Tetrahedron 67 (2011) 3194–3200

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Synthesis of substituted 3-iodopyrroles by cycloisomerization of propargylic aziridines with iodine

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ARTICLE INFO

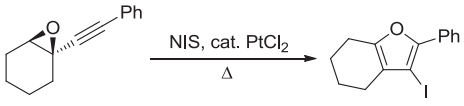
Article history:
Received 2 February 2011
Received in revised form 4 March 2011
Accepted 7 March 2011
Available online 12 March 2011

ABSTRACT

The electrophilic cyclizations of *N*-substituted propargylic aziridines are described. 3-Iodopyrroles having a variety of substituents at the 2- and 3-positions were synthesized by reacting propargylic aziridines with iodine. Whereas *N*-tosyl-substituted substrates require a platinum catalyst to promote the reaction, the iodine-promoted cycloisomerizations proceed when *N*-benzyl-substituted substrates are employed.

1. Introduction

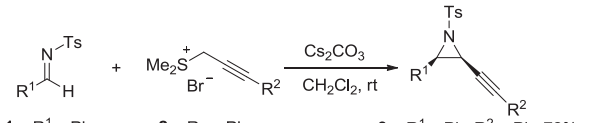
Substituted pyrroles are used extensively in heterocyclic chemistry as key structural subunits in biologically active molecules and in compounds for industrial purposes.[1] They are also widely utilized as synthetic intermediates in organic synthesis for further structural elaboration.[2] Consequently, considerable effort has been devoted to the development of an efficient methodology for the synthesis of pyrroles.[3] Transition metal-catalyzed cycloisomerization of propargylic aziridines is one such methodology, in which a variety of 2,5-disubstituted pyrroles is obtained with gold[4] or platinum[5] catalysts. During the course of our study of platinum-catalyzed cycloisomerization of propargylic oxiranes, it was found that 3-iodofurans could be synthesized in the presence of NIS as an electrophile (Scheme 1).[5,6] We anticipated that a similar reaction would proceed if propargylic aziridines were employed as the substrate. We report herein the synthesis of 3-iodopyrroles by cycloisomerization of propargylic aziridines with iodine, in which various 2,5-disubstituted 3-iodopyrroles were synthesized with high efficiency.[7]



Scheme 1. Synthesis of 3-iodofuran by cycloisomerization of propargylic oxiranes.

2. Results and discussion

N-Tosyl-substituted propargylic aziridines, the initial substrates for the cycloisomerization reaction, were easily prepared by ylide aziridination of the *N*-sulfonylimines with sulfonium propargylides (Scheme 2).[4b,8] Thus, when the imines **1a**–**f**, having a variety of substituents, were treated with the propargylic dimethylsulfonium salts **2a**–**c** and Cs_2CO_3 at rt, the corresponding *cis*-propargylic aziridines **3a**–**h** were selectively produced in moderate to good yields.



1a R^1 = Ph
1b R^1 = Cy
1c R^1 = Pr
1d R^1 = Bu
1e R^1 = ^{i}Pr
1f R^1 = 2-BrPh

2a R_2 = Ph
2b R_2 = Hex
2c R_2 = TMS

3a R^1 = Ph R^2 = Ph 72%
3b R^1 = Cy R^2 = Ph 61%
3c R^1 = Pr R^2 = Ph 53%
3d R^1 = Bu R^2 = Ph 32%
3e R^1 = ^{i}Pr R^2 = Ph 61%
3f R^1 = 2-BrPh R^2 = Ph 53%
3g R^1 = Ph R^2 = Hex 73%
3h R^1 = Ph R^2 = TMS 84%

Scheme 2. Synthesis of *N*-tosyl-substituted propargylic aziridines **3**.

The initial reactions for the synthesis of substituted pyrroles were attempted using the diphenyl-substituted propargylic aziridine **3a** (Table 1). When **3a** was subjected to the reaction with NIS and 10 mol % of $PtCl_2$ in dioxane/H_2O (2/1) at 100 °C following our procedure for the synthesis of 3-iodofuran,[5,6] only decomposition of the substrate was observed (entry 1). However, the desired 3-iodopyrrole **4a** was produced in 35% yield using iodine as the electrophile (entry 2). After experimenting with various solvents and temperatures (entries 3–8), we found that the yield of **4a** could be increased to 92% when the reaction was carried out in MeCN/H_2O (10/1) at 80 °C (entry 8).

Having identified a useful set of reaction conditions, we next conducted a study of the substrate scope (Table 2). Propargylic aziridine **3b** having a cyclohexyl group on the aziridine ring

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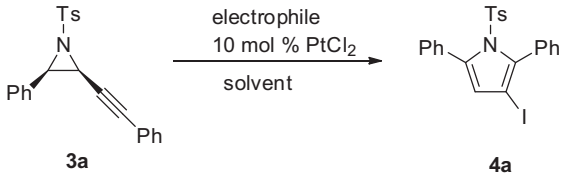
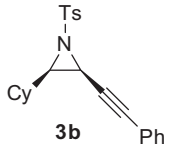
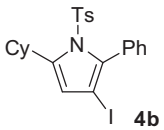
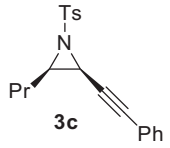
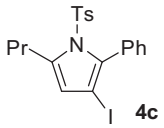
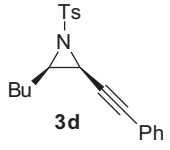
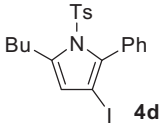
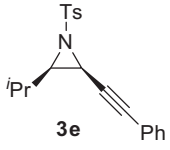
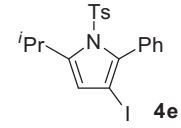
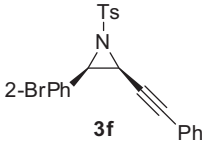
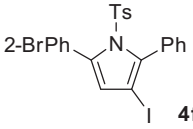
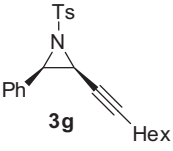
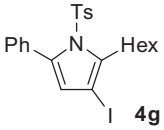
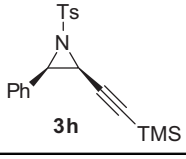
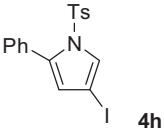
doi:10.1016/j.tet.2011.03.015

Table 1
Platinum-catalyzed iodocyclizations of **3a**



Entry	Electrophile	Solvent	Temp (°C)	Yield (%)
1	NIS	Dioxane/H_2O (2/1)	100	Decomp.
2	I_2	Dioxane/H_2O (2/1)	100	35
3	I_2	PhCN/H_2O (2/1)	100	48
4	I_2	MeCN/H_2O (2/1)	100	50
5	I_2	MeCN/H_2O (2/1)	80	55
6	I_2	MeCN/H_2O (2/1)	60	48
7	I_2	MeCN/H_2O (5/1)	80	60
8	I_2	MeCN/H_2O (10/1)	80	92

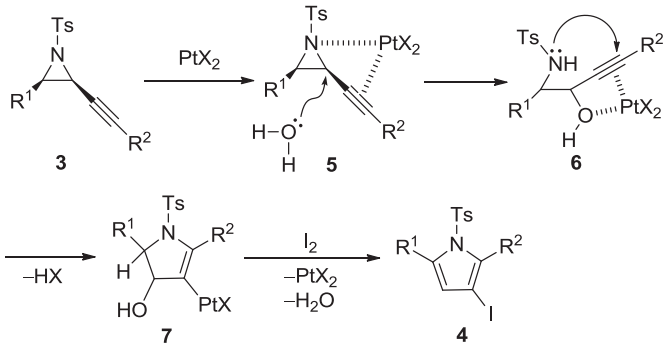
Table 2
Reactions with various propargylic aziridines **3b**–**h**[a]

Entry	Substrate	Product	Yield (%)
1			95
2			64
3			65
4			85
5			66
6			25
7			45

[a] All reactions were carried out in the presence of 2 equiv iodine and 10 mol % $PtCl_2$ MeCN/H_2O (10/1) at 80 °C for 10 min.

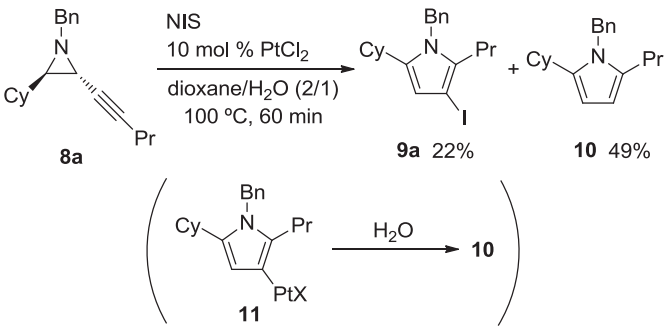
successfully reacted with iodine in the presence of the platinum catalyst to produce the 3-iodopyrrole **4b** in 95% yield (entry 1). When the reactions of the substrates **3c**, **3d**, and **3e** containing an alkyl group were carried out, the corresponding products **4c**, **4d**, and **4e** were obtained in moderate yields (entries 2–4). The reaction of **3f** having a 2-bromophenyl group also afforded the pyrrole **4f** without any problems (entry 5). The corresponding product **4g** was produced from the reaction of **3g** with a hexyl group on the alkynyl moiety; however, the yield was decreased (entry 6). When the TMS-substituted substrate **3h** was subjected to the reaction, the desilylated product **4h** was obtained in only moderate yield (entry 7).

A plausible mechanism for the platinum-catalyzed cycloisomerization of **3** is shown in Scheme 3. Recently, Pale reported results of mechanistic studies on the metal-catalyzed cycloisomerization of propargylic oxiranes to furans in the presence of alcohol, in which the epoxide ring opening product with a hydroxyl group was identified as the reaction intermediate.[9] We concluded that a similar process can be expected to occur using our aqueous reaction conditions. Thus, the platinum catalyst activates the substrate **3** by coordination to the aziridine nitrogen, which promotes the aziridine ring opening by water as shown in **5**. The resulting sulfonamide nitrogen in **6** attacks the distal position of the alkyne to form the cyclized intermediate **7**. Aromatization by elimination of water followed by iodo-demetalation with iodine produces the iodopyrrole **4**.



Scheme 3.

We next examined the reactions using *N*-benzyl-substituted propargylic aziridines.[5] In our initial attempt, we used *trans*-propargylic aziridine **8a** under platinum-catalyzed iodocyclization conditions. When **8a** was treated with 10 mol % of $PtCl_2$ and 2 equiv NIS in dioxane/H_2O (2/1) at 100 °C for 60 min, the desired 3-iodopyrrole **9a** was produced in 22% yield along with the non-iodinated pyrrole **10** as the inseparable major product[10] in 49% yield (Scheme 4). Several attempts under various platinum-catalyzed conditions resulted in similar results. For this reason, it was thought

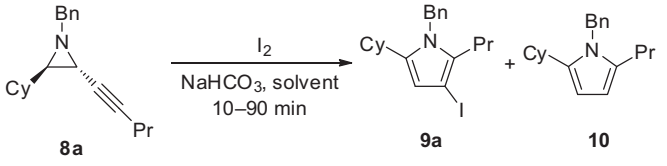


Scheme 4.

that proto-demetalation of the pyrrolyl-platinum intermediate **11** occurred prior to iodo-demetalation in the case of the *N*-benzyl-substituted propargylic aziridines **8a**.

We next turned our attention to the electrophilic activation of propargylic aziridines,[11] in which a similar process could take place in the reaction of **8a** with iodine (Table 3). When **8a** was treated with 2 equiv of iodine and 2 equiv of $NaHCO_3$ in THF at rt,[11r] no reaction occurred (entry 1). However, the desired product **9a** was obtained in 43% yield under reflux conditions in THF (entry 2). The yield was improved to 64% when the reaction was carried out in dioxane at 100 °C (entry 3), but the non-iodinated pyrrole **10** was isolated as a by-product in 28% yield. For this reason, it was expected that the hydrogen iodide produced in the reaction would catalyze the cycloisomerization of **8a** to the non-iodinated pyrrole **10**.[12] When 5 equiv of $NaHCO_3$ was used to neutralize the hydrogen iodide, the iodopyrrole **9a** was successfully obtained in 90% yield as the sole product (entry 4).

Table 3
Iodocyclizations of **8a** in the presence of iodine



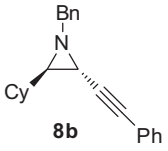
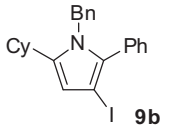
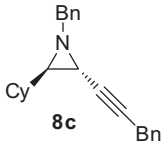
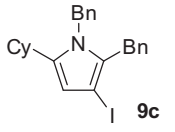
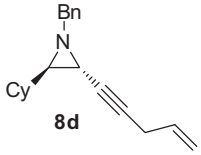
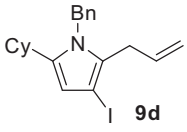
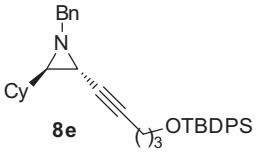
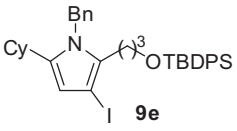
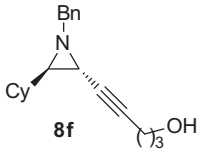
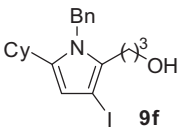
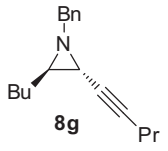
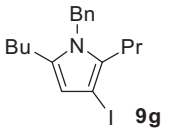
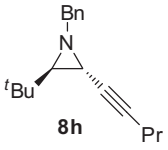
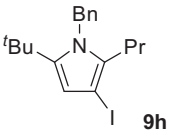
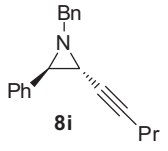
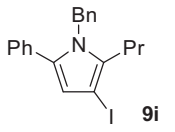
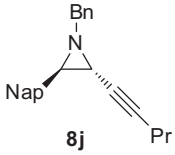
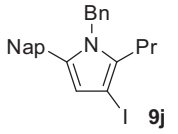
Entry	Solvent	$NaHCO_3$ (equiv)	Temp (°C)	Yields (%)	
				9a	**10**
1	THF	2	rt	N.R.	
2	THF	2	Reflux	43	—
3	Dioxane	2	100	64	28
4	Dioxane	5	100	90	—

The electrophilic cyclizations of the substituted propargylic aziridines **8b–j** under the optimized conditions are summarized in Table 4. When the reactions of the substrates **8b–e** containing, respectively, a phenyl, benzyl, allyl, and siloxypropyl group at the alkynyl position were carried out, the corresponding products **9b–e** were obtained in good yields (entries 1–4). The propargylic aziridine **8f** having a free hydroxyl group was uneventfully transformed to the 3-iodopyrrole **9f** in 76% yield (entry 5). The substrates **8g** and **8h**, which contain butyl and *tert*-butyl groups on the aziridine ring, were successfully transformed to the 3-iodopyrroles **9g** and **9h** in 94% and 95% yield, respectively (entries 6 and 7). The reactions of the phenyl- and 2-naphthyl-substituted substrates **8i** and **8j** also proceeded to afford the corresponding products **9i** and **9j** in 95% and 68% yield, respectively (entries 8 and 9).

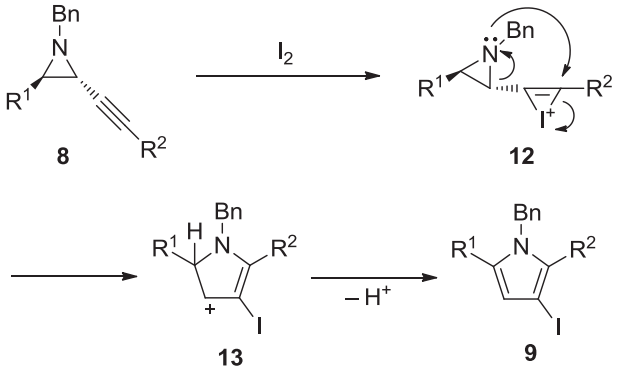
A plausible mechanism for the iodine-promoted cyclization of the *N*-benzyl-substituted propargylic aziridines **8** is shown in Scheme 5. Coordination of the propargylic triple bond to an iodine cation forms the cyclic iodonium ion **12**. Subsequent attack of the aziridine nitrogen on the iodonium ion produces the cyclized cationic intermediate **13**, which undergoes aromatization by elimination of the proton leading to the 3-iodopyrrole **9**.[13]

Further functionalization of the resulting products provides a broad insight into the 3-iodo-substitued pyrroles (Scheme 6). When the Miyaura–Suzuki coupling reaction of **4b** with 4-methoxyphenylboronic acid was carried out, the 4-methoxyphenyl group was introduced to give **14** in 76% yield. The Sonogashira coupling reaction of **4b** with phenylacetylene also afforded the coupled product **15** in 70% yield. The iodopyrrole **9a** likewise underwent the Negishi coupling with 3-methoxyphenylzinc chloride to produce the corresponding product **16** in 83% yield.

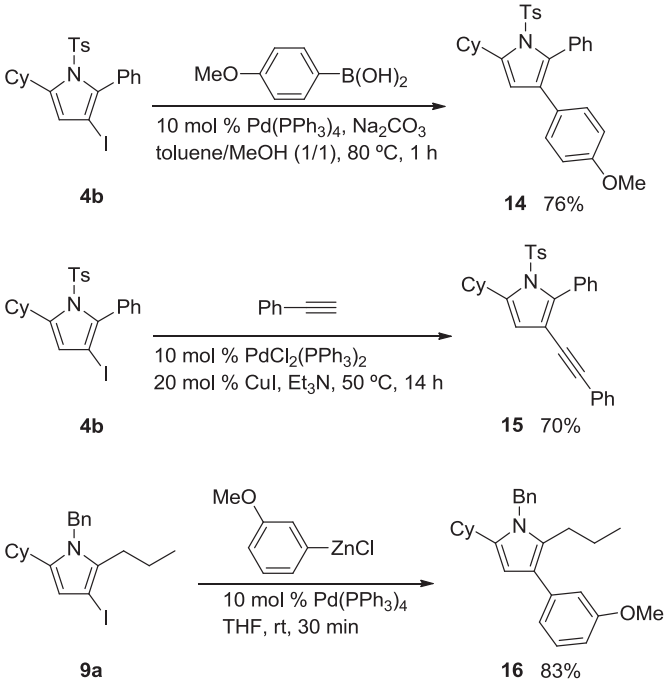
Table 4
Reactions with various propargylic aziridines **8b–j**[a]

Entry	Substrate	Product	Yield (%)
1	 **8b**	 **9b**	90
2	 **8c**	 **9c**	79
3	 **8d**	 **9d**	86
4	 **8e**	 **9e**	86
5	 **8f**	 **9f**	76
6	 **8g**	 **9g**	94
7	 **8h**	 **9h**	95
8	 **8i**	 **9i**	95
9[b]	 **8j**	 **9j**	68

[a] All reactions were carried out in the presence of 2 equiv iodine and 5 equiv $NaHCO_3$ in dioxane at 100 °C for 10 min.
[b] Nap=2-naphthyl.



Scheme 5.



Scheme 6.

3. Conclusion

In conclusion, we have developed a methodology for the synthesis of 3-iodopyrroles by an electrophilic cyclization of the *N*-substituted propargylic aziridines. Whereas *N*-tosyl-substituted substrates require a platinum catalyst to promote the reaction, the iodine-promoted cycloisomerizations proceed when *N*-benzyl-substituted substrates are employed. The reactions afford a variety of substituted 3-iodopyrroles, and the process is an efficient and convenient protocol for the preparation of these derivatives.

4. Experimental

4.1. General

Materials were obtained from commercial suppliers and used without further purification except when otherwise noted. Solvents were dried and distilled according to standard protocol. Propargylic aziridines **3a**–**c**,**e**,**h**,[4b,8] and **8a**–**j**[5] were prepared according to the procedures described in the literature.

4.2. General procedure for the synthesis of *N*-tosyl-substituted propargylic aziridines 3.[8] Reaction of 1f with 2a (Scheme 2)

To a stirred solution of *N*-sulfonyl imine **1f** (250 mg, 0.972 mmol) in CH_2Cl_2 (10 mL) were gradually added propargylic dimethylsulfonium salt **2a** (329 mg, 0.972 mmol) and Cs_2CO_3 (317 mg, 0.972 mmol). The reaction mixture was stirred for 1.5 h at rt. The reaction mixture was filtered through a pad of silica gel to remove the inorganic salt. Concentration at reduced pressure gave the residue, which was chromatographed on silica gel using hexane/AcOEt (80/20) as the eluent to give the propargylic aziridine **3f** (234 mg, 53%) as a yellow oil.

*4.2.1. 2-Butyl-3-phenylethynyl-1-(toluene-4-sulfonyl)aziridine (**3d**).* Yield: 32%; colorless oil; IR (neat): 3029, 2956, 2871, 2230, 2360, 1597, 1492, 1444, 1330 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.87 (2H, d, J=8.0 Hz), 7.40–7.35 (4H, m), 7.32–7.26 (3H, m), 3.58 (1H, d, J=6.8 Hz), 2.95 (1H, q, J=6.8 Hz), 2.45 (3H, s), 1.74–1.59 (4H, m), 1.32–1.29 (2H, m), 0.84 (3H, t, J=7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): 144.8, 134.8, 131.9, 129.7, 128.8, 128.2, 128.0, 121.9, 82.1, 45.3, 34.4, 28.7, 27.9, 22.2, 21.7, 13.9; HRMS (ESI): m/z calcd for $C_{21}H_{23}NNaO_2S$ (M^++Na): 376.1347; found 376.1347.

*4.2.2. 2-(2-Bromo-phenyl)-3-phenylethynyl-1-(toluene-4-sulfonyl)aziridine (**3f**).* Yield: 53%; yellow oil; IR (neat): 3024, 2924, 2233, 1597, 1569, 1492, 1442, 1380 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.94 (2H, d, J=8.0 Hz), 7.55 (1H, d, J=8.0 Hz), 7.38–7.32 (3H, m), 7.26–7.15 (5H, m), 7.08–7.06 (2H, m), 4.29 (1H, d, J=6.8 Hz), 3.94 (1H, d, J=6.8 Hz), 2.44 (3H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 145.0, 134.0, 132.0, 131.9, 131.6, 129.8, 129.7, 129.3, 128.6, 127.9, 127.9, 126.9, 123.2, 121.3, 84.4, 81.1, 46.8, 36.1, 21.5; HRMS (ESI): m/z calcd for $C_{23}H_{18}BrNNaO_2S$ (M^++Na): 474.0139; found 474.0136.

*4.2.3. 2-Oct-1-ynyl-3-phenyl-1-(toluene-4-sulfonyl)aziridine (**3g**).* Yield: 73%; colorless oil; IR (neat) 3061, 2931, 2859, 2248, 1598 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.88 (2H, d, J=8.3 Hz), 7.34–7.27 (7H, m), 3.94 (1H, d, J=6.9 Hz), 3.63 (1H, dt, J=6.9 and 1.7 Hz), 2.43 (3H, s), 2.00 (2H, td, J=6.8 and 1.7 Hz), 1.31–1.10 (8H, m), 0.84 (3H, t, J=7.2 Hz); ^{13}C NMR (400 MHz, $CDCl_3$): δ 144.8, 134.8, 132.3, 129.8, 128.6, 128.3, 127.9, 127.8, 86.8, 72.2, 46.2, 36.3, 31.2, 28.2, 28.0, 22.5, 21.7, 18.6, 14.0; HRMS (ESI) m/z calcd for $C_{23}H_{27}NNaO_2S$ (M^++Na): 404.1660; found 404.1654.

4.3. General procedure for the synthesis of *N*-tosyl-substituted 3-iodopyrroles 4. Reaction of 3b (entry 1 in Table 2)

To a stirred solution of propargylic aziridine **3b** (32.0 mg, 0.084 mmol) in CH_3CN/H_2O (10/1) were gradually added iodine (42.8 mg, 0.168 mmol) and $PtCl_2$ (2.2 mg, 8.4 μmol) at rt. After the stirring was continued for 25 min at 80 °C, the reaction mixture was cooled to rt and diluted with minimum amount of Et_2O. The solution was then dried over $MgSO_4$ and filtered through a small amount of silica gel. Concentration at reduced pressure gave the residue, which was chromatographed on silica gel using hexane/AcOEt (92/8) as the eluent to give the 3-iodopyrrole **4b** (34.0 mg, 95%) as a colorless oil.

*4.3.1. 3-Iodo-2,5-diphenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4a**).* Yield: 92%; colorless oil; IR (neat): 3060, 3029, 2924, 1597, 1487, 1444, 1376 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.47–7.37 (10H, m), 7.09 (2H, d, J=8.0 Hz), 7.04 (2H, d, J=8.0 Hz), 6.38 (1H, s), 2.38 (3H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.8, 140.8, 139.6, 135.0, 132.2, 131.5, 129.9, 129.6, 129.6, 129.1, 128.8, 128.7, 128.4, 128.3, 127.9, 127.6,

127.6, 127.5, 127.4, 127.1, 123.7, 74.8, 21.6; HRMS (ESI): *m*/*z* calcd for $C_{23}H_{18}INNaO_2S$ (M^++Na): 522.0001; found 522.0002.

*4.3.2. 5-Cyclohexyl-3-iodo-2-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4b**).* Yield: 95%; IR (neat): 3061, 3029, 2926, 2852, 1597, 1477, 1446, 1371 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.38–7.29 (4H, m), 7.25–7.22 (2H, m), 7.16–7.12 (3H, m), 6.20 (1H, s), 3.28 (1H, tt, *J*=2.8 and 11.2 Hz), 2.38 (3H, s), 2.07 (2H, d, *J*=11.2 Hz), 1.84–1.73 (3H, m), 1.48–1.18(5H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.2, 144.6, 137.1, 136.5, 132.4, 131.9, 129.5, 128.4, 127.3, 126.5, 117.6, 73.8, 37.6, 34.6, 26.7, 26.2, 21.6; HRMS (ESI): *m*/*z* calcd for $C_{23}H_{24}INNaO_2S$ (M^++Na): 528.0470; found 528.0475.

*4.3.3. 3-Iodo-2-phenyl-5-propyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4c**).* Yield: 64%; colorless oil; IR (neat): 3029, 2962, 2930, 2873, 1729, 1597, 1494, 1444, 1375 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.40–7.29 (3H, m), 7.26 (3H, d, *J*=8.0 Hz), 7.17–7.12 (3H, m), 6.19 (1H, s), 2.91 (2H, t, *J*=7.2 Hz), 2.39 (3H, s), 1.75 (2H, sext, *J*=7.2 Hz), 1.03 (3H, t, *J*=7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.7, 139.9, 137.1, 136.3, 132.2, 132.0, 130.5, 129.5, 128.5, 127.3, 127.2, 126.7, 126.4, 119.0, 73.2, 31.2, 22.5, 21.6, 14.0; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{20}INNaO_2S$ (M^++Na): 488.0157; found 488.0162.

*4.3.4. 5-Butyl-3-iodo-2-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4d**).* Yield: 65%; colorless oil; IR (neat): 3029, 2956, 2928, 2870, 2360, 1597, 1444, 1376 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.40–7.31 (3H, m), 7.27–7.25 (2H, m), 7.17–7.12 (4H, m), 6.19 (1H, s), 2.93 (2H, t, *J*=7.2 Hz), 2.40 (3H, s), 1.69 (2H, quint, *J*=7.2 Hz), 1.45 (2H, sext, *J*=7.2 Hz), 0.97 (3H, t, *J*=7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.7, 140.1, 137.1, 136.4, 132.3, 132.0, 130.5, 129.5, 129.3, 128.5, 127.3, 127.2, 126.7, 126.4, 118.9, 73.2, 31.3, 28.9, 22.5, 21.6, 13.9; HRMS (ESI): *m*/*z* calcd for $C_{21}H_{22}INNaO_2S$ (M^++Na): 502.0314; found 502.0312.

*4.3.5. 3-Iodo-5-isopropyl-2-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4e**).* Yield: 85%; colorless oil; IR (neat): 2969, 2360, 1597, 1559, 1523, 1444, 1378 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.39–7.29 (3H, m), 7.23 (3H, d, *J*=8.0 Hz), 7.15 (3H, d, *J*=8.0 Hz), 6.23 (1H, s), 3.65 (1H, sext, *J*=6.8 Hz), 2.39 (3H, s), 1.30 (6H, d, *J*=6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.2, 144.6, 137.5, 136.4, 132.3, 131.9, 129.5, 128.5, 127.3, 126.5, 117.5, 73.8, 27.9, 23.8, 21.6; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{20}INNaO_2S$ (M^++Na): 488.0157; found 488.0157.

*4.3.6. 5-(2-Bromo-phenyl)-3-iodo-2-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4f**).* Yield: 66%; colorless oil; IR (neat): 3028, 2924, 1596, 1561, 1478, 1456, 1379 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.66 (1H, d, *J*=8.0 Hz), 7.46–7.36 (4H, m), 7.30–7.27 (4H, m), 7.10 (4H, s), 6.46 (1H, s), 2.38 (3H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 144.9, 138.2, 137.1, 135.5, 133.8, 132.6, 132.6, 131.4, 129.9, 129.3, 128.8, 127.4, 127.4, 126.5, 125.1, 123.3, 73.2, 21.6; HRMS (ESI): *m*/*z* calcd for $C_{23}H_{17}BrINNaO_2S$ (M^++Na): 599.9106; found 599.9111.

*4.3.7. 2-Hexyl-3-iodo-5-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4g**).* Yield: 25%; yellow oil; IR (neat) 3061, 2926, 2856, 1597 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.36–7.21 (7H, m), 7.13 (2H, d, *J*=8.1 Hz), 6.17 (1H, s), 2.98 (2H, t, *J*=7.6 Hz), 2.37 (3H, s), 1.70 (2H, quint, *J*=7.6 Hz), 1.43–1.33 (6H, m), 0.92 (3H, t, *J*=7.2 Hz); ^{13}C NMR (400 MHz, $CDCl_3$): δ 144.7, 139.8, 138.8, 136.1, 132.2, 130.6, 129.5, 128.2, 127.3, 126.6, 122.2, 72.8, 31.6, 30.5, 30.1, 29.1, 22.7, 21.6, 14.1; HRMS (ESI) *m*/*z* calcd for $C_{23}H_{26}INNaO_2S$ (M^++Na): 530.0627; found 530.0627.

*4.3.8. 4-Iodo-2-phenyl-1-(toluene-4-sulfonyl)-1H-pyrrole (**4h**).* Yield: 45%; brown solid; mp: 109.1–113.6 °C; IR (neat) 3144, 3066, 2917, 1596 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.52 (1H, d, *J*=1.7 Hz), 7.39–7.09 (9H, m), 6.20 (1H, d, *J*=1.7 Hz), 2.36 (3H, s); ^{13}C NMR (400 MHz, $CDCl_3$): δ 145.2, 137.2, 135.1, 131.0, 130.0, 129.5, 128.8, 127.6, 127.4, 127.3, 121.9, 65.5, 21.6; HRMS (ESI) *m*/*z* calcd for $C_{17}H_{14}INNaO_2S$ (M^++Na): 445.9688; found 445.9678.

4.4. General procedure for the synthesis of *N*-benzyl-substituted 3-iodopyrroles 9. Reaction of 8a (entry 4 in Table 3)

To a stirred solution of propargylic aziridine **8a** (200 mg, 0.711 mmol) in dioxane (20.0 mL) were gradually added iodine (361 mg, 1.42 mmol) and $NaHCO_3$ (299 mg, 3.56 mmol) at rt. After stirring for 10 min at 100 °C, the reaction mixture was cooled to rt and the excess I_2 was removed by washing with a saturated aqueous solution of $Na_2S_2O_3$ (30.0 mL). The aqueous solution was then extracted with Et_2O (3×25 mL) and the combined organic layers were dried over $MgSO_4$. Concentration at reduced pressure gave the residue, which was purified by flash chromatography using hexane/AcOEt (98/2) as the eluent to give the 3-iodopyrrole **9a** (261 mg, 90%) as a colorless oil.

*4.4.1. 1-Benzyl-5-cyclohexyl-3-iodo-2-propyl-1H-pyrrole (**9a**).* Yield: 90%; colorless oil; IR (neat): 3087, 3063, 3028, 2927, 2851, 1605, 1545, 1496, 1453, 1415, 1373 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.30–7.21 (3H, m), 6.84 (2H, d, *J*=7.6 Hz), 6.02 (1H, s), 5.08 (2H, s), 2.44 (2H, t, *J*=7.6 Hz), 2.28 (1H, tt, *J*=10.8 and 3.2 Hz), 1.78–1.64 (5H, m), 1.41–1.18 (7H, m), 0.86 (3H, t, *J*=7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 140.5, 138.6, 133.2, 128.7, 127.1, 125.4, 110.5, 61.6, 47.4, 35.8, 33.9, 28.9, 26.5, 26.0, 23.2, 13.9; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{26}NNaI$ (M^++Na): 430.1008; found 430.1010.

*4.4.2. 1-Benzyl-5-cyclohexyl-3-iodo-2-phenyl-1H-pyrrole (**9b**).* Yield: 90%; white solid; mp: 102.5–102.7 °C; IR (neat): 3062, 3028, 2926, 2850, 1637, 1509, 1496, 1449, 1353 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.32–7.16 (8H, m), 6.79 (2H, d, *J*=7.2 Hz), 6.19 (1H, s), 5.03 (2H, s), 2.32 (1H, tt, *J*=11.2 and 3.2 Hz), 1.80–1.64 (5H, m), 1.39–1.27 (2H, m), 1.25–1.15 (3H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 141.7, 138.8, 134.7, 132.5, 131.0, 128.5, 128.0, 127.8, 127.0, 125.5, 112.0, 62.6, 48.4, 36.0, 34.0, 26.6, 25.9; HRMS (ESI): *m*/*z* calcd for $C_{23}H_{25}NI$ (M^++H): 442.1032; found 442.1031.

*4.4.3. 1,2-Dibenzyl-5-cyclohexyl-3-iodo-1H-pyrrole (**9c**).* Yield: 79%; colorless oil; IR (neat): 3061, 3027, 2925, 2850, 1603, 1546, 1495, 1454, 1417, 1354 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.28–7.14 (6H, m), 7.03 (2H, d, *J*=7.2 Hz), 6.76 (2H, d, *J*=7.6 Hz), 6.09 (1H, s), 4.88 (2H, s), 3.82 (2H, s), 2.30 (1H, tt, *J*=11.6 and 2.8 Hz), 1.77–1.64 (5H, m), 1.36–1.25 (2H, m), 1.24–1.19 (3H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 141.4, 139.0, 138.2, 131.4, 128.6, 128.4, 127.9, 127.1, 126.1, 125.4, 110.5, 63.7, 47.5, 35.8, 33.9, 32.8, 26.5, 25.9; HRMS (ESI): *m*/*z* calcd for $C_{24}H_{26}NNaI$ (M^++Na): 478.1008; found 478.1010.

*4.4.4. 2-Allyl-1-benzyl-5-cyclohexyl-3-iodo-1H-pyrrole (**9d**).* Yield: 86%; colorless oil; IR (neat): 3063, 3028, 2926, 2851, 1637, 1605, 1496, 1452, 1417, 1354 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.30–7.21 (3H, m), 6.83 (2H, d, *J*=7.6 Hz), 6.04 (1H, s), 5.71 (1H, ddt, *J*=17.2, 10.0 and 6.0 Hz), 5.07 (2H, s), 4.96 (1H, dd, *J*=10.0 and 1.6 Hz), 4.89 (1H, dd, *J*=17.2 and 1.6 Hz), 3.22 (2H, d, *J*=6.0 Hz), 2.33 (1H, tt, *J*=11.2 and 3.2 Hz), 1.79–1.64 (5H, m), 1.35–1.17 (5H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 141.1, 138.4, 135.1, 130.1, 128.7, 127.1, 125.4, 115.5, 110.5, 62.4, 47.3, 35.8, 33.9, 31.4, 26.5, 26.0; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{25}NaI$ (M^++H): 406.1032; found 406.1033.

*4.4.5. 1-Benzyl-2-[3-(tert-butyl-diphenyl-silanyloxy)-propyl]-5-cyclohexyl-3-iodo-1H-pyrrole (**9e**).* Yield: 86%; colorless oil; IR (neat): 3069, 3029, 2998, 2927, 2855, 1605, 1589, 1547, 1496, 1472, 1452, 1428, 1390 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.61 (4H, d, *J*=6.8 Hz), 7.42–7.32 (6H, m), 7.27–7.20 (3H, m), 6.78 (2H, d, *J*=6.8 Hz), 6.02 (1H, s), 5.08 (2H, s), 3.60 (2H, t, *J*=7.2 Hz), 2.59 (2H, t, *J*=7.6 Hz), 2.28 (1H, tt, *J*=10.8 and 3.2 Hz), 1.77–1.71 (4H, m), 1.63–1.55 (4H, m), 1.30–1.18 (4H, m), 1.02 (9H, s); ^{13}C NMR

(100 MHz, $CDCl_3$): δ 140.5, 138.6, 135.5, 133.8, 132.8, 129.5, 128.6, 127.5, 127.1, 125.4, 110.5, 63.2, 61.3, 47.3, 35.8, 33.9, 32.7, 26.8, 26.5, 26.0, 23.5, 19.1; HRMS (ESI): *m*/*z* calcd for $C_{36}H_{45}NOSiI$ (M^++H): 662.2315; found 662.2315.

4.4.6. 3-(1-Benzyl-5-cyclohexyl-3-iodo-1H-pyrrol-2-yl)propan-1-ol (***9f***). Yield: 76%; colorless oil; IR (neat): 3413, 3088, 3064, 2929, 2854, 1605, 1586, 1546, 1497, 1452, 1417, 1374 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.31–7.22 (3H, m), 6.84 (2H, d, *J*=7.6 Hz), 6.03 (1H, s), 5.12 (2H, s), 3.56 (2H, t, *J*=6.0 Hz), 2.59 (2H, t, *J*=7.6 Hz), 2.31 (1H, tt, *J*=11.6 and 3.2 Hz), 1.79–1.71 (4H, m), 1.66–1.55 (3H, m), 1.32–1.17 (6H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 140.9, 138.5, 132.2, 128.7, 127.2, 125.4, 110.6, 61.9, 61.8, 47.4, 35.9, 33.9, 32.5, 26.5, 25.9, 23.1; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{26}NONaI$ (M^++Na): 446.0957; found 446.0961.

4.4.7. 1-Benzyl-5-butyl-3-iodo-2-propyl-1H-pyrrole (***9g***). Yield: 94%; colorless oil; IR (neat): 3063, 3029, 2956, 2929, 2870, 1600, 1551, 1497, 1454, 1432, 1414, 1378, 1354 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.30–7.21 (3H, m), 6.85 (2H, d, *J*=7.6 Hz), 6.02 (1H, s), 5.06 (2H, s), 2.48 (2H, t, *J*=7.6 Hz), 2.36 (2H, t, *J*=7.6 Hz), 1.56–1.47 (2H, m), 1.42–1.26 (4H, m), 0.92–0.82 (6H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.3, 134.7, 133.6, 128.7, 127.1, 125.4, 112.1, 61.1, 47.5, 30.5, 28.9, 26.1, 23.3, 22.3, 13.8, 13.8; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{24}NNaI$ (M^++Na): 404.0851; found 404.0851.

4.4.8. 1-Benzyl-5-tert-butyl-3-iodo-2-propyl-1H-pyrrole (***9h***). Yield: 95%; colorless oil; IR (neat): 3063, 3028, 2961, 2927, 2870, 1605, 1567, 1497, 1466, 1454, 1397, 1364 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.29–7.19 (3H, m), 6.78 (2H, d, *J*=7.2 Hz), 6.07 (1H, s), 5.31 (2H, s), 2.32 (2H, t, *J*=7.6 Hz), 1.36 (2H, sext, *J*=7.6 Hz), 1.24 (9H, s), 0.85 (3H, t, *J*=7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 142.6, 139.1, 135.5, 128.5, 126.9, 125.3, 111.8, 61.4, 49.2, 32.2, 30.8, 29.6, 28.9, 23.0, 13.9; HRMS (ESI): *m*/*z* calcd for $C_{18}H_{24}NNaI$ (M^++Na): 404.0851; found 404.0855.

4.4.9. 1-Benzyl-3-iodo-5-phenyl-2-propyl-1H-pyrrole (***9i***). Yield: 95%; colorless oil; IR (neat): 3062, 3028, 2958, 2957, 2929, 2869, 1603, 1496, 1453, 1401, 1384, 1356 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.29–7.22 (8H, m), 6.87 (2H, d, *J*=7.2 Hz), 6.35 (1H, s), 5.16 (2H, s), 2.48 (2H, t, *J*=7.6 Hz), 1.45 (2H, sext, *J*=7.6 Hz), 0.90 (3H, t, *J*=7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.6, 136.0, 135.6, 132.6, 128.9, 128.7, 128.3, 127.2, 127.1, 125.5, 115.3, 62.9, 48.4, 29.1, 23.0, 14.0; HRMS (ESI): *m*/*z* calcd for $C_{20}H_{21}NI$ (M^++H): 402.0719; found 402.0719.

4.4.10. 1-Benzyl-3-iodo-5-naphthalen-2-yl-2-propyl-1H-pyrrole (***9j***). Yield: 68%; yellow oil; IR (neat): 3057, 3029, 2961, 2928, 2872, 1630, 1603, 1497, 1454, 1414, 1379, 1357 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.81–7.74 (2H, m), 7.68–7.65 (2H, m), 7.46–7.41 (2H, m), 7.39 (1H, d, *J*=7.6 Hz), 7.29–7.23 (3H, m), 6.91 (2H, d, *J*=7.6 Hz), 6.46 (1H, s), 5.23 (2H, s), 2.53 (2H, t, *J*=7.6 Hz), 1.49 (2H, sext, *J*=7.6 Hz), 0.93 (3H, t, *J*=7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.6, 136.0, 132.4, 128.7, 127.9, 127.9, 127.5, 127.5, 127.2, 127.0, 126.2, 126.0, 125.5, 115.8, 63.1, 48.6, 29.1, 23.0, 14.0; HRMS (ESI): *m*/*z* calcd for $C_{24}H_{22}NNaI$ (M^++Na): 474.0695; found 474.0696.

4.5. 5-Cyclohexyl-3-(4-methoxyphenyl)-2-phenyl-1-(toluene-4-sulfonyl)-1*H*-pyrrole (14)

To a stirred solution of 3-iodopyrrole **4b** (30.0 mg, 0.059 mmol) in toluene/MeOH (1/1, 2.0 mL) were added 4-methoxyphenylboronic acid (18.0 mg, 0.118 mmol), $Pd(PPh_3)_4$ (6.8 mg, 5.9 μmol), and Na_2CO_3 (18.8 mg, 0.177 mmol) at rt. After the stirring was continued for 60 min at 60 °C, the reaction mixture was filtered through a pad of Celite. Concentration at reduced pressure gave the residue, which was chromatographed on silica gel using hexane/AcOEt (85/15) as the eluent to give the coupled product **14** (22.0 mg, 76%) as a colorless oil; IR (neat) 3045, 2928, 2852, 1613, 1513 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.30–7.19 (5H, m), 7.13–7.07 (4H, m), 6.89 (2H, d, *J*=8.7 Hz), 6.64 (2H, d, *J*=8.7 Hz), 6.24 (1H, s), 3.70 (3H, s), 3.34 (1H, tt, *J*=11.2 and 2.9 Hz), 2.35 (3H, s), 2.14–2.18 (2H, m), 1.85–1.75 (3H, m), 1.52–1.19 (5H, m); ^{13}C NMR (400 MHz, $CDCl_3$): δ 158.0, 144.9, 144.1, 137.2, 132.4, 132.2, 131.3, 129.3, 129.1, 127.8, 127.4, 127.0, 126.9, 126.4, 113.4, 111.7, 55.1, 37.7, 34.8, 26.8, 26.4, 21.6; HRMS (ESI) *m*/*z* calcd for $C_{30}H_{31}NNaO_3S$ (M^++Na) 508.1922; found 508.1920.

4.6. 5-Cyclohexyl-2-phenyl-3-phenylethynyl-1-(toluene-4-sulfonyl)-1*H*-pyrrole (15)

To a stirred solution of 3-iodopyrrole **4b** (57.3 mg, 0.113 mmol) in Et_3N (3.8 mL) were added phenylacetylene (46.2 mg, 0.452 mmol), $PdCl_2(PPh_3)_2$ (7.9 mg, 0.011 mmol), and CuI (4.3 mg, 0.023 mmol) at rt. After the stirring was continued for 14 h at 60 °C, the reaction mixture was diluted with saturated aqueous solution of NH_4Cl and extracted with AcOEt. The combined extracts were washed with brine and the organic layer was dried over $MgSO_4$. Concentration at reduced pressure gave the residue, which was chromatographed on silica gel using hexane/AcOEt (90/10) as the eluent to give the coupled product **15** (38.0 mg, 70%) as a brown solid. Mp: 146.4–148.3 °C; IR (neat) 3061, 3032, 2928, 2853, 2213, 1597 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.44–7.35 (6H, m), 7.24–7.13 (8H, m), 6.19 (1H, s) 3.27 (1H, tt, *J*=11.5 and 2.8 Hz), 2.37 (3H, s), 2.07–2.11 (2H, m), 1.85–1.75 (3H, m), 1.51–1.18 (5H, m); ^{13}C NMR (400 MHz, $CDCl_3$): δ 145.6, 144.6, 140.5, 136.2, 131.6, 131.2, 131.2, 129.4, 128.2, 128.2, 127.9, 127.1, 126.4, 123.4, 113.5, 110.4, 91.3, 83.8, 37.8, 34.5, 26.7, 26.3, 21.6; HRMS (ESI) *m*/*z* calcd for $C_{31}H_{29}NNaO_2S$ (M^++Na) 502.1817; found 502.1815.

4.7. 1-Benzyl-5-cyclohexyl-3-(3-methoxy-phenyl)-2-propyl-1*H*-pyrrole (16)

To a stirred solution of 3-methoxybromobenzene (0.06 mL, 0.442 mmol) in THF (1.0 mL) was added dropwise *tert*-butyllithium (0.70 mL of a 1.32 M solution in pentane, 0.884 mmol) at −78 °C. Stirring was continued for 0.2 h at the same temperature, and anhydrous $ZnCl_2$ (60 mg, 0.442 mmol) was added to the reaction mixture and then the cold bath was removed. Whilst warming, 3-iodopyrrole **9a** (30.0 mg, 0.074 mmol) and $Pd(PPh_3)_4$ (8 mg, 0.007 mmol) were added to the reaction mixture, which was then stirred at rt for 0.5 h. The resulting mixture was filtered through a small amount of flash silica. Concentration at reduced pressure gave the residue, which was chromatographed on silica gel with hexane/AcOEt (98/2) as eluent to give the coupled product **16** (23.7 mg, 83%) as a yellow oil; IR (neat): 3062, 3028, 2927, 2852, 1605, 1515, 1495, 1453, 1411, 1353 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.31–7.21 (4H, m), 7.02–6.97 (2H, m), 6.89 (2H, d, *J*=7.6 Hz), 6.74 (1H, d, *J*=7.6 Hz), 6.09 (1H, s), 5.10 (2H, s), 3.83 (3H, s), 2.53–2.57 (2H, m), 2.30–2.36 (1H, m), 1.83–1.65 (5H, m), 1.53–1.21 (7H, m), 0.86 (3H, t, *J*=7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.5, 139.3, 139.2, 138.6, 129.0, 128.8, 128.6, 126.9, 125.5, 121.0, 120.3, 113.1, 110.6, 103.9, 55.1, 46.6, 35.8, 34.1, 27.4, 26.7, 26.1, 24.2, 14.2; HRMS (ESI): *m*/*z* calcd for $C_{27}H_{34}NO$ (M^++H): 388.2640; found 388.2644.

Acknowledgements

This study was supported in part by a Grant-in-Aid for the Encouragement of Young Scientists (B) from the Japan Society for the Promotion of Science (JSPS), the Takeda Science Foundation, the Uehara Memorial Foundation, and the Program for the Promotion of Basic and Applied Research for Innovations in the Bio-oriented Industry (BRAIN).

Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2011.03.015. These data include MOL files and InChiKeys of the most important compounds described in this article.

References and notes

1. (a) Fan, H.; Peng, J.; Hamann, M. T.; Hu, J.-F. *Chem. Rev.* **2008**, *108*, 264; (b) Bellina, F.; Rossi, R. *Tetrahedron* **2006**, *62*, 7213.
2. (a) Patterson, J. M. *Synthesis* **1976**, 281; (b) Lipshutz, B. H. *Chem. Rev.* **1986**, *86*, 795; (c) Schroeter, S.; Stock, C.; Bach, T. *Tetrahedron* **2005**, *61*, 2245.
3. (a) Trofimov, B. A.; Mikhaleva, A. I. *Heterocycles* **1994**, *37*, 1193; (b) Balme, G.; Bouyssi, D.; Monteiro, N. *Heterocycles* **2007**, *73*, 87; (c) Patil, N. T.; Yamamoto, Y. *ARKIVOC* **2007**, 121; (d) Schmuck, C.; Rupprecht, D. *Synthesis* **2007**, 3095; (e) Ono, N. *Heterocycles* **2008**, *75*, 243.
4. (a) Davies, P. W.; Martin, N. *Org. Lett.* **2009**, *11*, 2293; (b) Chen, D.-D.; Hou, X.-L.; Dai, L.-X. *Tetrahedron Lett.* **2009**, *50*, 6944; (c) Du, X.; Xie, X.; Liu, Y. *J. Org. Chem.* **2010**, *75*, 510.
5. Yoshida, M.; Al-Amin, M.; Shishido, K. *Synthesis* **2009**, 2454.
6. Yoshida, M.; Al-Amin, M.; Matsuda, K.; Shishido, K. *Tetrahedron Lett.* **2008**, *49*, 5021.
7. Preliminary studies have been published: Yoshida, M.; Al-Amin, M.; Shishido, K. *Tetrahedron Lett.* **2009**, *50*, 6268.
8. Li, A.-H.; Zhou, Y.-G.; Dai, L.-X.; Hou, X.-L.; Xia, L.-J.; Lin, L. *J. Org. Chem.* **1998**, *63*, 4338.
9. Blanc, A.; Tenbrink, K.; Weibel, J.-M.; Pale, P. *J. Org. Chem.* **2009**, *74*, 5342.
10. The structure of **10** was determined by comparison of the spectral data with our authentic sample, see Ref. 5.
11. For selected examples, see: (a) Flynn, B. L.; Verdier-Pinard, P.; Hamel, E. *Org. Lett.* **2001**, *3*, 651; (b) Huang, Q.; Hunter, J. A.; Larock, R. C. *Org. Lett.* **2001**, *3*, 2973; (c) Yue, D.; Larock, R. C. *J. Org. Chem.* **2002**, *67*, 1905; (d) Huang, Q.; Hunter, J. A.; Larock, R. C. *J. Org. Chem.* **2002**, *67*, 3437; (e) Arcadi, A.; Cacchi, S.; Giuseppe, S. D.; Fabrizi, G.; Marinelli, F. *Org. Lett.* **2002**, *4*, 2409; (f) Yao, T.; Larock, R. C. *J. Org. Chem.* **2003**, *68*, 5936; (g) Hessian, K. O.; Flynn, B. L. *Org. Lett.* **2003**, *5*, 4377; (h) Peng, A. Y.; Ding, Y. X. *Org. Lett.* **2004**, *6*, 1119; (i) Yao, T.; Campo, M. A.; Larock, R. C. *Org. Lett.* **2004**, *6*, 2677; (j) Yue, D.; Della, C. N.; Larock, R. C. *Org. Lett.* **2004**, *6*, 1581; (k) Yao, T.; Larock, R. C. *J. Org. Chem.* **2005**, *70*, 1432; (l) Barluenga, J.; Trincado, M.; Marco-Arias, M.; Ballesteros, A.; Rubio, E.; Gonzalez, J. M. *Chem. Commun.* **2005**, 2008; (m) Sniady, A.; Wheeler, K. A.; Dembinski, R. *Org. Lett.* **2005**, *7*, 1769; (n) Liu, Y.-H.; Song, F.-J.; Cong, L. Q. *J. Org. Chem.* **2005**, *70*, 6999; (o) Yue, D.; Yao, T.; Larock, R. C. *J. Org. Chem.* **2005**, *70*, 10292; (p) Bi, H.-P.; Guo, L.-N.; Duan, X.-H.; Gou, F.-R.; Huang, S.-H.; Liu, X.-Y.; Liang, Y.-M. *Org. Lett.* **2007**, *9*, 397; (q) Fischer, D.; Tomeba, H.; Pahadi, N. K.; Patil, N. T.; Yamamoto, Y. *Angew. Chem., Int. Ed.* **2007**, *46*, 4764; (r) Xie, Y.-X.; Liu, X.-Y.; Wu, L.-Y.; Han, Y.; Zhao, L.-B.; Fan, M.-J.; Liang, Y.-M. *Eur. J. Org. Chem.* **2008**, 1013; (s) Cherry, K.; Duchêne, A.; Thibonnet, J.; Parrain, J.-L.; Anselmi, E.; Abarbi, M. *Synthesis* **2009**, 257; (t) Ding, Q.; Chen, Z.; Yu, X.; Peng, Y.; Wu, J. *Tetrahedron Lett.* **2009**, *50*, 340.
12. It is known that Brønsted acid-catalyzed cycloisomerization of propargylic oxiranes occurs; see Ref. 5 and 6.
13. As another mechanism, the reaction was triggered by N-iodination and subsequent S_N2' ring opening of propargylic aziridine with the iodide ion. Then the resulting allene could be activated by additional iodine to form the dihydropyrrole, which would be converted to the 3-iodopyrrole by the aromatization along with the regeneration of iodine.