Tetrahedron 66 (2010) 6040–6046

Contents lists available at ScienceDirect

Tetrahedron

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

Synthesis of 1*H*-pyrrolo[3,2-*c*]quinoline derivatives via palladium-catalyzed heteroannulation of 2-aryl-3-iodo-4-(phenylamino)quinolines and 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinolines

Malose J. Mphahlele *, Lehlohonolo G. Lesenyeho, Hlamulo R. Makelane

Department of Chemistry, College of Science, Engineering and Technology, University of South Africa, PO Box 392, Pretoria 0003, South Africa

ARTICLE INFO

Article history:
Received 9 February 2010
Received in revised form 20 May 2010
Accepted 7 June 2010
Available online 12 June 2010

Keywords:
2-Aryl-3-iodo-4-(phenylamino)quinolines
4-(*N*,*N*-Allylphenylamino)-2-aryl-3-iodoquinolines
Sonogashira reaction
Intramolecular Heck reaction
1*H*-Pyrrolo[3,2-*c*]quinolines

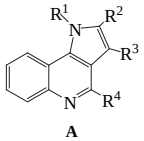
ABSTRACT

Palladium(0)/copper iodide catalyzed Sonogashira cross-coupling of 2-aryl-3-iodo-4-(phenylamino) quinolines with terminal alkynes afforded series of 1,2,4-trisubstituted 1*H*-pyrrolo[3,2-*c*]quinolines in a single-step operation. Conversely, the 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinoline derivatives were found to undergo $PdCl_2(PPh_3)_2$/CuI catalyzed intramolecular Heck reaction to yield the corresponding 1,3,4-trisubstituted 1*H*-pyrrolo[3,2-*c*]quinolines.

1. Introduction

Polynuclear heterocycles derived from quinolines represent an important class of compounds and have attracted a great deal of attention in recent years because of their wide range of pharmacological properties.[1] During our research on the development of polysubstituted quinolines,[2,3,4] we became interested in the synthesis of annulated quinoline derivatives based on the framework of 1*H*-pyrrolo[3,2-*c*]quinolines **A** (Fig. 1). This moiety forms the core structural unit of a number of biologically interesting compounds, such as gastric acid secretion inhibitors[1,5] and antitumour agents.[6] Iodofunctionalized organic molecules have established themselves as versatile intermediates in synthetic organic chemistry based on the ability of iodo substituents to facilitate carbon–carbon bond formation and metal exchange.[7] The Sonogashira reaction, which involves palladium catalyzed coupling of terminal acetylenes with aryl or heteroaryl halides has become an important tool for C–C bond formation reaction.[8] The experimental simplicity, high product yields and tolerance to a broad range of functional groups have made this reaction one of the most convenient and versatile methods for the synthesis of alkynylquinolines,[9] which are important precursors for the synthesis of polysubstituted quinolines.[10,11] Palladium acetate-catalyzed heteroannulation of 4-arylamino-3-iodoquinolines with internal alkynes in the presence of potassium acetate (2 equiv) and lithium chloride (1 equiv) in refluxing dimethylformamide (DMF) previously afforded 2-substituted 1-*H*-pyrrolo [3,2-*c*]quinoline derivatives.[10] Dichlorobis(triphenylphosphine)palladium(II) ($PdCl_2(PPh_3)_2$)/copper iodide (CuI) catalyzed Sonogashira reaction of 3-iodo-2-methyl-4-quinolinylamine with 1-hexyne in the presence of triethylamine in THF at room temperature followed by cyclization of the resulting 3-(1-hexynyl)-2-methyl-4-quinolinylamine using KH in refluxing *N*-methylpyrrolidinone (NMP) afforded 2-butyl-4-methyl-1*H*-pyrrolo[3,2-*c*]quinoline **A** ($R_{1,3}$=H, R_2=Bu, R_4=Me).[11] Series of 1,4-disubstituted pyrrolo[3,2-*c*]quinolines were also recently prepared in 52–94% yield via iron-catalyzed cross-coupling of 4-chloropyrrolo[3,2-*c*]quinoline with alkyl and aryl magnesium halides in a tetrahydrofuran (THF)/NMP mixture.[12]

Although several methods have been described in literature for the synthesis of pyrrolo[3,2-*c*]quinolines, corresponding data for the



A

Figure 1. Generalized structure of polysubstituted 1*H*-pyrrano[3,2-*c*]quinolines.

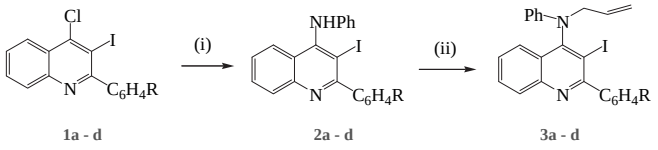
* Corresponding author. Tel.: +27 12 429 8805; fax: +27 12 429 8549; e-mail address: mphahmj@unisa.ac.za (M.J. Mphahlele).

0040-4020/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2010.06.018

synthesis of fully aromatized pyrrolo[3,2-*c*]quinoline derivatives is considerably less well documented.[5,10–12] Prompted by the scant attention paid in literature to the synthesis of polysubstituted 1*H*-pyrrolo[3,2-*c*]quinolines, we decided to investigate the possibility of direct one-pot synthesis of 1,2,3-trisubstituted 1*H*-pyrrolo[3,2-*c*]quinolines from 2-aryl-3-iodo-4-(*N*-phenylamino)quinolines using terminal alkynes as model for C–C bond formation. Moreover, the synthesis of 1,3,4-trisubstituted 1*H*-pyrrolo[3,2-*c*]quinolines using 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinolines derived from 2-aryl-3-iodo-4-(*N*-phenylamino)quinolines was also investigated.

2. Results and discussion

Our strategy for exploration of the structural features necessary for the synthesis of polysubstituted and annulated quinoline derivatives with potential biological activity consists of targeting 2-aryl-4-chloro-3-iodoquinolines as precursors. This approach takes advantage of the ease of displacement of the 4-chloro atom by nucleophiles and the potential for iodine to facilitate metal-catalyzed C–C bond formation and metal exchange reactions. In this investigation, we first subjected the previously described 2-aryl-4-chloro-3-iodoquinolines **1**[4] to aminobenzene (aniline) in refluxing ethanol and isolated the corresponding hitherto unknown 2-aryl-3-iodo-4-(phenylamino) quinolines **2** in good yields (Scheme 1). Whereas allylation of (4-arylamino)-3-iodoquinolines is reported to be complicated by quartenarization,[10] we were able to effect selective 4-*N* allylation of 2-aryl-4-(arylamino)-3-iodoquinolines **2** using allyl bromide in the presence of sodium hydride in DMF to afford previously undescribed 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinolines **3a**–**d** with no traces of the quartenarization products (Scheme 1).



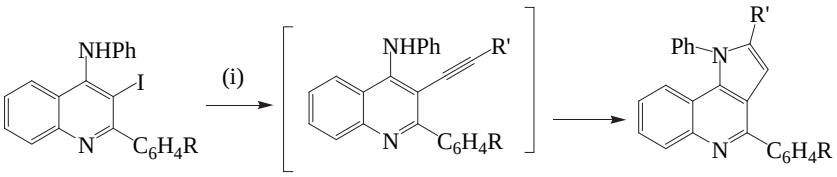
1a - d **2a - d** **3a - d**

	4-R	% Yield of 2	% Yield of 3
a	H	86	68
b	F	78	85
c	Cl	93	80
d	OCH_3	95	60

Scheme 1. Reagents (i) NH_2Ph, EtOH, heat, 18 h; (ii) $CH_2{=}CHCH_2Br$, NaH, DMF, room temperature, 12 h.

With the 2-aryl-3-iodo-4-(phenylamino)quinolines **2** and their 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinoline derivatives **3** in hands, we explored their reactivity towards palladium-catalyzed reactions. Accordingly, systems **2** were first exposed to $PdCl_2(PPh_3)_2$/CuI catalyzed Sonagashira cross-coupling with phenylacetylene in THF or DMF at room temperature in the presence of triethylamine for 24 h, but we isolated the starting material unchanged. Complete conversion of **2** to 1,2,4-trisubstituted 1*H*-pyrrolo[3,2-*c*]quinoline derivatives **5** was however observed by thin layer chromatography (TLC) within 3 h when the reaction mixture was performed in DMF at 120 °C. We were concerned about the low yields (<40%), which are presumably due to some decomposition as observed by TLC of the reaction mixtures and the crude products. After some experimentation we found the use of dioxane/water (3:1, v/v) as solvent mixture at 80 °C afforded products **5** within 4 h with no traces of decomposed products (Scheme 2). The reaction in dioxane/water mixture also proceeded well with 3-butyn-2-ol and trimethylsilylacetylene.

Participation of copper(I) salts in the intramolecular cyclization of the appropriately functionalized internal alkynes generated in situ has been documented well in the literature.[13–16] Mechanistically, the present one-pot coupling/cyclization process seems to proceed through initial Pd(0) catalyzed coupling of **2** with copper(I) acetylide generated in situ from terminal alkyne to afford the

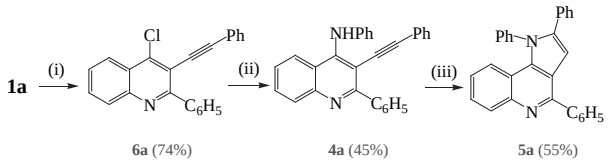


2a - d **4a - f** **5a - f**

	4-R	R'	% Yield
5a	H	$-C_6H_5$	58
5b	F	$-C_6H_5$	53
5c	Cl	$-C_6H_5$	65
5d	OCH_3	$-C_6H_5$	63
5e	H	$-CH(OH)CH_3$	62
5f	Cl	$-CH(OH)CH_3$	59
5g	OMe	$-CH(OH)CH_3$	61
5h	H	$-Si(CH_3)_3$	75
5i	F	$-Si(CH_3)_3$	65
5j	OMe	$-Si(CH_3)_3$	72

Scheme 2. Reagents (i) R′C≡CH, $PdCl_2(PPh_3)_2$, CuI, NEt_3, dioxane/water (3:1, v/v), 80 °C, 4 h.

incipient 2-aryl-3-(alkyl/arylethynyl)quinoline **4**. We strongly believe that nucleophilic attack on the triple bond by the amino group affords the annulated derivative **5**. To ascertain the involvement of intermediates **4** in the proposed mechanism, we subjected **1a** to Sonogashira cross-coupling with phenylacetylene to afford 4-chloro-2-phenyl-3-(phenylethynyl)quinoline **6a**, which was in turn, reacted with aniline in refluxing ethanol to yield 2-phenyl-4-(phenylamino)-3-(phenylethynyl)quinoline **4a** (Scheme 3). The latter was subjected to similar reaction conditions applied to **2** above to afford **5a**, thus confirming the involvement of the incipient intermediate **4** in the proposed mechanism. To our knowledge, the direct one-pot conversion of **2** to **5** described herein represents the first example of the synthesis of 1,2,4-trisubstituted 1-*H*-pyrrolo[3,2-*c*]quinolines of potential biological application. Such derivatives do not feature at all in a comprehensive review on synthetic approaches to various azoloquinoline derivatives.[1]



Scheme 3. Reagents (i) PhC≡CH, $PdCl_2(PPh_3)_2$, CuI, NEt_3; (ii) NH_2Ph, EtOH, heat, 18 h; (iii) $PdCl_2(PPh_3)_2$, CuI, NEt_3, dioxane/water (3:1, v/v), heat, 12 h.

Palladium-catalyzed intramolecular cyclization of nitrogen-containing *ortho*-iodoaryl alkenes to indoles, indolines, oxindoles, quinolines, isoquinolines and isoquinolones has been well investigated by Larock's group.[17] A one-pot palladium acetate/Xphos catalyzed N-alkylation/Heck cyclization of 2-chloroanilines recently yielded series of substituted indoles.[18] The tandem Heck coupling/isomerisation of iodinated *N*-allyl pyridines and pyrimidines with 5% palladium acetate and triethylamine in toluene to afford indole derivatives have also been described.[19] Our interest in the synthesis of polysubstituted 1-*H*-pyrrolo[3,2-*c*]quinolines prompted us to also investigate the possibility of palladium catalyzed intramolecular cyclization of the 4-(*N*,*N*-allylphenylamino)-3-iodoquinolines **3**. Previous attempts to synthesize 3-substituted 1-arylpyrrolo[3,2-*c*]quinolines via intramolecular Heck reaction of 4-allylarylamino-3-iodoquinolines led to low yields of the desired products with limited functional group tolerance.[6] Recourse to literature revealed one example involving palladium catalyzed cyclization of 4-allylamino-3-iodoquinoline to afford 6-methoxy-3-methyl-1-(2-methylphenyl)-1*H*-pyrrolo[3,2-*c*]quinoline, however, the generality of this method was not demonstrated.[20] With these considerations in mind, we subjected systems **3** to $PdCl_2(PPh_3)_2$/CuI catalytic system in DMF at 80 °C and we isolated 1,4-diaryl-3-methylpyrrolo[3,2-*c*]quinolines **7a**–**d** (Scheme 4).

Although intramolecular aryl–aryl bond formation of appropriately activated diarylamines to form carbazole moiety is well precedented,[21,22] systems **3** were found to undergo palladium-catalyzed intramolecular Heck reaction with complete selectivity over possible competitive intramolecular aryl–aryl coupling.

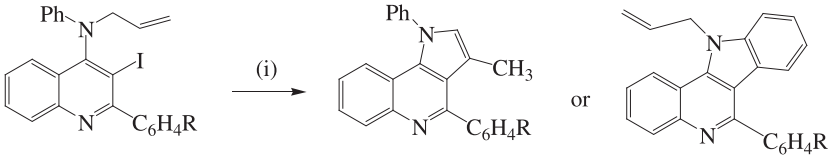
3. Conclusions

Sequential functionalization of 2-aryl-4-chloro-3-iodoquinolines via nucleophilic displacement of 4-chloro atom with aniline and *N*-4 allylation of the resulting 2-aryl-3-iodo-4-(phenylamino)quinolines yielded the corresponding 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinolines. The 2-aryl-3-iodo-4-(phenylamino)quinolines participated well in Pd-mediated C–C bond forming reactions providing an array of appropriately functionalized 1,2,4-trisubstituted pyrrolo[3,2-*c*]quinolines **5** in a one-pot operation. Moreover, the 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinoline derivatives afforded the 1,3,4-trisubstituted pyrrolo[3,2-*c*]quinolines **6** via intramolecular Heck cyclization. Thus, the Pd-Cu catalyzed cross-coupling reactions described herein provide useful strategies for the synthesis of analogues of 6-methoxy-3-methyl-1-(2-methylphenyl)-1*H*-pyrrolo[3,2-*c*]quinoline, a known gastric acid secretion inhibitor against ethanol induced gastric ulcer.[1,5] Likewise, the 2-aryl-3-iodo-4-(phenylamino)quinolines represent an important class of compounds with potent immunostimulants and non-nucleoside HIV-1 inhibitors.[23] The 2-aryl-4-chloro-3-iodoquinolines and their 4-arylamino derivatives described in this investigation represent suitable candidates for further studies of carbon–carbon bond forming reactions to generate novel polysubstituted and polynuclear derivatives with potential applications ranging from biology to materials.

4. Experimental

4.1. General

Melting points were recorded on a Thermocouple digital melting point apparatus. IR spectra were recorded as powders



3a - d **7a - d** **not formed**

	4-R	% Yield
7a	H	76
7b	F	75
7c	Cl	81
7d	OCH_3	74

Scheme 4. Reagents (i) $PdCl_2(PPh_3)_2$, CuI, NEt_3, DMF, 80 °C, 4 h.

using FTS 7000 Series Digilab Win-IR Pro ATR (attenuated total reflectance) spectrometer. For column chromatography, Merck Kieselgel 60 (0.063–0.200 mm) was used as stationary phase. NMR spectra were obtained as $CDCl_3$ solutions using a Varian Mercury 300 MHz NMR spectrometer and the chemical shifts are measured relative to the solvent peaks. Low and high-resolution mass spectra were recorded at the University of Stellenbosch using a Waters API Q-TOF Ultima (double focusing high resolution) instrument. The 2-aryl-4-chloro-3-iodoquinolines **1** used as substrates in this investigation were prepared as described in our previous communications.[3,4]

4.2. Synthesis of the 4-aminophenyl-2-aryl-3-iodoquinolines 2. Typical procedure

*4.2.1. 3-Iodo-2-phenyl-4-(phenylamino)quinoline (**2a**).* 4-Chloro-3-iodo-2-phenylquinoline (2.51 g, 6.84 mmol) and aniline (3.18 g, 34.2 mmol) in ethanol (50 mL) were heated at reflux for 18 h. The solvent was evaporated under reduced pressure and the residue was quenched with ice-cold water. The product was taken up into chloroform and the organic solution was washed with brine and then dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure and the residue was recrystallized from ethanol to afford **2a** as a solid (2.58 g, 86%), mp 159–161 °C (ethanol); ν_{max} (neat) 929, 1073, 1264, 1399, 1486, 1564, 1599, 3363 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 6.60 (s, 1H), 6.87 (d, *J* 7.8 Hz, 2H), 7.03 (t, *J* 7.8 Hz, 1H), 7.23–7.33 (m, 3H), 7.47 (t, *J* 7.8 Hz, 1H), 7.49 (d, *J* 7.5 Hz, 2H), 7.62 (d, *J* 9.3 Hz, 2H), 7.67 (d, *J* 7.5 Hz, 1H), 7.73 (d, *J* 7.5 Hz, 1H), 8.10 (1H, d, *J* 9.3 Hz); δ_C (75 MHz, $CDCl_3$) 90.4, 118.8, 121.1, 122.6, 124.9, 125.8, 128.0, 128.6, 129.0, 129.3, 129.7, 130.1, 143.6, 143.7, 148.3, 148.6, 162.4; *m/z* (100, MH^+) 423; HRMS (ES): MH^+, found: 423.0360. $C_{21}H_{16}IN_2^+$ requires 423.0358.

*4.2.2. 2-(4′-Fluorophenyl)-3-iodo-4-(phenylamino)quinoline (**2b**).* (1.46 g, 78%), mp 190–192 °C (ethanol); ν_{max} (neat) 835, 926, 1156, 1231, 1486, 1567, 1600, 3367 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 6.58 (s, 1H), 6.86 (d, *J* 8.4 Hz, 2H), 7.04 (t, *J* 7.8 Hz, 1H), 7.14–7.33 (m, 5H), 7.59 (d, *J* 7.5 Hz, 2H), 7.66 (t, *J* 8.7 Hz, 1H), 7.72 (d, *J* 7.5 Hz, 1H), 8.07 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 90.1, 115.0 (d, $^2J_{CF}$ 21.6 Hz), 118.9, 121.1, 122.8, 124.9, 125.9, 129.4, 129.6, 130.2, 131.1 (d, $^3J_{CF}$ 8.3 Hz), 139.7 (d, $^4J_{CF}$ 3.2 Hz), 143.6, 148.2, 148.7, 161.3, 162.9 (d, $^1J_{CF}$ 246.5 Hz); *m/z* (100, MH^+) 441; HRMS (ES): MH^+, found 441.0275. $C_{21}H_{15}IFN_2^+$ requires 441.0264.

*4.2.3. 2-(4′-Chlorophenyl)-3-iodo-4-(phenylamino)quinoline (**2c**).* (2.66 g, 93%), mp 199–201 °C (ethanol); ν_{max} (neat) 829, 927, 1176, 1243, 1397, 1494, 1566, 1600, 3369 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 6.58 (s, 1H), 6.87 (d, *J* 7.8 Hz, 2H), 7.04 (t, *J* 7.8 Hz, 1H), 7.22–7.33 (m, 4H), 7.46 (d, *J* 7.8 Hz, 2H), 7.56 (d, *J* 9.3 Hz, 2H), 7.66 (t, *J* 7.5 Hz, 1H), 7.71 (d, *J* 7.8 Hz, 1H), 8.06 (d, *J* 7.8 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 89.7, 118.9, 121.1, 122.8, 124.9, 126.0, 128.3, 129.4, 129.7, 130.2, 130.6, 134.7, 142.0, 143.5, 148.3, 148.8, 161.2; *m/z* (100, MH^+) 457; 459 (23); HRMS (ES): MH^+, found: 456.9973. $C_{21}H_{15}{}^{35}ClIN_2^+$ requires 456.9969.

*4.2.4. 3-Iodo-2-(4′-methoxyphenyl)-4-(phenylamino)quinoline (**2d**).* (2.70 g, 95%), mp 210–212 °C (ethanol); ν_{max} (neat) 829, 929, 1029, 1176, 1243, 1400, 1495, 1513, 1567, 1603, 3369 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 3.88 (s, 3H), 6.56 (s, 1H), 6.86 (d, *J* 7.8 Hz, 2H), 7.01 (d, *J* 9.0 Hz, 2H), 7.02 (t, *J* 7.8 Hz, 1H), 7.23 (d, *J* 9.0 Hz, 2H), 7.27 (t, *J* 7.5 Hz, 1H), 7.59 (d, *J* 9.0 Hz, 2H), 7.65 (t, *J* 7.8 Hz, 1H), 7.72 (d, *J* 9.0 Hz, 1H), 8.08 (d, *J* 9.0 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 55.4, 91.0, 113.3, 118.7, 121.1, 122.5, 124.9, 125.7, 129.3, 129.7, 130.0, 130.6, 136.3, 143.7, 148.3, 148.5, 159.9, 162.1; *m/z* (100, MH^+) 453; HRMS (ES): MH^+, found 453.0457. $C_{22}H_{18}IN_2O^+$ requires 453.0464.

4.3. Synthesis of the 4-(*N,N*-allylphenylamino)-2-aryl-3-iodoquinolines 3. Typical procedure

*4.3.1. 4-(N,N-Allylphenylamino)-3-iodo-2-phenylquinoline (**3a**).* A stirred solution of 3-iodo-2-phenyl-4-(phenylamino)quinoline **2a** (1.98 g, 4.69 mmol) in DMF (20 mL) was treated with NaH (0.22 g, 9.17 mmol) at room temperature. After 30 min, allyl bromide (1.12 g, 9.0 mmol) was added to the reaction mixture and stirring was continued for 12 h at room temperature. The mixture was quenched with crushed ice and the resulting precipitate was filtered, taken up into chloroform and dried ($MgSO_4$). The solvent was evaporated and the residue was purified by column chromatography to afford **3a** as a solid (1.46 g, 68%), mp 116–117 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.75; ν_{max} (neat) 921, 1241, 1392, 1481, 1498, 1557, 1598 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 4.34 (dd, *J* 6.0 and 15.3 Hz, 1H), 4.52 (dd, *J* 6.0 and 15.3 Hz, 1H), 5.19 (d, *J* 10.8 Hz, 1H), 5.33 (d, *J* 16.8 Hz, 1H), 6.09–6.23 (m, 1H), 6.58 (d, *J* 7.8 Hz, 2H), 6.79 (t, *J* 7.8 Hz, 1H), 7.20 (t, *J* 7.8 Hz, 2H), 7.43–7.54 (m, 4H), 7.66 (d, *J* 6.0 Hz, 2H), 7.73, (t, *J* 7.8 Hz, 1H), 7.82 (d, *J* 7.8 Hz, 1H), 8.19 (d, *J* 7.5 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 54.9, 100.4, 113.2, 118.2, 118.3, 124.4, 127.5, 127.6, 127.9, 128.7, 129.2, 129.3, 129.9, 130.4, 134.2, 143.2, 146.5, 149.0, 154.7, 164.0; *m/z* (100, MH^+) 463; HRMS (ES): MH^+, found: 463.0675. $C_{24}H_{20}IN_2^+$ requires 463.0671.

*4.3.2. 4-(N,N-Allylphenylamino)-2-(4′-fluorophenyl)-3-iodo-quinoline (**3b**).* (1.15 g, 85%), mp 160–162 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.76; ν_{max} (neat) 838, 936, 1158, 1211, 1394, 1481, 1596 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 4.32 (dd, *J* 6.3 and 15.2 Hz, 1H), 4.51 (dd, *J* 6.3 and 15.3 Hz, 1H), 5.18 (d, *J* 9.3 Hz, 1H), 5.31 (d, *J* 16.8 Hz, 1H), 6.07–6.21 (m, 1H), 6.55 (d, *J* 9.3 Hz, 2H), 6.79 (t, *J* 7.8 Hz, 1H), 7.14–7.22 (m, 4H), 7.45 (t, *J* 7.8 Hz, 1H), 7.63–7.68 (m, 2H), 7.73 (t, *J* 7.8 Hz, 1H), 7.80 (d, *J* 7.8 Hz, 1H), 8.16 (d, *J* 7.8 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 54.9, 100.3, 113.2, 115.0 (d, $^2J_{CF}$ 21.7 Hz), 118.3, 118.4, 124.5, 127.6, 127.8, 129.3, 129.9, 130.6, 131.4 (d, $^3J_{CF}$ 8.5 Hz), 134.1, 139.2 (d, $^4J_{CF}$ 3.4 Hz), 146.5, 149.0, 154.9, 162.9, 163.0 (d, $^1J_{CF}$ 246.7 Hz); *m/z* (100, MH^+) 481; HRMS (ES): MH^+, 481.0589. $C_{24}H_{19}FIN_2^+$ requires 481.0587.

*4.3.3. 4-(N,N-Allylphenylamino)-2-(4′-chlorophenyl)-3-iodoquinoline (**3c**).* (1.63 g, 80%), mp 119–122 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.82; ν_{max}(neat) 836, 1096, 1393, 1481, 1499, 1556, 1597 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 4.32 (dd, *J* 6.3 and 16.8 Hz, 1H), 4.52 (dd, *J* 6.3 and 16.8 Hz, 1H), 5.19 (d, *J* 10.8 Hz, 1H), 5.32 (d, *J* 16.8 Hz, 1H), 6.07–6.22 (m, 1H), 6.56 (d, *J* 7.8 Hz, 2H), 6.80 (t, *J* 7.8 Hz, 1H), 7.19 (t, *J* 7.8 Hz, 2H), 7.43–7.48 (m, 4H), 7.62 (d, *J* 9.0 Hz, 2H), 7.73 (t, *J* 7.5 Hz, 1H), 7.81 (d, *J* 9.3 Hz, 1H), 8.16 (d, *J* 7.8 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 55.0, 99.9, 113.2, 118.3, 118.4, 124.5, 127.6, 127.8, 128.2, 129.3, 129.9, 130.6, 130.8, 134.1, 134.9, 141.5, 146.5, 149.1, 154.9, 162.7; *m/z* (100, MH^+) 497; HRMS (ES): MH^+, found 497.0273. $C_{24}H_{19}{}^{35}ClIN_2^+$ requires 497.0282.

*4.3.4. 4-(N,N-Allylphenylamino)-3-iodo-2-(4′-methoxyphenyl)quinoline (**3d**).* (1.02 g, 60%), mp 110–112 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.78; ν_{max} (neat) 832, 1029, 1172, 1250, 1498, 1597 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 3.88 (s, 3H), 4.33 (dd, *J* 6.3 and 15.3 Hz, 1H), 4.52 (dd, *J* 6.0 and 15.3 Hz, 1H), 5.18 (d, *J* 10.8 Hz, 1H), 5.32 (d, *J* 18.3 Hz, 1H), 6.08–6.22 (m, 1H), 6.56 (d, *J* 9.3 Hz, 2H), 6.78 (t, *J* 7.8 Hz, 1H), 7.02 (d, *J* 9.0 Hz, 2H), 7.19 (t, *J* 7.5 Hz, 2H), 7.43 (t, *J* 7.5 Hz, 1H), 7.65 (d, *J* 9.3 Hz, 2H), 7.71 (t, *J* 7.5 Hz, 1H), 7.79 (d, *J* 9.0 Hz, 1H), 8.17 (d, *J* 9.3 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 55.0, 55.3, 100.8, 113.2, 113.3, 118.2 (2×C), 124.5, 127.3, 127.4, 129.3, 129.8, 130.4, 130.9, 134.2, 135.7, 146.5, 149.1, 154.7, 160.0,

163.5; *m*/*z* (100, MH^+) 481; HRMS (ES): MH^+, 481.0580. $C_{25}H_{23}IN_2O^+$ requires 423.1893.

4.4. Sonogashira coupling of 2-aryl-3-iodo-4-(phenylamino) quinolines (4). Typical procedure

*4.4.1. 1,2,4-Triphenyl-1H-pyrrano[3,2-c]quinoline (**5a**).* A mixture of **2a** (0.20 g, 0.47 mmol), $PdCl_2(PPh_3)_2$ (0.017 g, 0.024 mmol) and CuI (0.005 g, 0.024 mmol) in dioxane/water (3:1, v/v; 20 mL) in a three-necked flask equipped with a stirrer, condenser and rubber septum was flushed with nitrogen gas for 20 min. Phenylacetylene (0.058 g, 0.57 mmol) and triethylamine (0.266 mL, 1.89 mmol) were added sequentially to the flask via a syringe. The mixture was flushed for additional 10 min and then refluxed at 80 °C for 4 h under nitrogen atmosphere and then allowed to cool. The cooled mixture was added to a beaker containing ice-cold water and the product was extracted into ethyl acetate and the combined organic extracts were dried over $MgSO_4$. The solvent was evaporated under reduced pressure and the residue was passed through a column of silica gel eluting with hexane/ethyl acetate mixture to afford (**5a**) as solid (0.11 g. 58%), mp 210–212 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.90; ν_{max} (neat) 807, 1028, 1315, 1349, 1371, 1499, 1564 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.10–7.20 (m, 3H), 72.3 (s, 5H), 7.43–7.61 (m, 9H), 8.13 (d, *J* 8.1 Hz, 2H), 8.27 (d, *J* 8.7 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 104.7, 117.6, 119.5, 120.4, 125.0, 126.3, 127.7, 128.1, 128.6, 128.8, 129.1, 129.3, 129.4, 129.5, 129.7, 130.6, 131.9, 136.6, 139.5, 140.3, 141.2, 145.2, 154.5; *m*/*z* (100, MH^+) 397; HRMS (ES): MH^+, found 397.1697. $C_{28}H_{21}N_2^+$ requires 397.1705.

*4.4.2. 4-(4-Fluorophenyl)-1,2-diphenyl-1H-pyrrano[3,2-c]quinoline (**5b**).* (0.100 g, 53%), mp 159–160 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.94; ν_{max} (neat) 838, 1154, 1221, 1499, 1598 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.06 (s, 1H), 7.11 (dt, *J* 1.2 and 8.2 Hz, 1H), 7.16 (dt, *J* 1.2 and 8.2 Hz, 1H), 7.23 (s, 5H), 7.26 (t, *J* 8.7 Hz, 2H), 7.41–7.45 (m, 2H), 7.48–7.56 (m, 4H), 8.11 (dd, *J* 5.4 and 9.0 Hz, 2H), 8.23 (dd, *J* 0.9 and 8.2 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 104.4, 115.5 (d, $^2J_{CF}$ 21.3 Hz), 117.6, 119.4, 120.4, 125.1, 126.4, 127.8, 128.1, 129.3, 129.4, 129.5, 129.8, 130.5, 130.9 (d, $^3J_{CF}$ 8.3 Hz), 131.8, 136.4 (d, $^4J_{CF}$ 3.2 Hz), 139.4, 141.4, 145.1, 153.3, 163.4 (d, $^1J_{CF}$ 246.5 Hz); *m*/*z* (100, MH^+) 415; HRMS (ES): MH^+, found 415.1602. $C_{28}H_{20}FN_2^+$ requires 415.1611.

*4.4.3. 4-(4-Chlorophenyl)-1,2-diphenyl-1H-pyrrano[3,2-c]quinoline (**5c**).* (0.105 g, 65%), mp 165–167 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.93; ν_{max} (neat) 839, 1223, 1450, 1500, 1600 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.08 (s, 1H), 7.10–7.22 (m, 2H), 7.25 (s, 5H), 7.43–7.56 (m, 7H), 8.09 (d, *J* 8.4 Hz, 2H), 8.25 (d, *J* 8.7 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 104.3, 117.6, 119.4, 120.4, 125.2, 126.5, 127.8, 128.1, 128.8, 129.3, 129.4, 129.5, 129.8, 130.4, 130.5, 131.7, 134.9, 136.7, 138.7, 139.3, 141.4, 145.0, 153.0; *m*/*z* (100, MH^+) 431; HRMS (ES): MH^+, found 431.1321. $C_{28}H_{20}{}^{35}ClN_2^+$ requires 431.1315.

*4.4.4. 4-(4-Methoxyphenyl)-1,2-diphenyl-1H-pyrrano[3,2-c]quinoline (**5d**).* (0.120 g, 64%), mp 153–155 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.78; ν_{max} (neat) 832, 1029, 1246, 1501, 1605 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 3.91 (s, 3H), 7.07–7.22 (m, 5H), 7.23–7.26 (m, 5H), 7.42–7.56 (m, 6H), 8.10 (d, *J* 7.0 Hz, 2H), 8.24 (dd, *J* 0.9 and 8.6 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 55.4, 104.8, 114.0, 117.5, 119.4, 120.4, 124.7, 126.3, 127.6, 128.1, 129.3, 129.4, 129.5, 129.7, 130.4, 130.5, 132.0, 133.0, 136.6, 139.5, 141.1, 145.2, 154.0, 160.3; *m*/*z* (100, MH^+) 427; HRMS (ES): MH^+, found 427.1831. $C_{29}H_{23}N_2O^+$ requires 427.1810.

*4.4.5. 2-(1-Hydroxyethyl)-1,4-diphenyl-1H-pyrrano[3,2-c]quinoline (**5e**).* (0.130 g, 62%), mp 183–185 °C (ethanol); R_f (30% ethyl acetate/hexane) 0.44; ν_{max} (neat) 1071, 1364, 1494, 3389 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.56 (d, *J* 6.3 Hz, 3H), 1.98 (br s, 1H), 4.73 (q, *J* 6.3 Hz, 1H), 6.92 (dd, *J* 1.5 and 8.6 Hz, 1H), 6.97 (s, 1H), 7.13 (dt, *J* 1.2 and 7.8 Hz, 1H), 7.38–7.66 (m, 8H), 7.95 (d, *J* 8.4 Hz, 2H), 8.03 (dd, *J* 1.5 and 8.2 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 22.7, 62.1, 101.0, 117.4, 118.8, 120.3, 125.0, 126.4, 128.6, 128.8, 128.9, 129.1, 129.4, 129.9, 130.0, 130.1, 130.5, 136.5, 138.8, 140.2, 144.2, 145.0, 154.6; *m*/*z* (100, MH^+) 365; HRMS (EI): MH^+, found 365.1662. $C_{25}H_{21}N_2O^+$ requires 365.1654.

*4.4.6. 4-(4-Chlorophenyl)-2-(1-hydroxyethyl)-1-phenyl-1H-pyrrano [3,2-c]quinoline (**5f**).* (0.101 g, 59%), mp 202–204 °C (2-propanol); R_f (30% ethyl acetate/hexane) 0.47; ν_{max} (neat) 834, 1009, 1087, 1310, 1444, 1499, 1567, 3210 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.54 (d, *J* 6.6 Hz, 3H), 2.26 (br s, 1H), 4.71 (q, *J* 6.6 Hz, 1H), 6.88 (s, 1H), 6.90 (d, *J* 8.4 Hz, 1H), 7.14 (dt, *J* 1.2 and 7.8 Hz, 1H), 7.35–7.39 (1H, m), 7.45–7.52 (m, 4H), 7.58–7.66 (m, 3H), 7.95 (d, *J* 8.4 Hz, 2H), 8.19 (d, *J* 8.1 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 22.8, 62.0, 100.6, 117.4, 118.6, 120.3, 125.3, 126.5, 128.8, 128.9, 129.3, 129.8, 130.0, 130.1, 130.3, 130.4, 134.9, 136.6, 138.5, 138.6, 144.5, 144.8, 153.1; *m*/*z* (100, MH^+) 399; HRMS (ES): MH^+, found 399.1261. $C_{25}H_{20}{}^{35}ClN_2O^+$ requires 399.1264.

*4.4.7. 2-(1-Hydroxyethyl)-4-(4-methoxyphenyl)-1-phenyl-1H-pyrrano[3,2-c]quinoline (**5g**).* (0.11 g, 61%), mp 221–223 °C (ethanol); R_f (30% ethyl acetate/hexane) 0.27; ν_{max} (neat) 835, 1171, 1244, 1301, 1440, 1501, 1606, 3170 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.56 (3H, d, *J* 6.6 Hz), 1,98 (br s, 1H), 3.90 (s, 3H), 4.72 (q, *J* 6.6 Hz, 1H), 6.90 (d, *J* 7.5 Hz, 1H), 8.98 (s, 1H), 7.06–7.14 (m, 3H), 7.37–7.42 (m, 1H), 7.47 (t, *J* 7.5 Hz, 1H), 7.52–7.55 (m, 1H), 7.59–7.66 (m, 3H), 8.01 (d, *J* 8.4 Hz, 2H), 8.20 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 22.8, 55.4, 62.1, 101.0, 114.0, 117.3, 118.7, 120.3, 124.8, 126.3, 128.9, 129.4, 129.7, 129.9, 130.1, 130.3, 130.4, 132.8, 136.5, 138.8, 144.2, 145.0, 154.1, 160.3; *m*/*z* (100, MH^+) 395; HRMS (ES): MH^+, found 395.1743. $C_{26}H_{23}N_2O_2^+$ requires 395.1746.

*4.4.8. 1,4-Diphenyl-2-(trimethylsilyl)-1H-pyrrano[3,2-c]quinoline (**5h**).* (0.30 g, 75%), mp 160–163 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.87; ν_{max} (neat) 838, 980, 1247, 1372, 1500, 1562 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.09 (s, 9H), 7.00 (td, *J* 0.9 and 8.6 Hz, 1H), 7.14 (dt *J* 1.5 and 7.7 Hz, 1H), 7.17 (s, 1H), 7.47–7.66 (m, 9H), 8.10 (dd, *J* 1.5 and 7.5 Hz, 2H), 8.25 (dd, *J* 0.6 and, 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 0.33, 114.4, 117.6, 119.9, 120.5, 124.9, 126.5, 128.6, 128.7, 129.1 (2×C), 129.4, 129.6 (2×C), 130.4, 139.2, 140.4, 141.6, 142.7, 145.1, 154.6; *m*/*z* (100, MH^+) 392; HRMS (ES): MH^+, found 393.1789. $C_{26}H_{25}N_2Si^+$ requires 393.1787.

*4.4.9. 2-(4-Fluorophenyl)-2-(trimethylsilyl)-4-phenyl-1H-pyrrano [3,2-c]quinoline (**5i**).* (0.20 g, 65%), mp 185–187 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.91; ν_{max} (neat) 834, 933, 1221, 1503, 1597 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.09 (s, 9H), 6.99 (dd, *J* 0.9, 8.6 Hz, 1H), 7.11 (1H, s), 7.13 (dt, *J* 1.5 and 7.7 Hz, 1H), 7.27 (t, *J* 8.4 Hz, 2H), 7.47–7.53 (m, 3H), 7.59–7.67 (m, 3H), 8.08 (dd, *J* 5.4 and 8.9 Hz, 2H), 8.20 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 0.02, 114.1, 115.5 (d, $^2J_{CF}$ 21.4 Hz), 117.6, 119.7, 120.5, 125.0, 126.6, 129.3, 129.6, 129.7, 130.3, 130.9 (d, $^3J_{CF}$ 8.3 Hz), 136.5 (d, $^4J_{CF}$ 2.9 Hz), 139.2, 141.5, 143.0, 145.0, 153.5, 163.3 (d, $^1J_{CF}$ 246.5 Hz); *m*/*z* (100, MH^+) 411; HRMS (ES): MH^+, found 411.1693. $C_{26}H_{24}FN_2Si^+$ requires 411.1693.

*4.4.10. 4-(4-Methoxyphenyl)-2-(trimethylsilyl)-1-phenyl-1H-pyrrano[3,2-c]quinoline (**5j**).* (0.37 g, 72%), mp 173–175 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.75; ν_{max} (neat) 840, 935, 981, 1174, 1249, 1509, 1608 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.07 (s, 9H), 3.91 (s, 3H), 6.96 (d, *J* 8.4 Hz, 1H), 7.10 (dt, *J* 1.5 and 7.5 Hz, 1H), 7.11 (d, *J* 9.3 Hz, 2H), 7.16 (s, 1H), 7.47 (dt, *J* 1.5 and 7.5 Hz, 1H), 7.49 (dd, *J* 1.5 and 8.2 Hz, 2H), 7.57–7.66 (m, 3H), 8.09 (d, *J* 9.3 Hz, 2H), 8.20 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 0.02, 55.4, 114.0, 114.5, 117.5, 119.8, 120.5, 124.7, 126.4, 129.3, 129.5, 129.6, 130.2, 130.5, 133.1, 139.2, 141.7, 142.6, 145.2, 154.3, 160.2; *m*/*z* (100, MH^+)

423; HRMS (ES): MH^+, found 423.1879. $C_{27}H_{27}N_2OSi^+$ requires 423.1893.

4.5. Indirect synthesis of 1,2,4-triphenyl-1*H*-pyrrano[3,2-*c*] quinoline (5a)

*4.5.1. 4-Chloro-2-phenyl-3-(phenylethynyl)quinoline (**6a**).* A mixture of **1a** (1.00 g, 2.74 mmol), $PdCl_2(PPh_3)_2$ (0.10 g, 0.14 mmol) and CuI (0.03 g, 0.14 mmol) in a three-necked flask equipped with a stirrer, condenser and rubber septum was flushed with nitrogen gas for 20 min. Phenylacetylene (0.36 g, 3.30 mmol) and triethylamine (8.0 mL) were added sequentially to the flask via a syringe. The mixture was flushed for additional 10 min and then refluxed for 2 h under nitrogen atmosphere. The cooled mixture was added to a beaker containing ice-cold water and extracted with ethyl acetate. The combined organic solution was dried over Mg_2SO_4, filtered and then evaporated. The residue was purified by column chromatography to afford **6a** as a solid (0.69 g; 74%), mp 145–148 °C; R_f (10% ethyl acetate/hexane) 0.44; ν_{max} (neat) 822, 1070, 1234, 1345, 1400, 1442, 1474, 1492, 1563, 1599, 2213 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.31–7.36 (m, 3H), 7.39–7.44 (m, 2H), 7.49 (m, 3H), 7.65 (dt, *J* 1.2 and 7.5 Hz, 1H), 7.77 (dt, *J* 1.5 and 7.7 Hz, 1H), 8.00–8.04 (m, 2H), 8.15 (dd, *J* 0.9 and 7.7 Hz, 1H), 8.27 (dd, *J* 0.9 and 8.6 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 85.5, 100.6, 116.4, 122.7, 124.4, 124.8, 127.8, 127.9, 128.4, 129.0, 129.2, 129.6, 130.0, 130.7, 131.5, 139.5, 145.1, 146.9, 159.8; *m*/*z* (100, MH^+) 340; HRMS (ES): MH^+, found 340.0888. $C_{23}H_{15}N^{35}Cl^+$ requires 340.0893.

*4.5.2. 2-Phenyl-4-(phenylamino)-3-(phenylethynyl)quinoline **4′a**.* A mixture of **6a** (0.18 g, 0.53 mmol) and aniline (0.05 g, 0.53 mmol) in ethanol (20 mL) was heated at 80 °C for 18 h and then evaporated under reduced pressure. The residue was acidified with 2 M HCl and then extracted into chloroform. The organic solution was washed with saturated solution of Na_2CO_3, water and then dried over $MgSO_4$. The salt was filtered off and the organic solution was evaporated under reduced pressure. The residue was purified by column chromatography to afford (**4′a**) as a solid (0.09 g, 45%), mp 175–176 °C (EtOH); R_f (30% ethyl acetate/hexane) 0.57; ν_{max} (neat) 1261, 1354, 1400, 1485, 1529, 1560, 1599, 3182, 3225 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.06 (d, *J* 7.8 Hz, 2H), 7.09 (t, *J* 7.5 Hz, 1H), 7.14 (s, 1H), 7.20–7.33 (m, 8H), 7.46–7.55 (m, 3H), 7.64 (dt, *J* 1.5 and 7.5 Hz, 1H), 7.70 (d, *J* 8.4 Hz, 1H), 8.04 (dd, *J* 1.5 and 7.5 Hz, 2H), 8.11 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 85.1, 101.3, 104.9, 119.2, 120.3, 122.8, 123.2, 124.4, 125.2, 127.9, 128.3, 128.5, 128.8, 129.2, 129.5, 130.0, 130.3, 131.1, 140.3, 143.3, 147.9, 149.0, 160.1; *m*/*z* (100, MH^+) 397; HRMS (ES): MH^+, found 397.1695. $C_{29}H_{21}N_2^+$ requires 397.1705.

*4.5.3. 1,2,4-Triphenyl-1H-pyrrano[3,2-c]quinoline (**5a**).* A mixture of **4′a** (0.08 g, 0.20 mmol), $PdCl_2(PPh_3)_2$ (0.01 g, 0.01 mmol), CuI (0.02 g, 0.01 mmol) and triethylamine (0.1 mL, 0.06 mmol) in dioxane/water (3:1, v/v; 20 mL) was treated as described for the synthesis of systems **5**. Work-up and column chromatography afforded **5a** as a solid (0.04 g, 55%).

4.6. Heteroannulation of 4-(*N*,*N*-allylphenylamino)-2-aryl-3-iodoquinolines (3). Typical procedure

*4.6.1. 3-Methyl-1,4-diphenyl-1H-pyrrano[3,2-c]quinoline (**7a**).* A mixture of **3a** (0.20 g, 0.43 mmol), $PdCl_2(PPh_3)_2$ (0.015 g, 0.022 mmol) and CuI (0.004 g, 0.0022 mmol) in dry DMF (20 mL) in a three-necked flask equipped with a stirrer, condenser and rubber septum was flushed with nitrogen gas for 20 min. Triethylamine (0.24 mL, 1.72 mmol) was added to the flask via a syringe and the mixture was flushed for additional 10 min. The mixture was heated at reflux for 4 h under nitrogen atmosphere and then allowed to cool. The cooled mixture was added to a beaker containing ice-cold saturated ammonium chloride and the resulting precipitate was taken into ethyl acetate. The combined organic solution was washed with brine and dried over $MgSO_4$. The solvent was evaporated under reduced pressure and the residue was passed through a column of silica gel eluting with ethyl acetate/hexane mixture to afford **7a** as a solid (0.11 g, 76%), mp 138–141 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.75; ν_{max} (neat) 976, 1370, 1433, 1497, 1557 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.94 (3H, s), 7.00 (s, 1H), 7.21 (t, *J* 7.2 Hz, 1H), 7.35 (d, *J* 8.4 Hz, 1H), 7.46–7.62 (m, 9H), 7.66 (dd, *J* 1.6 and 6.6 Hz, 2H), 8.23 (d, *J* 8.4 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 12.4, 113.9, 117.4, 119.9, 120.6, 124.8, 126.5, 127.4, 127.9, 128.2, 128.7, 128.8, 129.2, 129.7, 130.2, 135.3, 140.9, 141.1, 144.2, 156.5; *m*/*z* 335 (100, MH^+); HRMS (ES) MH^+, found 335.1549. $C_{24}H_{19}N_2^+$ requires 335.1548.

*4.6.2. 4-(4-Fluorophenyl)-3-methyl-1-phenyl-1H-pyrrano[3,2-c] quinoline (**7b**).* (0.11 g, 75%), mp 123–125 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.81; ν_{max} (neat) 839, 977, 1219, 1371, 1499, 1600 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.93 (d, *J* 1.2 Hz, 3H), 7.01 (d, *J* 1.2 Hz, 1H), 7.16–7.36 (m, 3H), 7.34 (dd, *J* 0.9 and 8.3 Hz, 1H), 7.48–7.67 (m, 8H), 8.20 (dd, *J* 0.9 and 8.6 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 12.5, 113.7, 114.9 (d, $^3J_{CF}$ 21.3 Hz), 117.4, 119.9, 120.6, 124.9, 126.6, 127.4, 128.8, 128.9, 129.8, 130.2, 131.0 (d, $^3J_{CF}$ 8.3 Hz), 135.4, 137.2 (d, $^4J_{CF}$ 3.2 Hz), 140.8, 144.2, 155.4, 163.0 (d, $^1J_{CF}$ 245.0 Hz); *m*/*z*: 353 (100, MH^+); HRMS (ES): MH^+, found 353.1449. $C_{24}H_{18}FN_2^+$ requires 353.1454.

*4.6.3. 4-(4-Chlorophenyl)-3-methyl-1-phenyl-1H-pyrrano[3,2-c] quinoline (**7c**).* (0.12 g, 81%), mp 165–167 °C (ethanol); R_f (20% ethyl acetate/hexane) 0.85; ν_{max} (neat) 825, 977, 1085, 1371, 1433, 1490, 1557, 1559 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.95 (s, 3H), 7.01 (s, 1H), 7.20 (t, *J* 7.5 Hz, 1H), 7.34 (d, *J* 9.0 Hz, 1H), 7.47–7.62 (m, 10H), 8.20 (d, *J* 7.5 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 12.6, 113.6, 117.4, 119.7, 120.6, 125.1, 126.6, 127.3, 128.1, 128.8, 128.9, 129.6, 129.8, 130.1, 130.6, 134.4, 139.6, 140.7, 144.2, 155.1; *m*/*z* 369 (100, MH^+); HRMS (ES): MH^+, found 369.1168. $C_{24}H_{18}{}^{35}ClN_2^+$ requires 369.1159.

*4.6.4. 4-(4-Methoxyphenyl)-3-methyl-1-phenyl-1H-pyrrano[3,2-c] quinoline (**7d**).* (0.11 g, 74%), mp 175–177 °C (2-propanol); R_f (20% ethyl acetate/hexane) 0.58; ν_{max} (neat) 826, 1030, 1169, 1245, 1434, 1495, 1607 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.97 (d, *J* 1.2 Hz, 3H), 3.89 (s, 3H), 6.99 (d, *J* 1.2 Hz, 1H), 7.04 (d, *J* 9.0 Hz, 2H), 7.17 (dt, *J* 1.5 and 7.8 Hz, 1H), 7.33 (td, *J* 0.6 and 8.4 Hz, 1H), 7.47–7.53 (m, 2H), 7.55–7.62 (m, 5H), 8.20 (dd, *J* 0.6 and 8.1 Hz, 1H); δ_C (75 MHz, $CDCl_3$) 12.6, 55.4, 113.3, 114.0, 117.4, 120.0, 120.6, 124.7, 126.4, 127.4, 128.7, 128.8, 129.7, 130.2, 130.5, 133.8, 135.4, 140.9, 144.4, 156.3, 159.8; *m*/*z* 365 (100, MH^+); HRMS (ES): MH^+, found 365.1660. $C_{25}H_{21}N_2O^+$ requires 365.1654.

Acknowledgements

The authors are grateful to the University of South Africa (UNISA) and the National Research Foundation (RSA) for financial assistance. Mr. L.G.L. thanks UNISA for allowing him to pursue this work as part of his M.Sc. program.

References and notes

1. Abass, M. *Heterocycles* **2005**, *65*, 901–965 and references therein.
2. Mphahlele, M. J.; El-Nahas, A. M. *J. Mol. Struct.* **2004**, *688*, 129–136.
3. Mphahlele, M. J.; Mtshemla, V. *J. Chem. Res.* **2008**, 437–440.
4. Mphahlele, M. J.; Mtshemla, V. *J. Heterocycl. Chem.* **2008**, *45*, 1343–1350.
5. Brown, T. H.; Ife, R. J.; Keeling, D. J.; Laing, S. M.; Leach, C. A.; Parsons, M. E.; Price, C. A.; Reavill, D. R.; Wiggall, K. J. *J. Med. Chem.* **1990**, *33*, 527–533.
6. Marquez, V. E.; Crauston, J. W.; Ruddon, R. W.; Kier, L. B.; Burckhalter, T. H. *J. Med. Chem.* **1972**, *15*, 36–39.
7. For review on the use of iodofunctionalized system in metal-catalyzed C–C formation see: Kirsch, G.; Hesse, S.; Comel, A. *Curr. Org. Synth.* **2004**, *1*, 47–63.

8. Sonogashira, K.; Tohda, Y.; Hagihara, N. *Tetrahedron Lett.* **1975**, 4467–4470.
9. Sonogashira, K. *J. Organomet. Chem.* **2002**, *653*, 46–49.
10. Kang, S. K.; Park, S. S.; Kim, S. S. *Tetrahedron Lett.* **1999**, *40*, 4379–4382.
11. Koradin, C.; Dohle, W.; Rodriguez, A. L.; Schmid, B.; Knochel, P. *Tetrahedron* **2003**, *59*, 1571–1587.
12. Colacino, E.; Benakki, H.; Gunoum, F.; Martinez, J.; Lamaty, F. *Synth. Commun.* **2009**, *39*, 1583–1591.
13. Pal, M.; Subramanian, V.; Batchu, V. R.; Dager, I. *Synlett* **2004**, 1965–1969.
14. Subramanian, V.; Batchu, V. R.; Barange, D.; Pal, M. *J. Org. Chem.* **2005**, *70*, 4778–4783.
15. Venkataraman, S.; Barange, D. K.; Pal, M. *Tetrahedron Lett.* **2006**, *47*, 7317–7322.
16. Layek, L.; Rao, A. V. D.; Gajare, V.; Kalita, D.; Barange, D. P.; Islam, A.; Mokkanti, K.; Pal, M. *Tetrahedron Lett.* **2009**, *50*, 4878–4881.
17. Larock, R. C.; Babu, S. *Tetrahedron Lett.* **1987**, *28*, 5291–5294 and references therein.
18. Weinrich, M. L.; Beck, H. P. *Tetrahedron Lett.* **2009**, *50*, 6968–6972.
19. Kaim, L. E.; Gizzi, M.; Grimaud, L. *Org. Lett.* **2008**, *10*, 3417–3419.
20. Choi, J.-K.; Yum, E.K.; Kim, S.S.; Kang, S.K.; Cheon, H.G.; Kim, H.J. PCT Int. Appl. WO 2000001696 A1 20000113, 2000.
21. Campeau, L.-C.; Parisien, M.; Jean, A.; Fagnou, K. *J. Am. Chem. Soc.* **2006**, *128*, 581–590.
22. Alberico, D.; Scott, M. E.; Lautens, M. *Chem. Rev.* **2007**, *107*, 174–238.
23. Palacios, F.; Ochoa de Retana, A. M.; Oyarzabal, J. *Tetrahedron* **1999**, *55*, 5947–5964 and references cited therein.