopalladium Chemistry for Organic Synthesis*; Negishi, E.-I., Ed.; Wiley-Interscience: New York, 2002; Vol. 1; pp 249−262. (b) Beller, M. *Adv. Synth. Catal.* **2009**, *351*, 3027.

(17) Mulder, J. A.; Kurtz, K. C. M.; Hsung, R. P.; Coverdale, H.; Frederick, M. O.; Shen, L.; Zificsak, C. A. *Org. Lett.* **2003**, *5*, 1547.

Table 2. Synthesis of (*E*)-9-(Buta-1,3-dien-1-yl)-9*H*-carbazoles

compound	R	isomeric purity (%)[a]	yield (%)[b]
3a	H[c]	94 (*E*)	80 (65)
3b	Ph	80 (*E,E*)[d]	66 (50)
3c	4-MeC$_6$H$_4$	84 (*E,E*)[e]	70
3d	3-FC$_6$H$_4$	85 (*E,E*)[f]	72

[a] Determined by GCMS. [b] Measured by GC (isolated yields in parentheses). [c] 2 equiv of 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane and 10 mol % of Pd(PPh$_3$)$_4$ were used. [d] (*E,E*)/(*E,Z*)/(*Z,Z*) = 80:16:4. [e] (*E,E*)/(*E,Z*)/(*Z,Z*) = 84:10:6. [f] (*E,E*)/(*E,Z*)/(*Z,Z*) = 85:10:5.

the desired (*E,E*)-9-(buta-1,3-dien-1-yl)-9*H*-carbazoles (**3b–d**, Table 2). Thus, the coupling reactions were performed in a toluene/ethanol mixture using Pd(PPh$_3$)$_4$ (5 mol %) as a catalyst, in the presence of a 2 M aqueous solution of K$_2$CO$_3$ (3 equiv) at 50 °C.

In conclusion, the proposed one-pot ruthenium catalyzed silylative coupling of *N*-vinylcarbazole with trimethylvinyl-silane followed by iododesilylation provides the facile entry to (*E*)-9-(2-iodovinyl)-9*H*-carbazole, which is a versatile building block shown to undergo subsequent palladium-catalyzed Sonogashira and Suzuki−Miyaura coupling reactions en route to carbazole-containing (*E*)-but-1-en-3-ynes and (*E,E*)-buta-1,3-dienes.

Supporting Information Available. Experimantal procedures, NMR spectra, and compound characterization data as well as X-ray analysis details. This material is free of charge via the Internet at http://pubs.acs.org.