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# Synthesis of Polysubstituted Pyrroles *via* Tandem 1,3-Addition-5-*Endo*-Dig Cyclization of 1-(1-Alkynyl)Cyclopropyl Imines

Aurelija Urbanaitė,[a] Inga Čikotienė*[a]

**Abstract:** Reactions of cyclopropyl-tethered 3-alkynyl imines with polarized covalent bond containing compounds lead to formation of polyfunctionalized pyrroles. Particularly, this observation provides a mild and effective method for the simultaneous introduction of halogen, chalcogen or hydrogen groups onto 3rd position of the pyrrole ring together with incorporation of halogen, azido or alkoxy/aryloxy groups into side ethyl chain.

## Introduction

Pyrroles are important class of heterocycles with valuable chemical, biological and photophysical properties. This heterocycle presents in a number of natural compounds[1], synthetic bioactive molecules[2] and scaffolds for material science.[3] Although a wide variation of classical[4] or more modern transition metal-mediated[5] pyrrole synthetic methods presents in the literature, the development of new synthetic methods of polyfunctionalized pyrroles is highly desirable. Cyclopropyl-tethered functionalized alkynes can be useful synthones for preparation of five-membered heteroaromatic compounds. Thus, 1-arylalkynylcyclopropyl carbaldehydes or ketones were recently introduced as suitable starting materials for the preparation of various furans. These compounds, due to their unique structure and reactivity serve as all carbon 1,4-carbon dipoles,[6] therefore can undergo gold catalyzed reactions with nucleophiles,[7] [4+2][6,8b] or [4+3][8] cycloadditions, rhodium catalyzed carbonylative reactions[9] and copper (II) halide mediated cyclization[10] (Scheme 1). 1-Cyclopropylalkynylimines or oximes are not used so often, however there are some reports in the literature about their transition-mediated transformations to pyrroles.[11] Electrophile-assisted cyclizations of cyclopropyl-tethered alkynylketones to the corresponding furanes have been proposed by Huang et al some time ago and to the best of our knowledges, this is the only example of this type of ring closure of 1-(1-alkynyl)-cyclopropyl ketones.[12]

It is noteworthy, that electrophile-assisted cyclizations have their scope and some benefits in organic synthesis, because these methods do not require transition-metal catalysis and the final products contain halogen, chalcogen or alkoxyarylmethyl functional groups suitable for further functionalizations.[13] In continuation of our recent studies in the field of electrophile-mediated transformations of functionally substituted alkynes,[14] we decided to prepare some cyclopropyl-tethered imines and to evaluate their reactivity towards electrophilic reagents. However, the obtained results showed a unique reactivity of 1-alkynylcyclopropyl imines towards covalent polar bonds containing molecules and this process cannot be classified as electrophile-assisted transformations. Herein we present the results of our investigations.

## Results and Discussion

The starting 1-arylalkynylcyclopropyl carbaldehydes **1** were prepared by the known methods.[11a] With prepared starting aldehydes in hands, for the synthesis of the desired starting imines, we tried to utilize the classical reaction with primary amines. Thus, 1-((4-methoxyphenyl)ethynyl)-cyclopropanecarbaldehyde **1a** and benzylamine was chosen for the synthesis of cyclopropyl-tethered 3-alkynyl imine **3a**. However no TLC-detectable product was formed during heating of aldehyde with amine in dichloromethane in the presence of magnesium sulfate in sealed tube.[11a] So therefore we decided to utilize microwave assisted synthesis for smoother formation of imine functionality. After irradiation of solution of starting aldehyde and benzylamine in 1,2-dichloroethane in the presence of activated 3Å molecular sieves at 120 °C, a spot of new product together with spot of unreacted starting material were detected on TLC. Longer irradiation of the reaction mixture did not improve the conversion. After preparative column chromatography 57 % of the starting aldehyde **1a** was recovered and product **2a** was isolated in 29 % yield. To our deep surprise, after structural analysis of product we elucidated that it was 1-benzyl-4-(2-chloroethyl)-2-(4-methoxyphenyl)-*1H*-pyrrole **2a**, instead of desired imine **3a** (Scheme 2).

We presumed that hydrogen chloride presenting as impurity in the solvent reacted with *in situ* formed imine. This reaction could lead to tandem proton-assisted cyclization to 5-membered heterocyclic ring and chloride-mediated cyclopropane ring opening. Heating of solution of 1-((4-methoxyphenyl)ethynyl)cyclopropanecarbaldehyde **1a** and benzylamine in saturated hydrogen chloride solution in dichloroethane, resulted in higher yield (72%) of compound **2a**. Next, we changed the solvent to non-acidic acetonitrile and monitored the formation of imine by $^1$H NMR spectroscopy. We noticed, that imine functional group formed successfully after 20 min heating of reaction solutions at 120 °C in microwave oven. For the full conversion of the aldehyde, two equivalents of amines were required. However, the purification of the desired imine by column chromatography led to full product hydrolysis to the starting aldehyde.

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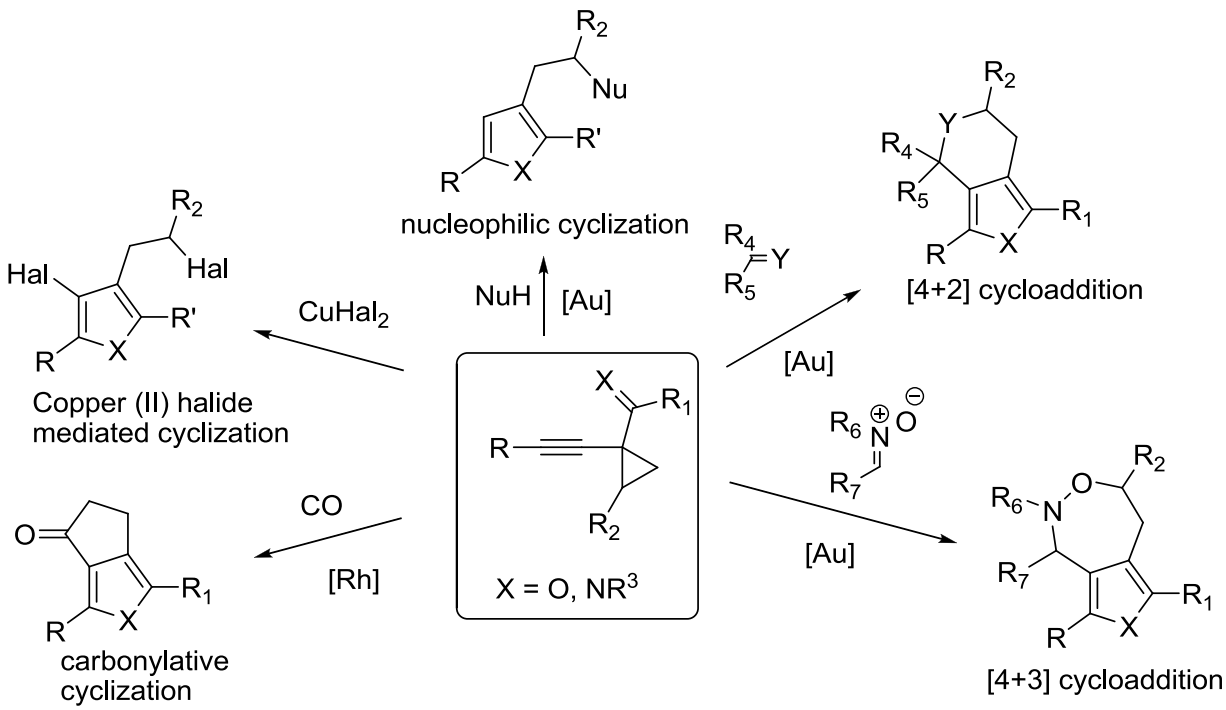
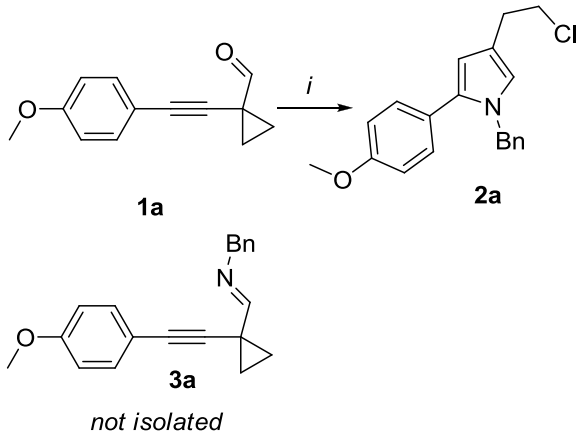



**Scheme 1.** Transition metal catalyzed reactions of cyclopropyl-tethered functionalized alkynes.

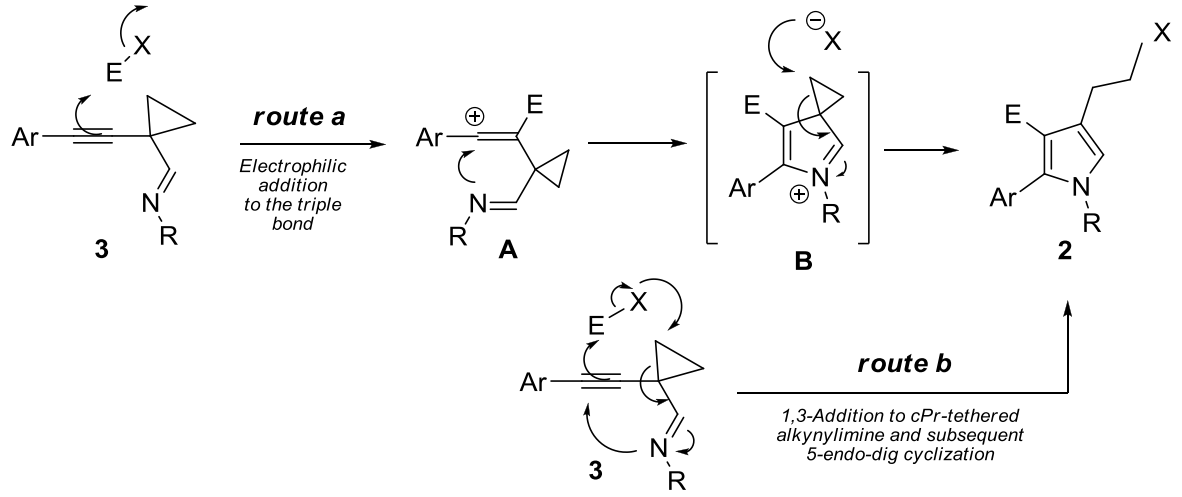



**Scheme 2.** Reaction between 1-((4-methoxyphenyl)ethynyl)-cyclopropanecarbaldehyde **1a** and benzylamine in dichloroethane. i: 1.1 eq. of benzylamine, 1,2-dichloroethane, 3Å MS, MW, 120 $^{o}$C, 15 min.

So we decided to prepare cyclopropyl tethered alkynyl imines *in situ* just before addition of electrophilic reagent. First of all, we tried to perform iodo-cyclization of intermediate imine. After heating of starting aldehyde **1a** with excess of *tert*-butylamine in acetonitrile for 20 min at 120 $^{o}$C in microwave oven, the obtained solution was cooled to room temperature and molecular iodine was added. A very quick consumption of the starting material was observed by TLC, showing formation of one product in 5 minutes. Spectroscopic analysis together with HRMS data of isolated compound proved the structure of 1-*tert*-butyl-3-iodo-4-(2-iodoethyl)-2-(4-methoxyphenyl)-*1H*-pyrrole (**2b**) (Table 1, entry 1). Iodocyclizations/cyclopropane ring cleavage reactions underwent very smoothly with other substrates, resulting in formation of di-iodo derivatives **2c-h** in good yields (Table 1, entries 6 - 13). For preparation of polysubstituted pyrroles containing different functional groups on pyrrole ring and ethyl chain, we turned our attention to unsymmetric covalent bond containing reagents. Thus, using of iodine monochloride resulted in formation of 2-aryl-4-(2-chloroethyl)-3-iodo-*1H*-pyrroles (**2i – k**) (Table 1, entries 14 - 16), phenylselenyl chloride gave the corresponding 2-aryl-4-(2-chloroethyl)-3-(phenylselanyl)-*1H*-pyrroles (**2l,m**) (Table 1, entries 15,17). Reactions between intermediate imines and freshly prepared iodine azide or acetyl hipoiodite resulted in the formation of the corresponding 2-aryl-4-(2-azidooethyl)-3-iodo-*1H*-pyrroles (**2l,m**) and 2-aryl-4-(2-chloroethyl)-3-(phenylselanyl)-*1H*-pyrroles (**2n,o**) and 2-(5-aryl-4-iodo-*1H*-pyrrol-3-yl)ethyl acetates (**2p, 4**) (Table 1, entries 18 – 20). And finally, we were pleasantly surprised to see that when solutions of the starting aldehydes **1** and amines were irradiated in microwave oven in the presence of alcohols or phenol, the selective formation of *N*-substituted 4-(2-alkoxyethyl)-2-aryl-*1H*-pyrroles (**2r,t,u**) and 1-*tert*-butyl-4-(2-phenoxyethyl)-2-phenyl-*1H*-pyrrole (**2s**) took place (Table 1, entries 21, 23-25).

From the obtained results the following mechanism could be proposed: after the addition of electrophile to the triple bond and formation of vinylic carbocation **A**, the subsequent nucleophilic

*anti*-attack of imine nitrogen occurs resulting in formation of intermediate **B** (Scheme 3, route a). The analogous scenario was proposed by Huang et al for the synthesis of functionalized furanes.[12] However, the introduction of an excess of some external nucleophiles (indole, piperidine, methanol, sodium azide or potassium iodide) to reaction mixtures (Table 1, entries 2 – 5, 16, 22), did not result in logical incorporation of the nucleophilic fragment in ethyl chain of final products. In all cases diiodo compound **2b** (entries 2- 5), chloroethyl group containing compound **2l** (entry 16) and methoxyethyl group containing compound **2r** (entry 22) were isolated as sole reaction products. Moreover, the rate of the cyclization reaction did not depend on the presence or absence of strong electron donating methoxy group on the benzene ring, as it usually observed in reactions proceeding *via* vinylic carbocations.[14b,c,15] These observations gave support to route b (Scheme 3). Thus, we believe this reaction is promoted by formal 1,3-addition reaction of polar covalent bond containing reagent to $C_{sp}$-*c*-Pr fragment, allowing the consequent 5-*endo*-dig cyclization to the final pyrroles **2** (Scheme 3, route b).




**Scheme 3.** Reaction between 1-((4-methoxyphenyl)ethynyl)-cyclopropanecarbaldehyde **1a** and benzylamine in dichloroethane. i: 1.1 eq. of benzylamine, 1,2-dichloroethane, 3Å MS, MW, 120 °C, 15 min.

**Table 1.** Data on the synthesis of polysubstituted pyrroles **2**.

| Entry | Starting aldehyde **1** | Amine $RNH_2$ | E-X | Additive (3 equiv) | Reaction conditions[a] | Product **2** (yield, %) |
|---|---|---|---|---|---|---|
| 1 | **1a**: Ar = 4-$MeOC_6H_4$- | R = *t*Bu | $I_2$ | - | Method A | **2b** (81); E = X = I |
| 2 | **1a** | R = *t*Bu | $I_2$ | Indole | Method A | **2b** (56) |
| 3 | **1a** | R = *t*Bu | $I_2$ | Piperidine | Method A | **2b** (59) |
| 4 | **1a** | R = *t*Bu | $I_2$ | $CH_3OH$ | Method A | **2b** (16) |
| 5 | **1a** | R = *t*Bu | $I_2$ | $NaN_3$ | Method A | **2b** (76) |
| 6 | **1a** | R = Bn | $I_2$ | - | Method A | **2c** (78); E = X = I |
| 7 | **1b**: Ar = Ph | R = *t*Bu | $I_2$ | - | Method A | **2d** (57); E = X = I |
| 8 | **1b** | R = Bu | $I_2$ | - | Method A | **2e** (46); E = X = I |
| 9 | **1c**: Ar = 4-$MeC_6H_4$- | R = *t*Bu | $I_2$ | - | Method A | **2f** (58); E = X = I |
| 10 | **1c** | R = Bn | $I_2$ | - | Method A | **2g** (59); E = X = I |
| 11 | **1c** | R = *c*Hex | $I_2$ | - | Method A | **2h** (64); E = X = I |
| 12 | **1b** | R = *t*Bu | ICl | - | Method B | **2i** (52); E = I; X = Cl |
| 13 | **1c** | R = *c*Hex | ICl | - | Method B | **2j** (95); E = I; X = Cl |

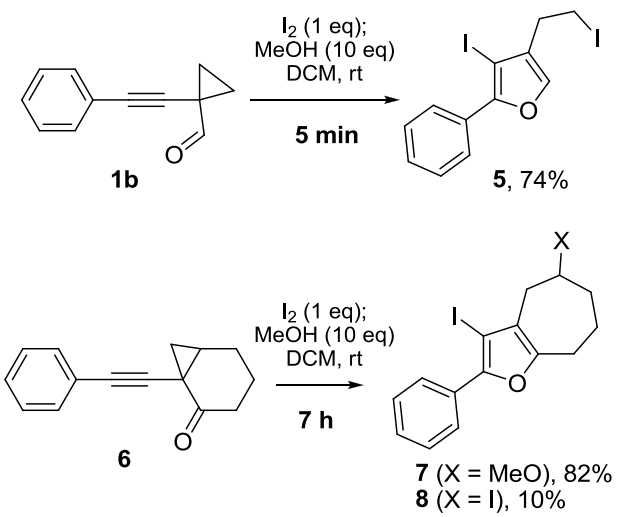
| | | | | | | |
|---|---|---|---|---|---|---|
| 14 | **1c** | R = *i*Pr | ICl | - | Method B | **2k** (55); E = I; X = Cl |
| 15 | **1b** | R = *t*Bu | PhSeCl | - | Method B | **2l** (53); E = PhSe; X = Cl |
| 16 | **1b** | R = *t*Bu | PhSeCl | KI | Method B | **2l** (48) |
| 17 | **1c** | R = *t*Bu | PhSeCl | - | Method B | **2m** (65); E = PhSe; X = Cl |
| 18 | **1b** | R = *c*Hex | $IN_3$ | - | Method B | **2n** (56); E = I; X = $N_3$ |
| 19 | **1c** | R = *t*Bu | $IN_3$ | - | Method B | **2o** (76); E = I; X = $N_3$ |
| 20 | **1b** | R = *t*Bu | IOAc | - | Method C | **2p** (21); E = I; X = OAc[b] |
| 21 | **1a** | R = Bn | $HOCH_3$ | - | Method D | **2r** (49); E = H; X = $OCH_3$ |
| 22 | **1a** | R = Bn | $HOCH_3$ | KI | Method D | **2r** (47); E = H; X = $OCH_3$ |
| 23 | **1b** | R = *t*Bu | HOPh | - | Method D | **2s** (56); E = H; X = OPh |
| 24 | **1c** | R = *t*Bu | $HOC_3H_7$ | - | Method D | **2t** (63); E = H; X = $OC_3H_7$ |
| 25 | **1c** | R = *c*Hex | $HOCH_3$ | - | Method D | **2u** (70); E = H; X = $OCH_3$ |

[a] Method A. The starting aldehyde, 2 eq. of the corresponding amine, acetonitrile, 3Å MS, MW, 120 $^{o}$C, 20 min; then addition of molecular iodine (1 equiv) at rt. Method B. The starting aldehyde, 2 eq. of the corresponding amine, acetonitrile, 3Å MS, MW, 120 $^{o}$C, 20 min; then evaporation of the solvent and excess of amine, resolving in fresh acetonitrile and addition of the corresponding reagent. Method C. The starting aldehyde, 2 eq. of the corresponding amine, acetonitrile, 3Å MS, MW, 120 $^{o}$C, 20 min; then evaporation of the solvent and excess of amine, resolving in fresh chloroform (2 mL) and addition of the resulting mixture to a solution of freshly prepared acetyl hypoiodite (2 eq.) in chloroform (1 mL). Method D. The starting aldehyde, 2 eq. of the corresponding amine, the corresponding alcohol (2 mL), 3Å MS, MW, 120 oC, 50 min. [b] Additional product 2-(1-tert-butyl-2,4-diiodo-5-phenyl-1H-pyrrol-3-yl)ethyl acetate (**4**) was isolated in 19% yield.

Moreover, we performed additional control experiments including cyclization of starting 1-(phenylethynyl)cyclopropanecarbaldehyde **1b** and Huang's 1-(phenylethynyl)bicyclo[4.1.0]heptan-2-one **6**[12] (Scheme 4). When compound **1b** was stirred in methanol-dichloromethane mixture in the presence of an equivalent of molecular iodine, a very smooth (5 min) and selective formation of 3-iodo-4-(2-iodoethyl)-2-phenylfuran **5** took place without any incorporation of methoxy group from methanol in the structure of the product. In contrast, Huang's ketone **6** at the same conditions reacted more slowly (7 h) and two products were isolated after the work-up of reaction mixture. The main product, as it was showed by Huang et al[12] was 3-iodo-5-methoxy-2-phenyl-5,6,7,8-tetrahydro-4*H*-cyclohepta[*b*]furan **7** and the minor one contained iodo group on the cycloheptane ring. Differences in rates as well as in the outcome of reactions indicate that cyclizations of cyclopropyl-tethered functionalized alkynes can udergo *via* different mechanisms. Unsubstituted cyclopropyl tether favors the formal 1,3-addition process and smooth subsequent cyclization, while the presence of bulky cyclohexane ring next to cyclopropyl tether gives precedent to the classical electrophile-assisted cyclization with incorporation of external nucleophiles. Unfortunately, theHuang's ketone did not form any imine under the standard conditions, so we were not able to synthesize derivatives of 5,6,7,8-tetrahydro-4*H*-cyclohepta[*b*]pyrrole.

## Conclusions

In summary it was shown that 1-(1-alkynyl)cyclopropyl imines are able to react with polarized covalent bond containing compounds and these reactions lead to a variety of polysubstituted pyrroles. Particularly, this observation provides a mild and effective method for the simultaneous introduction of halogen, chalcogen or hydrogen groups onto 3$^{rd}$ position of the pyrrole ring together with incorporation of halogen, azido or alkoxy/aryloxy groups into side ethyl chain. This unique reactivity of cyclopropyl-tethered functionalized alkynes towards covalent polar bonds containing molecules point toward a broad and divergent synthetic applicability of analogous substrates.




**Scheme 4.** Control experiments with 1-arylalkynylcyclopropyl carbaldehyde **1b** and Huang's ketone **6**.

## Experimental Section

**General information**. IR spectra were run in KBr discs on a Perkin-Elmer FT spectrophotometer Spectrum BX II. $^{1}$H and $^{13}$C NMR spectra were recorded with a Brucker (400 MHz) or Varian Unity INOVA (300 MHz) spectrometers in chloroform-d, using residual solvent signal as internal standard. Signal multiplicity as follows: s (singlet), d (doublet), t (triplet), q (quartet), quint (quintet), m (multiplet). HRMS spectra were obtained on a mass spectrometer Dual-ESI Q-TOF 6520 (Agilent Technologies). All reactions and the purity of the synthesized compounds monitored by TLC using Silica gel 60 F254 aluminium plates (Merck). Visualization was accomplished by UV light and by treating the plates with vanillin stain followed by heating.

**General procedures for the synthesis of polysubstituted pyrroles 2**

*Method A.* A solution of corresponding cyclopropanecarbaldehyde **1** (0.5 mmol) and amine (1 mmol.) in acetonitrile (2 mL) was irradiated in closed vessel in scientific microwave oven (CEM Focused Microwave™ Synthesis System, Discover® SP) at 150 W, 120 °C for 20 min. Then the reaction mixture was cooled to room temperature and molecular iodine (0.127 g, 0.5 mmol) was added. The resulting solution was stirred at room temperature and the progress of reaction was monitored by TLC. After all starting material was consumed, the solvent was evaporated under reduced pressure. The residue was purified by flash column chromatography eluting with hexane/ethyl acetate (20 : 1) mixture.

*Method B.* A solution of corresponding cyclopropanecarbaldehyde **1** (0.5 mmol) and amine (1 mmol) in acetonitrile (2 mL) was irradiated in closed vessel in scientific microwave oven (CEM Focused Microwave™ Synthesis System, Discover® SP) at 150 W, 120 °C for 20 min. Then the solvent and the amine were evaporated under reduced pressure. The residue was dissolved in acetonitrile (2 mL) and the iodine monochloride (81.25 mg, 0.5 mmol), phenyl hypochloroselenoite (95.5 mg, 0.5 mmol) or solution of freshly prepared hypoiodyl azide[16] (1 mmol) was added. The resulting solution was stirred at room temperature and was monitored by TLC. After all starting material was consumed, the solvent was evaporated under reduced pressure. The residue was purified by flash column chromatography eluting with hexane - ethyl acetate (20 :1) mixture.

*Method C*. Synthesis of 2-(1-*tert*-butyl-4-iodo-5-phenyl-1H-pyrrol-3-yl)ethyl acetate (**2p**) and 2-(1-tert-butyl-2,4-diiodo-5-phenyl-1H-pyrrol-3-yl)ethyl acetate (**4**). A solution of 1-(phenylethynyl) cyclopropanecarbaldehyde (**1b**) (67 mg, 0.4 mmol) and *tert*-butylamine (1 mL, 9.5 mmol, 24 eq.) in acetonitrile (2 mL) was irradiated in closed vessel in scientific microwave oven (CEM Focused Microwave™ Synthesis System, Discover® SP) at 150 W, 120 °C for 20 min. Then the solvent and the *tert*-butylamine were evaporated under reduced pressure. The residue was dissolved in chloroform (2 mL) and added to a solution of freshly prepared solution of acetyl hypoiodite[17] (2 eq.) in chloroform (1 mL). The resulting mixture was stirred in the dark at room temperature for 20 min. After reaction was finished, the solution was diluted with DCM and was washed with saturated sodium thiosulfate solution (2 x 10 mL), saturated sodium bicarbonate solution (2 x 10 mL) and brine (2 x 10 mL). The organic layer was dried over sodium sulfate, filtered and evaporated under reduced pressure. The residue was purified by flash column chromatography eluting with hexane - ethyl acetate (20 - 1) mixture.

*Method D.* A solution of corresponding cyclopropanecarbaldehyde **1** (0.5 mmol) and amine (1 mmol) in appropriate alcohol (2 mL) was irradiated in closed vessel in scientific microwave oven (CEM Focused Microwave™ Synthesis System, Discover® SP) at 100 – 150 W, 100 – 120 °C for 50 min. After all starting material was consumed; the solvent was evaporated under reduced pressure. The residue was purified by flash column chromatography eluting with hexane - ethyl acetate (20 : 1) mixture.

**1-Benzyl-4-(2-chloroethyl)-2-(4-methoxyphenyl)-1*H*-pyrrole (2a)**

Yellowish oil. Yield 47.1 mg, 29 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 2.99 (2H, t, $^{3}J$ = 7.6 Hz, $CH_2$), 3.72 (2H, t, $^{3}J$ = 7.6 Hz, $CH_2Cl$), 3.83 (3H, s, $OCH_3$), 5.09 (2H, s, $C\underline{H}_2Ph$), 6.13 (1H, s, $CH_{pyrrole}$), 6.60 (1H, br.s, $NCH_{pyrrole}$), 6.90 (2H, d, $^{3}J$ = 8.8 Hz, ArH), 7.05 (2H, d, $^{3}J$ = 7.2 Hz, ArH), 7.26 (2H, d, $^{3}J$ = 8.4 Hz, ArH), 7.28 – 7.35 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 31.0 ($CH_2$), 45.3 ($CH_2Cl$), 50.4 ($\underline{C}H_2Ph$), 55.2 ($OCH_3$), 108.5 ($CH_{pyrrole}$), 113.8 (ArC), 120.0 (ArC), 120.3 ($NCH_{pyrrole}$), 125.5 (ArC), 126.4 (ArC), 127.2 (ArC), 128.6 (ArC), 130.0 (ArC), 134.8 (ArC), 138.8 (ArC), 158.8 (ArC) ppm HRMS (ESI): M+H, found 326.1306. $C_{20}H_{21}{}^{35}ClNO$ requires 326.1306.

**1-*Tert*-butyl-3-iodo-4-(2-iodoethyl)-2-(4-methoxyphenyl)-1*H*-pyrrole (2b)**

White solid, m.p. 129 – 130 °C. Yield 0.206 g, 81 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 1.38 (9H, s, $3xCH_3$), 3.01 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.33 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 3.87 (3H, s, $OCH_3$), 6.87 (1H, s, $CH_{pyrrole}$), 6.94 (2H, d, $^{3}J$ = 8.0 Hz, ArH), 7.19 (2H, d, $^{3}J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.1 ($CH_2I$), 31.5 ($3xCH_3$), 33.6 ($CH_2$), 55.2 ($OCH_3$), 58.0 ($C(CH_3)_3$), 72.5 (CI), 113.2 (ArC), 117.1 ($CH_{pyrrole}$), 122.8 (ArC), 128.3 (ArC), 133.6 (ArC), 135.0 (ArC), 159.4 (ArC) ppm. HRMS (ESI): M+H, found 509.9787. $C_{17}H_{22}{}^{127}I_2NO$ requires 509.9785.

**1-Benzyl-3-iodo-4-(2-iodoethyl)-2-(4-methoxyphenyl)-1*H*-pyrrole (2c)**

Yellowish oil. Yield 0.211 g, 78 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 3.02 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.34 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 3.83 (3H, s, $OCH_3$), 4.97 (2H, s, $C\underline{H}_2Ph$), 6.69 (1H, s, $CH_{pyrrole}$), 6.91 (2H, d, $^{3}J$ = 8.0 Hz, ArH), 6.95 (2H, d, $^{3}J$ = 8.0 Hz, ArH), 7.19 (2H, d, $^{3}J$ = 8.0 Hz, ArH), 7.23 – 7.30 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.2 ($CH_2I$), 33.3 ($CH_2$), 51.7 ($\underline{C}H_2Ph$), 55.2 ($OCH_3$), 67.5 (CI), 113.7 (ArC), 120.0 ($CH_{pyrrole}$), 124.3 (ArC), 125.0 (ArC), 126.6 (ArC), 127.5 (ArC), 128.6 (ArC), 132.1 (ArC), 135.8 (ArC), 138.0 (ArC), 159.5 (ArC) ppm. HRMS (ESI): M+H, found 543.9636. $C_{20}H_{20}I_2NO$ requires 543.9634.

**1-*Tert*-butyl-3-iodo-4-(2-iodoethyl)-2-phenyl-1*H*-pyrrole (2d)**

White solid, m.p. 100 – 101 °C. 0.137 g, Yield 57 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 1.39 (9H, s, $3xCH_3$), 3.02 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.34 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 6.88 (1H, s, $CH_{pyrrole}$), 7.28 – 7.30 (2H, m, ArH), 7.41 – 7.42 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.1 ($CH_2I$), 31.5 ($3xCH_3$), 33.6 ($CH_2$), 58.2 ($C(CH_3)_3$), 71.9 (CI), 117.2 ($CH_{pyrrole}$), 123.0 (ArC), 127.8 (ArC), 128.3 (ArC), 132.5 (ArC), 135.2 (ArC), 136.4 (ArC) ppm. HRMS (ESI): M+H, found 479.9683. $C_{16}H_{20}{}^{127}I_2N$ requires 479.9680.

**1-Butyl-3-iodo-4-(2-iodoethyl)-2-phenyl-1*H*-pyrrole (2e)**

Colorless oil. Yield 0.11 g, 46 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 0.79 (3H, t, $^{3}J$ = 7.6 Hz, $CH_3$), 1.15 (2H, sexst, $^{3}J$ = 7.6 Hz, $CH_{2n\text{-}Bu}$), 1.52 (2H, p, $^{3}J$ = 7.6 Hz, $CH_{2n\text{-}Bu}$), 3.02 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.34 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 3.78 (2H, t, $^{3}J$ = 7.2 Hz, $CH_{2n\text{-}Bu}$), 6.72 (1H, s, $CH_{pyrrole}$), 7.32 – 7.34 (2H, m, ArH), 7.34 – 7.46 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.2 ($CH_2I$), 13.5 ($CH_3$), 19.6 ($CH_{2n\text{-}Bu}$), 33.3 ($CH_2$), 33.4 ($CH_{2n\text{-}Bu}$), 48.0 ($CH_{2chex}$), 66.8 (CI), 119.6 ($CH_{pyrrole}$), 124.7 (ArC), 128.1 (ArC), 128.3 (ArC), 130.8 (ArC), 132.5 (ArC), 135.4 (ArC) ppm. HRMS (ESI): M+H, found 479.9689. $C_{16}H_{20}I_2N$ requires 479.9685.

**1-*Tert*-butyl-3-iodo-4-(2-iodoethyl)-2-*p*-tolyl-1*H*-pyrrole (2f)**

White solid, m.p. 129 – 130 °C. Yield 0.143 g, 58 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 1.38 (9H, s, $3xCH_3$), 2.42 (3H, s, $CH_3$), 3.01 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.33 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 6.86 (1H, s, $CH_{pyrrole}$), 7.16 (2H, d, $^{3}J$ = 8.0 Hz, ArH), 7.22 (2H, d, $^{3}J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.1 ($CH_2I$), 21.4 ($CH_3$), 31.5 ($3xCH_3$), 33.6 ($CH_2$), 58.1 ($C(CH_3)_3$), 72.0 (CI), 117.1 ($CH_{pyrrole}$), 122.9 (ArC), 128.6 (ArC), 132.3 (ArC), 133.3 (ArC), 135.3 (ArC), 138.1 (ArC) ppm. HRMS (ESI): M+H, found 493.9841. $C_{17}H_{22}I_2N$ requires 493.9836.

**1-Benzyl-3-iodo-4-(2-iodoethyl)-2-*p*-tolyl-1*H*-pyrrole (2g)**

Colorless oil. Yield 0.155 g, 59 %

$^{1}$H NMR (400 MHz, $CDCl_3$) δ: 2.39 (3H, s, $CH_3$), 3.03 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2$), 3.35 (2H, t, $^{3}J$ = 8.0 Hz, $CH_2I$), 4.98 (2H, s, $C\underline{H}_2Ph$), 6.69 (1H, s, $CH_{pyrrole}$), 6.97 (2H, d, $^{3}J$ = 6.4 Hz, ArH), 7.16 – 7.21 (4H, m, ArH), 7.25 – 7.30 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.1 ($CH_2I$), 21.3 ($CH_3$), 33.3 ($CH_2$), 51.7 ($\underline{C}H_2Ph$), 67.3 (CI), 120.0 ($CH_{pyrrole}$), 125.2 (ArC),

126.7 (ArC), 127.5 (ArC), 128.6 (ArC), 129.0 (2xArC), 130.7 (ArC), 136.0 (ArC), 137.9 (ArC), 138.1 (ArC) ppm. HRMS (ESI): M+H, found 527.9689. $C_{20}H_{20}{}^{127}I_2N$ requires 527.9685.

**1-Cyclohexyl-3-iodo-4-(2-iodoethyl)-2-*p*-tolyl-1*H*-pyrrole (2h)**

Colorless oil. Yield 0.166 g, 64 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.14 – 1.18 (2H, m, $CH_{2chex}$), 1.52 – 1.65 (4H, m, $CH_{2chex}$), 1.78 – 1.80 (2H, m, $CH_{2chex}$), 1.91 (2H, d, $^2J$ = 12.0 Hz, $CH_{2chex}$), 2.43 (3H, s, $CH_3$), 3.03 (2H, t, $^3J$ = 8.0 Hz, $CH_2$), 3.34 (2H, t, $^3J$ = 8.0 Hz, $CH_2I$), 3.78 (1H, tt, $^3J$ = 12.0 Hz, $^3J$ = 3.6 Hz, $CH_{chex}$), 6.79 (1H, s, $CH_{pyrrole}$), 7.20 (2H, d, $^3J$ = 8.0 Hz, ArH), 7.26 (2H, d, $^3J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 6.1 ($CH_2I$), 21.4 ($CH_3$), 25.3 ($CH_{2chex}$), 25.7 ($CH_{2chex}$), 33.6 ($CH_2$), 34.6 ($CH_{2chex}$), 56.5 ($CH_{chex}$), 66.5 (CI), 115.8 ($CH_{pyrrole}$), 124.6 (ArC), 129.0 (ArC), 129.6 (ArC), 130.7 (ArC), 134.8 (ArC), 137.8 (ArC) ppm. HRMS (ESI): M+H, found 519.9987. $C_{19}H_{24}{}^{127}I_2N$ requires 519.9993.

**1-*Tert*-butyl-4-(2-chloroethyl)-3-iodo-2-phenyl-1*H*-pyrrole (2i)**

Brownish solid, m.p. 147 – 148 °C. Yield 0.101 g, 52 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.38 (9H, s, 3x$CH_3$), 2.91 (2H, t, $^3J$ = 8.0 Hz, $CH_2$), 3.69 (2H, t, $^3J$ = 8.0 Hz, $CH_2Cl$), 6.88 (1H, s, $CH_{pyrrole}$), 7.27 – 7.30 (2H, m, ArH), 7.41 – 7.42 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 31.5 (3x$CH_3$), 32.3 ($CH_2$), 44.3 ($CH_2Cl$), 58.2 ($C(CH_3)_3$), 72.4 (CI), 117.6 ($CH_{pyrrole}$), 120.0 (ArC), 127.8 (ArC), 128.3 (ArC), 132.5 (ArC), 135.2 (ArC), 136.5 (ArC) ppm. HRMS (ESI): M+H, found 388.0328. $C_{16}H_{20}{}^{35}Cl^{127}IN$ requires 388.0323.

**4-(2-Chloroethyl)-1-cyclohexyl-3-iodo-2-*p*-tolyl-1*H*-pyrrole (2j)**

White solid, m.p. 118 – 119 °C. Yield 0.203 g, 95 %

$^1$H NMR (400 MHz, $CDCl_3$) 1.16 – 1.18 (2H, m, $CH_{2chex}$), 1.52 – 1.65 (4H, m, $CH_{2chex}$), 1.78 – 1.79 (2H, m, $CH_{2chex}$), 1.91 (2H, d, $^2J$ = 12.0 Hz, $CH_{2chex}$), 2.43 (3H, s, $CH_3$), 2.93 (2H, t, $^3J$ = 7.6 Hz, $CH_2$), 3.69 (2H, t, $^3J$ = 7.6 Hz, $CH_2Cl$), 3.78 (1H, tt, $^3J$ = 12.0 Hz, $^3J$ = 3.6 Hz, $CH_{chex}$), 6.79 (1H, s, $CH_{pyrrole}$), 7.20 (2H, d, $^3J$ = 8.0 Hz, ArH), 7.26 (2H, d, $^3J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.4 ($CH_3$), 25.3 ($CH_{2chex}$), 25.7 ($CH_{2chex}$), 32.4 ($CH_2$), 34.6 ($CH_{2chex}$), 44.3 ($CH_2Cl$), 56.5 ($CH_{chex}$), 66.9 (CI), 116.2 ($CH_{pyrrole}$), 121.6 (ArC), 129.1 (ArC), 129.6 (ArC), 130.7 (ArC), 134.8 (ArC), 137.9 (ArC) ppm. HRMS (ESI): M+H, found 428.0641. $C_{19}H_{24}ClIN$ requires 428.0642.

**4-(2-Chloroethyl)-3-iodo-1-isopropyl-2-*p*-tolyl-1*H*-pyrrole (2k)**

White solid, m.p. 121 – 122 °C. Yield 0.106 g, 55 %

$^1$H NMR (400 MHz, $CDCl_3$) 1.30 (6H, d, $^3J$ = 6.8 Hz, $CH_{3i\text{-}Pr}$), 2.42 (3H, s, $CH_3$), 2.93 (2H, t, $^3J$ = 7.6 Hz, $CH_2$), 3.69 (2H, t, $^3J$ = 8.0 Hz, $CH_2Cl$), 4.23 (1H, sept, $^3J$ = 6.8 Hz, $CH_{i\text{-}Pr}$), 6.79 (1H, s, $CH_{pyrrole}$), 7.20 (2H, d, $^3J$ = 8.0 Hz, ArH), 7.26 (2H, d, $^3J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.3 ($CH_3$), 23.8 ($CH_{3i\text{-}Pr}$), 32.4 ($CH_2$), 44.3 ($CH_2Cl$), 48.6 ($CH_{i\text{-}Pr}$), 67.0 (CI), 115.3 ($CH_{pyrrole}$), 122.0 (ArC), 129.1 (ArC), 129.7 (ArC), 130.8 (ArC), 134.9 (ArC), 138.0 (ArC) ppm. HRMS (ESI): M+H, found 388.0326. $C_{16}H_{20}{}^{35}ClIN$ requires 388.0323.

**1-*Tert*-butyl-4-(2-chloroethyl)-2-phenyl-3-(phenylselanyl)-1*H*-pyrrole (2l)**

White solid, m.p. 122 – 123 °C. Yield 0.111 g, 53 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.44 (9H, s, 3x$CH_3$), 2.95 (2H, t, $^3J$ = 7.6 Hz, $CH_2$), 3.60 (2H, t, $^3J$ = 7.6 Hz, $CH_2Cl$), 6.97 (1H, s, $CH_{pyrrole}$), 7.06 – 7.10 (3H, m, ArH), 7.12 – 7.16 (2H, m, ArH), 7.20 – 7.23 (2H, m, ArH), 7.27 – 7.29 (2H, m, ArH), 7.34 (1H, t, $^3J$ = 7.2 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 30.7 ($CH_2$), 31.7 (3x$CH_3$), 45.0 ($CH_2Cl$), 58.0 ($C(CH_3)_3$), 106.8 (ArC), 117.9 ($CH_{pyrrole}$), 121.4 (ArC), 125.0 (ArC), 127.3 (ArC), 128.0 (ArC), 128.1 (ArC), 128.7 (ArC), 132.1 (ArC), 135.3 (ArC), 135.7 (ArC), 139.1 (ArC) ppm. HRMS (ESI): M+H, found 418.0830. $C_{22}H_{25}{}^{35}ClNSe$ requires 418.0834.

**1-*Tert*-butyl-3-iodo-4-(2-iodoethyl)-2-*p*-tolyl-1*H*-pyrrole (2m)**

White solid, m.p. 137 – 138 °C. Yield 0.14 g, 65 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.44 (9H, s, 3x$CH_3$), 2.37 (3H, s, $CH_3$), 2.94 (2H, t, $^3J$ = 7.6 Hz, $CH_2$), 3.58 (2H, t, $^3J$ = 7.6 Hz, $CH_2Cl$), 6.96 (1H, s, $CH_{pyrrole}$), 7.07 – 7.09 (3H, m, ArH), 7.10 (4H, br.s, ArH), 7.13 – 7.16 (2H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.3 ($CH_3$), 30.7 ($CH_2$), 31.7 (3x$CH_3$), 45.0 ($CH_2Cl$), 57.9 ($C(CH_3)_3$), 106.7 (ArC), 117.8 ($CH_{pyrrole}$), 121.3 (ArC), 125.0 (ArC), 128.1 (ArC), 128.7 (ArC), 131.9 (ArC), 132.6 (ArC), 135.3 (ArC), 137.7 (ArC), 139.2 (ArC) ppm. HRMS (ESI): M+H, found 432.0982. $C_{23}H_{27}{}^{35}ClNSe$ requires 432.0990.

**4-(2-Azidoethyl)-1-cyclohexyl-3-iodo-2-phenyl-1*H*-pyrrole (2n)**

Yellowish oil. Yield 0.118 g, 56 %

R (KBr): $\upsilon_{max}$ = 2098 ($N{=}N^+{=}N^-$) $cm^{-1}$.

$^1$H NMR (400 MHz, $CDCl_3$) 1.16 – 1.20 (2H, m, $CH_{2chex}$), 1.53 – 1.64 (4H, m, $CH_{2chex}$), 1.78 – 1.80 (2H, m, $CH_{2chex}$), 1.92 (2H, d, $^2J$ = 12.4 Hz, $CH_{2chex}$), 2.77 (2H, t, $^3J$ = 7.2 Hz, $CH_2$), 3.47 (2H, t, $^3J$ = 7.2 Hz, $CH_2N_3$), 3.77 (1H, tt, $^3J$ = 12.0 Hz, $^3J$ = 3.6 Hz, $CH_{chex}$), 6.80 (1H, s, $CH_{pyrrole}$), 7.31 – 7.35 (2H, m, ArH), 7.39 – 7.49 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 25.2 ($CH_{2chex}$), 25.7 ($CH_{2chex}$), 28.4 ($CH_2$), 34.6 ($CH_{2chex}$), 51.4 ($CH_2N_3$), 56.6 ($CH_{chex}$), 67.1 (CI), 116.3 ($CH_{pyrrole}$), 121.3 (ArC), 128.1 (ArC), 128.3 (ArC), 130.9 (ArC), 132.7 (ArC), 134.9 (ArC) ppm. HRMS (ESI): M+H, found 421.0901. $C_{18}H_{22}{}^{127}IN_4$ requires 421.0884.

**4-(2-Azidoethyl)-1-*tert*-butyl-3-iodo-2-*p*-tolyl-1*H*-pyrrole (2o)**

Yellowish solid, m.p. 92 – 93 °C. Yield 0.155 g, 76 %

IR (KBr): $\upsilon_{max}$ = 2096 ($N{=}N^+{=}N^-$) $cm^{-1}$.

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.39 (9H, s, 3x$CH_3$), 2.42 (3H, s, $CH_3$), 2.75 (2H, t, $^3J$ = 7.2 Hz, $CH_2$), 3.46 (2H, t, $^3J$ = 7.2 Hz, $CH_2N_3$), 6.87 (1H, s, $CH_{pyrrole}$), 7.17 (2H, d, $^3J$ = 8.0 Hz, ArH), 7.22 (2H, d, $^3J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.4 ($CH_3$), 28.4 ($CH_2$), 31.5 (3x$CH_3$), 51.4 ($CH_2N_3$), 58.1 ($C(CH_3)_3$), 72.5 (CI), 117.5 ($CH_{pyrrole}$), 119.4 (ArC), 128.6 (ArC), 132.3 (ArC), 133.4 (ArC), 135.4 (ArC), 138.1 (ArC) ppm. HRMS (ESI): M+H, found 409.0890. $C_{17}H_{22}N_4I$ requires 409.0884.

**2-(1-*tert*-butyl-4-iodo-5-phenyl-1*H*-pyrrol-3-yl)ethyl acetate (2p)**

Yellow oil. Yield 43.2 mg, 21 %

IR (KBr): $\upsilon_{max}$ = 1738 (C=O) $cm^{-1}$.

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.37 (9H, s, 3x$CH_3$), 2.09 ($COCH_3$), 2.77 (2H, t, $^3J$ = 7.6 Hz, $CH_2CH_2O$), 4.25 (2H, t, $^3J$ = 7.6 Hz, $CH_2CH_2O$), 6.83 (1H, s, $CH_{pyrrole}$), 7.27 – 7.29 (2H, m, ArH), 7.40 – 7.41 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.1 ($COCH_3$), 28.0 ($CH_2CH_2O$), 31.6 (3x$CH_3$), 58.1 ($C(CH_3)_3$), 64.4 ($CH_2CH_2O$), 72.9 (CI), 117.2 ($CH_{pyrrole}$), 119.4 (ArC), 127.8 (ArC), 128.3 (ArC), 132.6 (ArC), 135.1 (ArC), 136.6 (ArC), 171.1 (CO) ppm. HRMS (ESI): M+H, found 412.0771. $C_{18}H_{23}{}^{127}INO_2$ requires 412.0768.

**1-Benzyl-4-(2-methoxyethyl)-2-(4-methoxyphenyl)-1*H*-pyrrole (2r)**

Yellowish wax. Yield 78.6 mg, 49 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 2.81 (2H, t, $^3J$ = 7.2 Hz, $CH_2CH_2OCH_3$), 3.41 (3H, s, $CH_2CH_2OCH_3$), 3.63 (2H, t, $^3J$ = 7.2 Hz, $CH_2CH_2OCH_3$), 3.81 (3H, s, $OCH_3$), 5.06 (2H, s, $CH_2Ph$), 6.12 (1H, d, $^4J$ = 1.2 Hz, $CH_{pyrrole}$), 6.57 (1H, br.s, $NCH_{pyrrole}$), 6.87 (2H, d, $^3J$ = 8.4 Hz, ArH), 7.05 (2H, d, $^3J$ = 7.6 Hz, ArH), 7.24 – 7.33 (5H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 27.5 ($CH_2CH_2OCH_3$), 50.3 ($CH_2Ph$), 55.1 ($OCH_3$), 58.5 ($CH_2CH_2OCH_3$), 73.7 ($CH_2CH_2OCH_3$), 108.7 ($CH_{pyrrole}$), 113.7 (ArC), 120.1 ($NCH_{pyrrole}$), 120.4 (ArC), 125.8 (ArC), 126.4 (ArC), 127.1 (ArC), 128.5 (ArC), 130.0 (ArC), 134.5 (ArC), 139.0 (ArC), 158.6 (ArC) ppm. HRMS (ESI): M+H, found 322.1804. $C_{21}H_{24}NO_2$ requires 322.1802.

**1-*Tert*-butyl-4-(2-phenoxyethyl)-2-phenyl-1*H*-pyrrole (2s)**

White solid, m.p. 72 – 73 °C. Yield 89.3 mg, 56 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.47 (9H, s, 3x$CH_3$), 3.04 (2H, t, $^3J$ = 7.4 Hz, $CH_2CH_2OPh$), 3.04 (2H, t, $^3J$ = 7.5 Hz, $CH_2CH_2OPh$), 6.01 (1H, d, $^4J$ = 1.9 Hz, $CH_{pyrrole}$), 6.84 (1H, d, $^4J$ = 1.8 Hz, $NCH_{pyrrole}$), 6.97 – 7.01 (3H, m, ArH), 7.32 – 7.36 (2H, m, ArH), 7.38 – 7.39 (3H, m, ArH), 7.45 – 7.47 (2H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 27.2 ($CH_2CH_2OPh$), 31.9 (3x$CH_3$), 56.9 ($C(CH_3)_3$), 68.8 ($CH_2CH_2OPh$), 112.2 ($CH_{pyrrole}$), 114.5 (ArC), 116.8 (ArC), 117.0 ($NCH_{pyrrole}$), 120.4 (ArC), 127.3 (ArC), 127.4 (ArC), 129.3 (ArC), 131.6 (ArC), 133.8 (ArC), 137.3 (ArC), 159.0 (ArC) ppm. HRMS (ESI): M+H, found 320.2011. $C_{22}H_{25}NO$ requires 320.2014.

**1-*Tert*-butyl-4-(2-propoxyethyl)-2-*p*-tolyl-1*H*-pyrrole (2t)**

Yellowish oil. Yield 94.2 mg, 63 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 0.94 (3H, t, $^3J$ = 7.6 Hz, $OCH_2CH_2C\underline{H}_3$), 1.41 (9H, s, 3x$CH_3$), 1.63 (2H, sext, $^3J$ = 7.2 Hz, $OCH_2C\underline{H}_2CH_3$), 2.39 (3H, s, $CH_3$), 2.77 (2H, t, $^3J$ = 7.6 Hz, $C\underline{H}_2CH_2O$), 3.44 (2H, t, $^3J$ = 6.8 Hz, $OC\underline{H}_2CH_2CH_3$), 3.64 (2H, t, $^3J$ = 7.6 Hz, $CH_2C\underline{H}_2O$), 5.87 (1H, d, $^4J$ = 2.0 Hz, $C\underline{H}_{pyrrole}$), 6.72 (1H, d, $^3J$ = 2.0 Hz, $NCH_{pyrrole}$), 7.14 (2H, d, $^3J$ = 7.6 Hz, ArH), 7.27 (2H, d, $^3J$ = 8.0 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 10.6 ($OCH_2CH_2\underline{C}H_3$), 21.2 ($CH_3$), 22.9 ($OCH_2\underline{C}H_2CH_3$), 27.6 ($\underline{C}H_2CH_2O$), 31.9 (3x$CH_3$), 56.8 ($C(CH_3)_3$), 71.9 ($CH_2\underline{C}H_2O$), 72.5 ($O\underline{C}H_2CH_2CH_3$), 112.2 ($CH_{pyrrole}$), 116.6 ($NCH_{pyrrole}$), 117.5 (ArC), 128.0 (ArC), 131.5 (ArC), 133.6 (ArC), 134.5 (ArC), 137.0 (ArC) ppm. HRMS (ESI): M+H, found 300.2320. $C_{20}H_{30}NO$ requires 300.2322.

**1-Cyclohexyl-4-(2-methoxyethyl)-2-*p*-tolyl-1*H*-pyrrole (2u)**

Yellowish oil. Yield 0.104 g, 70 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.19 – 1.27 (2H, m, $CH_{2chex}$), 1.60 – 1.70 (4H, m, $CH_{2chex}$), 1.83 (2H, d, $^2J$ = 12.8 Hz, $CH_{2chex}$), 2.00 (2H, d, $^2J$ = 12.8 Hz, $CH_{2chex}$), 2.41 (3H, s, $CH_3$), 2.81 (2H, t, $^3J$ = 7.2 Hz, $C\underline{H}_2CH_2O$), 3.41 (3H, s, $OCH_3$), 3.63 (2H, t, $^3J$ = 7.2 Hz, $CH_2C\underline{H}_2O$), 3.98 (1H, tt, $^3J$ = 12.0 Hz, $^3J$ = 3.6 Hz, $CH_{chex}$), 6.00 (1H, d, $^4J$ = 1.6 Hz, $CH_{pyrrole}$), 6.70 (1H, br.s, $NCH_{pyrrole}$), 7.21 (2H, d, $^3J$ = 8.4 Hz, ArH), 7.25 (2H, d, $^3J$ = 7.6 Hz, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.1 ($CH_3$), 25.4 ($CH_{2chex}$), 25.9 ($CH_{2chex}$), 27.6 ($\underline{C}H_2CH_2O$), 34.9 ($CH_{2chex}$), 55.0 ($CH_{chex}$), 58.5 ($OCH_3$), 73.8 ($CH_2\underline{C}H_2O$), 108.3 ($CH_{pyrrole}$), 115.8 ($NCH_{pyrrole}$), 119.6 (ArC), 128.9 (ArC), 129.0 (ArC), 131.0 (ArC), 133.6 (ArC), 136.3 (ArC) ppm. HRMS (ESI): M+H, found 298.2162. $C_{20}H_{28}NO$ requires 298.2165.

**2-(1-*Tert*-butyl-2,4-diiodo-5-phenyl-1*H*-pyrrol-3-yl)ethyl acetate (4)**

Yellow oil. Yield 51 mg, 19 %

IR (KBr): $\upsilon_{max}$ = 1739 (C=O) $cm^{-1}$.

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.57 (9H, s, 3x$CH_3$), 2.09 ($COC\underline{H}_3$), 2.92 (2H, t, $^3J$ = 7.6 Hz, $C\underline{H}_2CH_2O$), 4.17 (2H, t, $^3J$ = 7.6 Hz, $CH_2C\underline{H}_2O$), 7.19 – 7.22 (2H, m, ArH), 7.36 – 7.38 (3H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 21.2 ($CO\underline{C}H_3$), 31.5 ($\underline{C}H_2CH_2O$), 33.2 (3x$CH_3$), 62.1 ($C(CH_3)_3$), 63.3 ($CH_2\underline{C}H_2O$), 67.2 (CI), 73.3 (CI), 127.9 (ArC), 128.2 (2xArC), 131.6 (ArC), 138.8 (ArC), 140.4 (ArC), 171.0 (CO) ppm. HRMS (ESI): M+H, found 537.9745. $C_{18}H_{22}{}^{127}I_2NO_2$ requires 537.9734.

**General procedure for the synthesis of furanes 5, 7 and 8.**

A solution of corresponding 1-(phenylethynyl)cyclopropanecarbaldehyde **1b** (85 mg, 0.5 mmol) or 1-(phenylethynyl)bicyclo[4.1.0]heptan-2-one **6** (105 mg, 0.5 mmol) in dichloromethane (2 mL) methanol (0.202 mL, 5 mmol) and molecular iodine (0.127 g, 0.5 mmol) were added. The resulting solution was stirred at room temperature and the progress of reaction was monitored by TLC. After all starting material was consumed, the solvent was evaporated under reduced pressure. The residue was purified by flash column chromatography eluting with hexane/ethyl acetate (20 : 1) mixture.

**3-Iodo-4-(2-iodoethyl)-2-phenylfuran (5)**

Yellow oil. Yield 0.157 g, 74 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 3.00 (2H, t, $^3J$ = 7.5 Hz, $CH_2$), 3.36 (2H, t, $^3J$ = 7.5 Hz, $CH_2I$), 7.36 (1H, tt, $^3J$ = 7.2 Hz, $^4J$ = 2.0 Hz, ArH), 7.42 – 7.46 (3H, m, ArH and $CH_{furan}$), 7.96 – 7.99 (2H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 3.6 ($CH_2I$), 31.0 ($CH_2$), 66.5 (CI), 126.3 (ArC), 128.3 (ArC), 128.4 (ArC), 128.6 (ArC), 130.1 (ArC), 139.0 ($CH_{furan}$), 152.2 (ArC) ppm. HRMS (ESI): M+H, found 424.8902. $C_{12}H_{11}{}^{127}I_2O$ requires 424.8899.

**3-Iodo-5-methoxy-2-phenyl-5,6,7,8-tetrahydro-4*H*-cyclohepta[*b*]furan (7)**

Colorless oil. Yield 0.151 g, 82 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.59 – 1.68 (1H, m, $CH_2CH(OCH_3)CH_2C\underline{H}HCH_2$), 1.75 – 1.83 (1H, m, $CH_2CH(OCH_3)C\underline{H}H(CH_2)_2$), 1.94 – 2.03 (1H, m, $CH_2CH(OCH_3)CH_2C\underline{H}HCH_2$), 2.14 – 2.19 (1H, m, $CH_2CH(OCH_3)CH\underline{H}(CH_2)_2$), 2.55 (1H, dd, $^2J$ = 15.3 Hz, $^3J$ = 9.2 Hz, $C\underline{H}H_2CH(OCH_3)(CH_2)_3$), 2.74 – 2.81 (1H, m, $CH_2CH(OCH_3)(CH_2)_2C\underline{H}H$), 2.84 – 2.90 (2H, m, $CH\underline{H}CH(OCH_3)(CH_2)_2CH\underline{H}$), 3.35 (1H, tt, $^3J$ = 9.0 Hz, $^3J$ = 2.8 Hz, $CH_2C\underline{H}(OCH_3)(CH_2)_3$), 3.41 (3H, s, $OCH_3$), 7.30 (1H, t, $^3J$ = 7.4 Hz, ArH), 7.40 (2H, t, $^3J$ = 7.6 Hz, ArH), 7.93 – 7.95 (2H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 22.3 ($CH_2CH(OCH_3)CH_2\underline{C}H_2CH_2$), 28.3 ($CH_2CH(OCH_3)CH_2CH_2\underline{C}H_2$), 31.9 ($\underline{C}H_2CH(OCH_3)(CH_2)_3$), 35.5 ($CH_2CH(OCH_3)\underline{C}H_2(CH_2)_2$), 56.3 ($OCH_3$), 70.5 (CI), 78.9 ($CH_2\underline{C}H(OCH_3)(CH_2)_3$), 119.7 (ArC), 125.9 (ArC), 127.6 (ArC), 128.3 (ArC), 130.6 (ArC), 148.7 (ArC), 152.7 (ArC) ppm. HRMS (ESI): M+H, found 369.0358. $C_{16}H_{18}{}^{127}I_2O$ requires 369.0351.

**3-Iodo-4-(2-iodoethyl)-2-phenylfuran (8)**

White solid, m.p. 97 – 99 °C. Yield 23.2 mg, 10 %

$^1$H NMR (400 MHz, $CDCl_3$) δ: 1.67 – 1.77 (1H, m, $CH_2CHICH_2C\underline{H}_2CH_2$), 1.84 – 1.93 (1H, m, $CH_2CHICH_2C\underline{H}_2CH_2$), 2.30 – 2.39 (1H, m, $CH_2CHIC\underline{H}_2(CH_2)_2$), 2.41 – 2.48 (1H, m, $CH_2CHIC\underline{H}_2(CH_2)_2$), 2.79 – 2.91 (1H, m, $CH_2CHIC\underline{H}_2(CH_2)_2$), 3.13 (1H, dd, $^2J$ = 15.8 Hz, $^3J$ = 9.0 Hz, $C\underline{H}_2CHI(CH_2)_3$), 3.22 (1H, dd, $^2J$ = 15.8 Hz, $^3J$ = 3.2 Hz, $C\underline{H}_2CHI(CH_2)_3$), 4.54 (2H, tt, $^3J$ = 9.0 Hz, $^3J$ = 3.0 Hz, $CH_2C\underline{H}I(CH_2)_3$), 7.31 (1H, t, $^3J$ = 7.4 Hz, ArH), 7.41 (2H, t, $^3J$ = 7.6 Hz, ArH), 7.95 – 7.97 (2H, m, ArH) ppm. $^{13}$C NMR (100 MHz, $CDCl_3$) δ: 26.5 ($CH_2CHICH_2\underline{C}H_2CH_2$), 28.2 ($CH_2CHI(CH_2)_2\underline{C}H_2$), 31.0 ($CH_2\underline{C}HI(CH_2)_3$), 39.5 ($C\underline{H}_2CHI(CH_2)_3$), 43.2 ($CH_2CHI\underline{C}H_2(CH_2)_2$), 69.4 (CI), 123.7 (ArC), 125.9 (ArC), 127.7 (ArC), 128.3 (ArC), 130.4 (ArC), 148.6 (ArC), 153.2 (ArC) ppm. HRMS (ESI): M+H, found 464.9214. $C_{15}H_{15}{}^{127}I_2O$ requires 464.9212.

**Keywords:** pyrrole • cyclization • cyclopropyl-tethered • alkynylimines • 5-*endo*-dig

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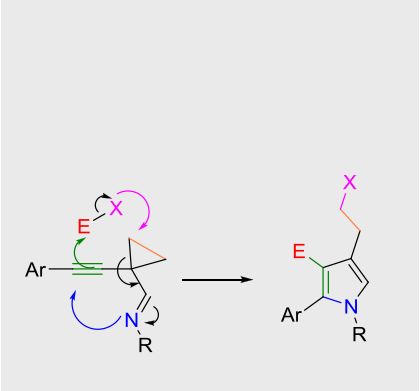


**Synthetic methods**

*Aurelija Urbanaitė, Inga Čikotienė**

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**Synthesis of Polysubstituted Pyrroles *via* Tandem 1,3-Addition -5-*Endo*-Dig Cyclisation of 1-(1-Alkynyl)-Cyclopropyl Imines**