New Strategies for the Synthesis of Heterocycles

Project Report

Submitted by

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Synthesis of Various Substituted Derivatives of Carbazoles (Heterocycles) for Studying their Photophysical Properties

ACKNOWLEDGEMENT

The success of any endeavour is due to the contributions of several individuals and institutions.

I would like to express my heartfelt gratitude to my supervisor **Prof. Santosh J. Gharpure** who gave me the golden opportunity to work on this project. I acknowledge with thanks the kind of patronage, loving inspiration, and guidance, which I have received from Anusha Khandelwal and Surya Kant Pandey, and all other lab members.

ANCHIT PRASAD

CONTENTS

1. ABBREVATIONS

Ac	acetyl
anhyd.	Anhydrous
aq.	aqueous
Bu	butyl
br	broad
calcd.	calculated
cm	centimetre
d	doublet
dd	doublet of doublet
dddd	doublet of doublet of doublet of doublet
DEPT	Distortionless Enhancement by Polarisation Transfer
DIBAL-H	Diisobutyl Aluminium Hydride
dt	doublet of triplet
dq	doublet of quartet
equiv.	equivalent
ESI	ElectroSpray Ionization
Et	ethyl
g	gram
H	hour
HRMS	High Resolution Mass Spectrum
IR	infrared
lit.	Literature
m	multiplet
Me	methyl
mg	milligram
MHz	megahertz
mL	millilitre
mmol	millimole
m/z	mass/charge
mol	mole
NMR	Nuclear Magnetic Resonance
Ppm	parts per million
Ph	phenyl
Q	quartet
r.t.	room temperature
Rf	retention factor

S	singlet
T	triplet
T	temperature
TLC	thin layer chromatography
TMS	trimethylsillyl

2. Introduction

A large number of biologically active compounds contain carbazole moiety. Although the carbazole itself is a natural product isolated from coal tar by Graebe and Glaser in 1872, the first carbazole from plant sources wasn't discovered until the 1960s. The first carbazole alkaloid to be isolated from plant source was murrayanine A extracted from the stembark of the small tree Murraya Koenig II (Fam. Rutaceae), an Indian medicinal plant commonly known as "curry-leaf tree" and used externally to cure eruptions.

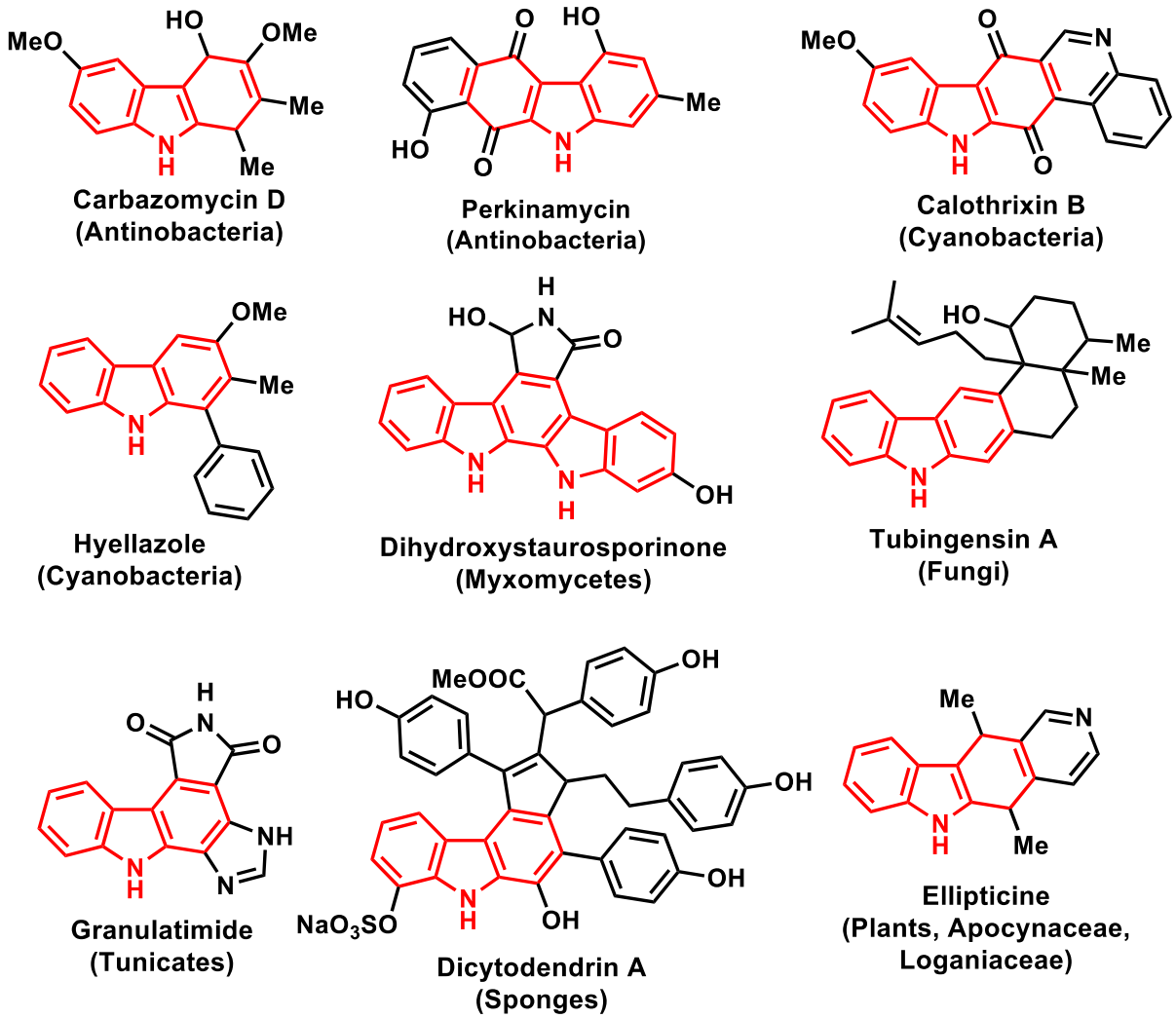


Figure 1. Carbazole Containing Biologically Active Molecules

Carbazole containing natural products exhibit biological properties such as antibiotic, anti-histaminic, anti- inflammatory, antitumor, psychotropic and anti-oxidative activities, as well as photo physical activities such as photo-reactive, photo conductive, and light emitting properties. Due to interesting structural features and useful bioactivities, carbazoles seeks the

attention of synthetic chemists and led to the development of many different synthetic strategies. Since 1979, new highly substituted carbazole alkaloids have been found by several groups in different terrestrial plants.

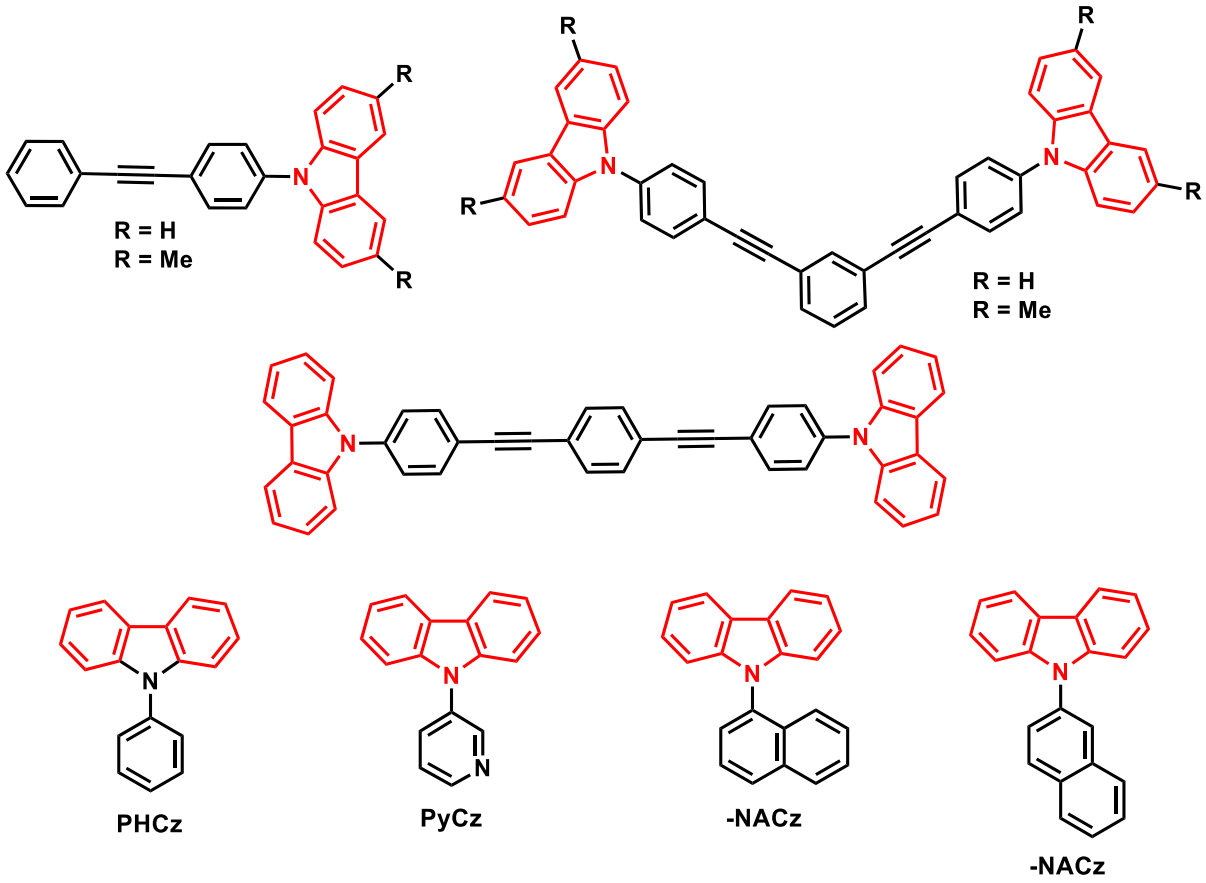


Figure 2. Carbazole Containing Highly Fluorescent Compounds

Small molecule-fluorophores are being used to visualize the biological events and thus attracted attention in recent years because of its high sensitivity, quick response time and easy preparation.[1,2] There are many fluorescent dyes have been synthesized with chemical modifications such as quinine sulphate, fluorescein, rhodamine B, BODIPY, indocyanine green, coumarin, Nile red, pyrene etc. and are being for selective cell labelling in biological systems.[3-5]

Similarly, highly fluorescent compounds with good thermal stability are being used as an organic light emitting diodes (OLEDS) for creating displays in computer monitors, television screens, smartphones and many other electronic devices used in day-to-day life.[6, 7]

Carbazole derivatives have been widely used as OLEDs due to good hole transporting ability and sufficiently large triplet energies.[8-10] The advantages of using carbazole as OLED can be highlighted as inexpensive starting material, ease of functionalization on carbazole backbone and nitrogen and aromatic properties grants stability under the wide range of the conditions.

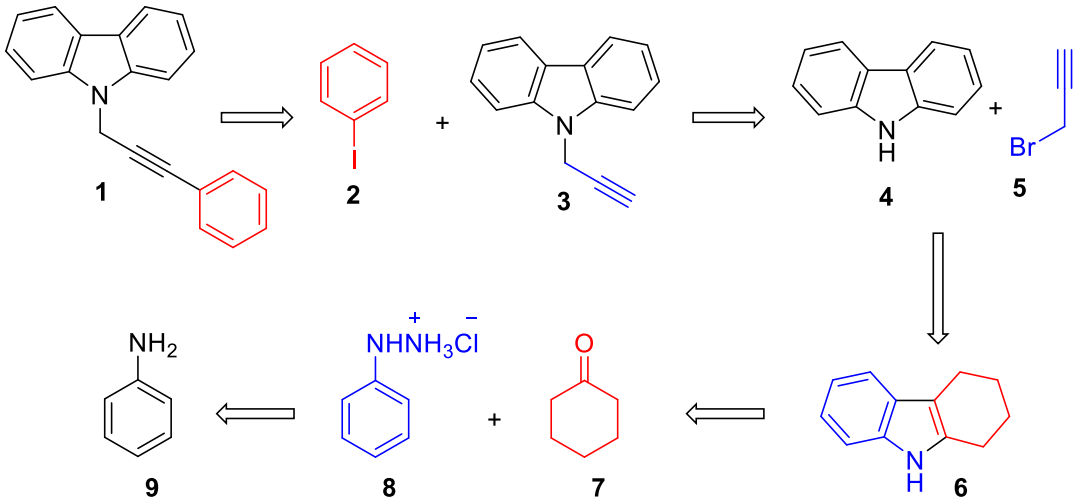
3. Objective and scope of the work

As discussed above the carbazoles are the key elements of many natural products and highly conjugated carbazole for OLEDs. Therefore, the designing and synthesis of such moiety have attracted attention in recent years and our strategy was to designed to small molecule which serve as precursors to highly fluorescent carbazoles and thus the objective of our work is to "synthesize various substituted carbazoles for the study of their photophysical properties."

4. Retrosynthetic Analysis

The retrosynthetic strategies for substituted derivatives of carbazole was envisioned. Phenylpropynyl carbazole **1** could be synthesized from propynyl carbazole **2** by Sonogashira coupling with iodobenzene **2**. Propynyl carbazole **3** can be obtained from carbazole **4** by N-propargylation with propargyl bromide **5**. Carbazole **4** can be obtained from tetrahydrocarbazole **6** *via* aromatization using $CuCl_2 \cdot 2H_2O$. Tetrahydrocarbazole **6** could be obtained by Borsche–Drechsel cyclization of the condensate of cyclohexanone **7** with phenylhydrazinium chloride salt **8**. The phenylhydrazinium chloride salt **8** could be obtained from commercially available aniline **9** by diazotization followed by reduction (scheme 1).

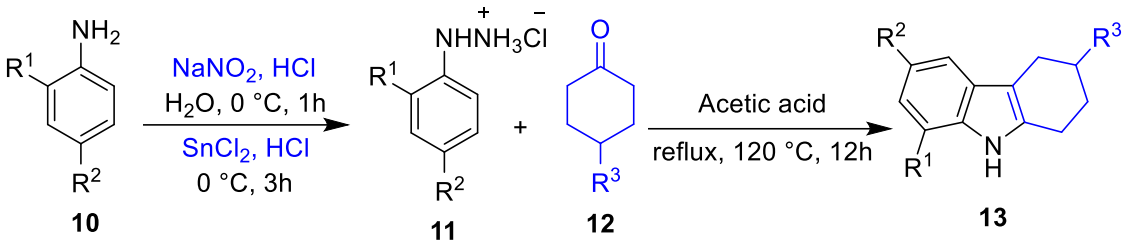
Scheme 1



4. Results and Discussion

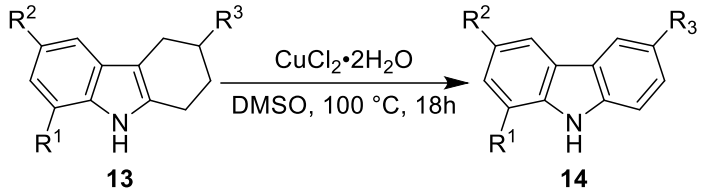
The forward reaction starts with commercially available methylaniline **10**. It was treated with $NaNO_2$ and HCl in water at 0 °C to give the diazo salt, which was further subjected with $SnCl_2$ and HCl at 0 °C to furnish phenylhydrazinium chloride salt **11**. The phenylhydrazinium chloride salt **11** was subjected to Borsche–Drechsel cyclization with commercially available methylcyclohexanone **12** in acetic acid at 120 °C to yield tetrahydrocarbazole **13** (scheme 2).

Scheme 2



Tetrahydrocarbazole **13** was subjected for aromatization in the presence of $CuCl_2 \cdot 2H_2O$ in DMSO at 100 ºC for 18h to furnish 9H-carbazole **14** (scheme 3)**.** By using this method different carbazoles were prepared in good to moderate yield in three steps. Successful coupling reaction of the carbazoles can give access to differently substituted carbazoles.

Scheme 3



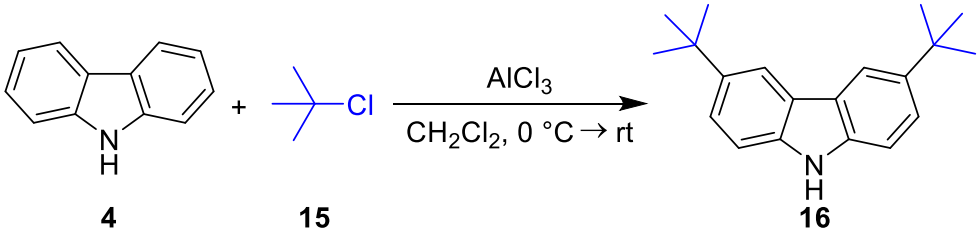
a: R^1 = H, R^2 = Me, R^3 = Me

b: R^1 = Br, R^2 = H, R^3 = H

c: R^1 = Me, R^2 = Me, R^3 = H

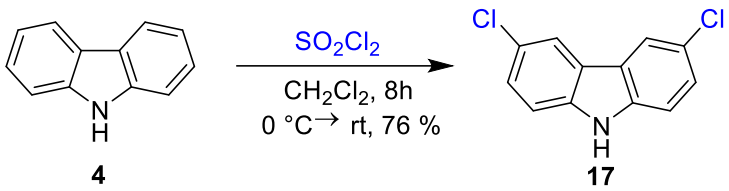
Next in our substrate scope, we perform Friedel Crafts Alkylation on Carabazole **4** by treating it with *t*-BuCl **15** in $AlCl_3$ to produce 3,6 di-tert-butyl-carbazole **16** with a yield of 53 % (scheme 4).

Scheme 4



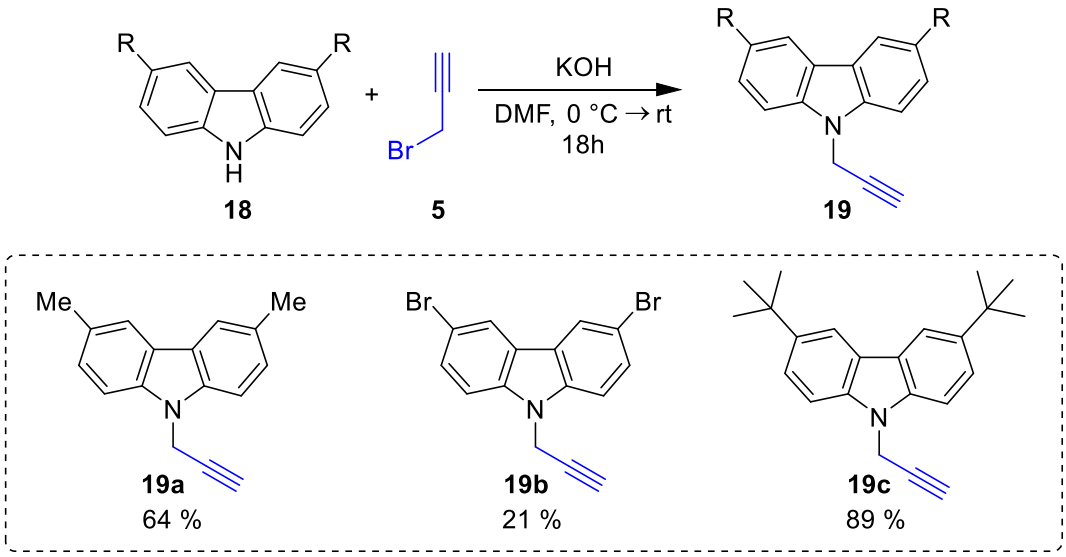
Commercially available 9H-carbazole **4** dissolved in CH_2Cl_2 was treated with sulfuryl chloride to furnish 3, 6 dichloro carbazole **17** (scheme 5), with a 76 % yield, which can further be propargylated and coupled with iodobenzene following the approach detailed in schemes 6 and 7.

Scheme 5



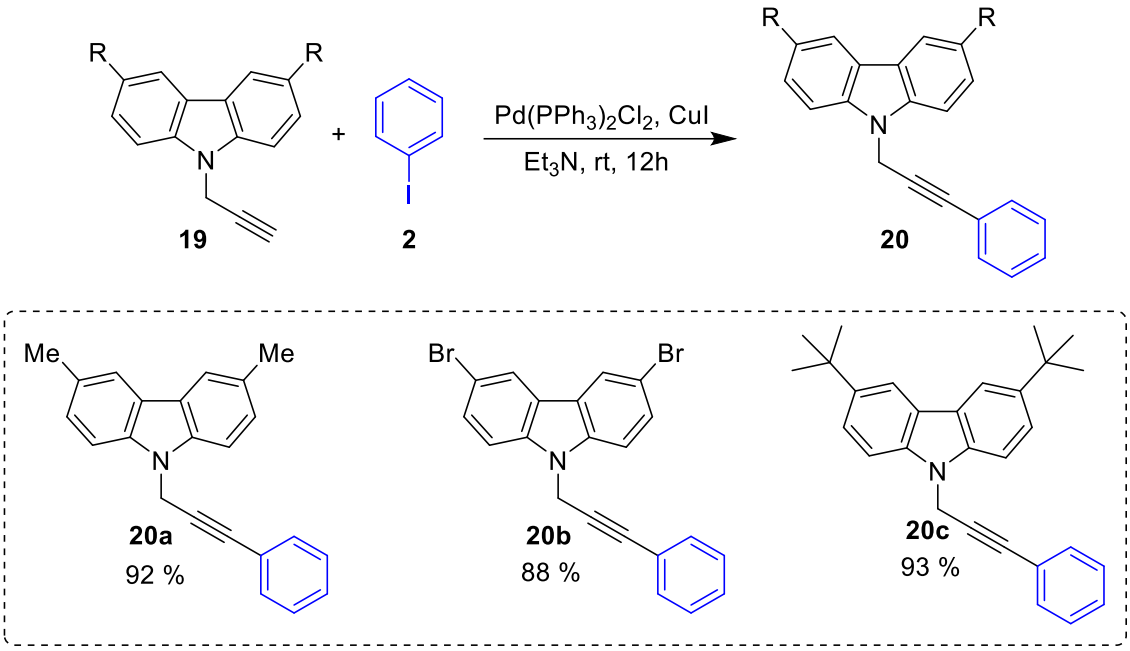
Next, we carry out a substrate scope on 3, 6 di-substituted carbazoles **18** by dissolving them in DMF and adding KOH pellet followed by propargyl bromide at 0 ^{o}C-rt that led to the *N*-propargylation, resulting in the production of 3, 6 di-substituted propynyl carbazoles **19** (scheme 6)**.**

Scheme 6



Following the propargylation, the 3, 6 di-substituted propynyl carbazoles **19** undergoes Sonogashira coupling with iodobenzene in the presence of $Pd(PPh_3)_2Cl_2$ and CuI catalysts to generate 3, 6 di-substituted phenyl propynyl carbazole **20** (scheme 7). The resulting products of this scheme were obtained in excellent yields.

Scheme 7



5. Conclusion

The synthesis of carbazoles has been done successfully. This strategy gives simplest approach toward the synthesis of carbazoles *via* Borsche-Drechsel cyclization which follows a mechanism like the Fischer Indole synthesis. The study presents synthesis of the differently substituted carbazoles as a substrate scope. Coupling reactions on synthesized carbazoles using Sonogashira proves that the carbazole can be used as a building block for designing polymerized and functionalized form of carbazoles which can be studied for their photophysical properties.

6. References

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General experimental:

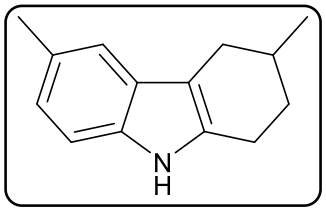
Melting points are recorded using sigma melting point apparatus in capillary tubes and are uncorrected. IR spectra were recorded on Nicolet 6700 spectrophotometer. ^{1}H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded on Bruker Avance 400 spectrometer. ^{1}H (500 MHz) and ^{13}C (125 MHz) NMR spectra were recorded on Bruker Avance 500 spectrometer. The chemical shifts (δ ppm) and coupling constants (Hz) are reported in the standard fashion with reference to either internal tetramethylsilane or residual $CHCl_3$ (7.26 ppm for ^{1}H) or the central line (77.16 ppm) of $CDCl_3$ (for ^{13}C). In the ^{13}C NMR spectra, the nature of the carbons (C, CH, CH_2 or CH_3) was determined by recording the DEPT-135 experiment, and is given in parentheses. Purity of the synthesized carbazoles were studied using High Performance Liquid Chromatography (HPLC) Agilent 1260 Infinity, USA.

High resolution mass measurements were carried out using Maxis impact (Bruker) instrument using direct inlet mode. X-ray diffraction studies were carried out using Bruker Single Crystal Kappa Apex II. Analytical thin-layer chromatographies (TLC) were performed on glass plates (7.5 Å ~ 2.5 and 9 Å ~ 5.0 cm) coated with Merck or Acme's silica gel G containing 13% calcium sulfate as a binder or on pre-coated 0.2 mm thick Merck 60 F245 silica plates and various combinations of ethyl acetate and hexanes were used as eluent. Visualization of spots was accomplished by either exposure to iodine vapour or $KMnO_4$ stain. All small-scale dry reactions were carried out using standard syringe septum technique. Dry dichloromethane was prepared by refluxing over anhydrous P_2O_5 and distillation on to calcium hydride. Dry tetrahydrofuran was prepared by refluxing over anhydrous P_2O_5 and wire of sodium on benzophenone. Dry DMF/DMSO was prepared by stirring on CaH and distillation on to molecular sevies. $AlCl_3$ and CuI were obtained from Aldrich. All other Lewis/Bronsted acids, Na_2CO_3, $[Pd(PPh_3)_2]Cl_2$, aryl halides, cyclohexanone, anilines, acetic acid, $CuCl_2 \cdot 2H_2O$ are commercial reagents and were used as such without further purification. All carbazoles and alkynes were prepared using literature established protocol.

Synthesis of carbazoles

3,6-dimethyl-2,3,4,9-tetrahydro-1H-carbazole:

To a magnetically stirred solution of 4-methylcyclohexan-1-one (2.53 g, 22.568 mmol) in acetic acid (50 mL) was added 2-(p-tolyl)hydrazin-1-ium chloride (3.58 g, 22.568 mmol), portion-wise, at room temperature. Stirred the reaction mixture at 120 ^{o}C until starting material consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water, and filtered using Buchner funnel using water for washing. The organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (2.8676 g, 63 %) as an orange solid.



Physical appearance: Orange solid.

Melting Point: 110 – 112 ℃.

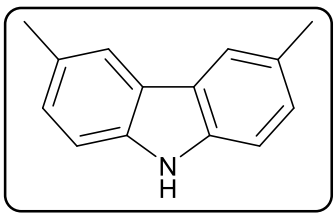
R_f: 0.5 (1.0:9.0, EtOAc:PE).

IR (neat): 3389, 2955, 2915, 2881, 1457, 790, 754, 590 cm^{-1}.

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{14}H_{18}N$ 200.1425 found 200.1425.

3,6-dimethyl-9H-carbazole:

To a magnetically stirred solution of 3,6-dimethyl-2,3,4,9-tetrahydro-1H-carbazole (2.8676 g, 14.388 mmol) in DMSO (30 mL) was added $CuCl_2 \cdot 2H_2O$ (245.2 mg, 1.4388 mmol) at room temperature). Stirred the reaction mixture at 100 ^{o}C until starting material consumed (monitored by TLC). The reaction mixture was quenched with ice, and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (708.1 mg, 25 %) as an orange solid.



Physical appearance: Orange solid.

Melting Point: 173 – 175 ℃.

R_f: 0.5 (1.0:9.0, EtOAc:PE).

IR (neat): 3398, 2918, 1695, 1468, 1300, 1042, 807 cm^{-1}.

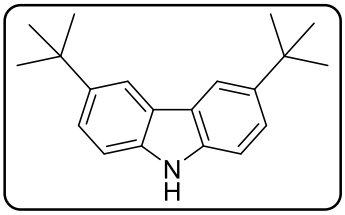
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.96 (s, 1H), 7.84 (s, 2H), 7.34 (d, *J* = 8 Hz, 2H), 7.17 (d, *J* = 8 Hz, 2H), 2.45 (s, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 138.3 (2 × C), 126.8 (2 × C), 126.7 (2 × CH), 122.4 (2 × C), 119.8 (2 × CH), 110.6 (2 × CH), 21.2 (2 × CH_3).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{14}H_{14}N$ 196.1111 found 196.1111.

3,6-di-tert-butyl-9H-carbazole:

To a magnetically stirred solution of 9H-carbazole (2 g, 11.961 mmol) in CH_2Cl_2 (50 mL) was added $AlCl_3$ (1.755 g, 13.1571 mmol) and $(CH_3)_3CCl$ (2.60 mL, 22.922 mmol) dropwise at 0°C. Stirred the reaction mixture up to starting material consumed at room temperature (monitored by TLC). The reaction mixture was quenched with 1N HCl solution and the organic layer was extracted first with 1N HCl (3 × 15 mL), and then with 3N NaCl solution (3 × 15 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (1.796 g, 53 %) as a white solid.



Physical appearance: White solid.

Melting Point: 233 – 235 ℃.

R_f: 0.5 (1.0:9.0, EtOAc: Petether).

IR (neat): 3413, 3057, 2960, 2871,1610, 1492, 1464, 1362, 1296, 1256, 880, 812, 749, 617 cm^{-1}.

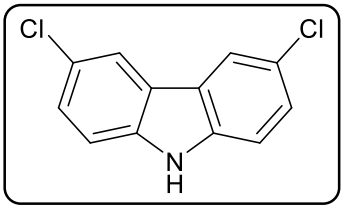
^{1}H NMR (400 MHz, DMSO): δ 11.0 (bs, 1H), 8.10 (d, *J* = 11.2 Hz, 2H), 7.43-7.35 (m, 4H), 1.38 (s, 18H).

^{13}C NMR (100 MHz, DMSO): δ 140.9 (2 × C), 138.4 (2 × C), 123.5 (2 × C), 123.2 (2 × CH), 116.1 (2 × CH), 110.5 (2 × CH), 34.5 (2 × C), 32.07 (6 × CH_3).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{20}H_{26}N$ 280.2068 found 280.2068.

***3,6-dichloro-9H-carbazole*:**

To a magnetically stirred solution of 9H-carbazole (500 g, 2.99 mmol) in CH_2Cl_2 (30 mL) was added SO_2Cl_2 (483.26 µL, 5.98 mmol) dropwise at 0°C. Stirred the reaction mixture until starting material was completely consumed at room temperature (monitored by TLC). Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (706 mg, 76%) as a white solid.



Physical appearance: White Solid

Melting Point: 201 – 203 ℃.

R_f: 0.2 (1.0:9.0, EtOAc: Petether).

IR (neat): 3796, 3525, 3403, 2922, 2854, 2400, 2305, 1734, 1435, 807, 760, 568 cm^{-1}.

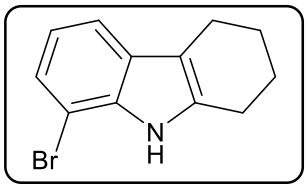
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.87 (bs, 1H), 7.89 (s, 2H), 7.36 – 7.34 (m, 2H), 7.28 – 7.25 (m, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 138.4 (2 × C), 125.6 (2 × CH), 123.5 (2 × C), 122.6 (2 × C), 119.3 (2 × CH), 111.9 (2 × CH).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{12}H_8Cl_2N$ 236.0018 found 236.0018.

***8-bromo-2,3,4,9-tetrahydro-1H-carbazole*:**

To a magnetically stirred solution of cyclohexan-1-one (2.659 g, 11.895 mmol) in acetic acid (50 mL) was added 2-(2-bromophenyl)hydrazin-1-ium chloride (1.167 g, 11.895 mmol), portion-wise, at room temperature. Stirred the reaction mixture at 120 ^{o}C until starting material consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water, and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (2.144 g, 72 %) as a red solid.



Physical appearance: Red solid.

Melting Point: 52 – 54 ℃.

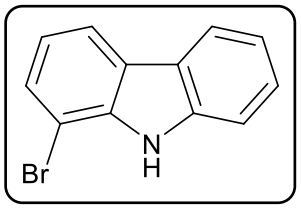
R_f: 0.7 (1.0:9.0, EtOAc: Petether).

IR (neat): 3430, 3057, 2925, 2847, 1620, 1588, 1486, 1461, 1442, 1359, 1324, 1300, 1208, 1188, 1151, 1130, 998, 903, 770, 732 cm^{-1}.

HRMS (ESI, M^+): m/z calcd. for $C_{12}H_{12}BrN$ 249.0123 found 249.0123.

1-bromo-9H-carbazole:

To a magnetically stirred solution of 8-bromo-2,3,4,9-tetrahydro-1H-carbazole (2.12 g, 8.475 mmol) in DMSO (30 mL) was added $CuCl_2 \cdot 2H_2O$ (144.48 mg, 0.847 mmol) at room temperature). Stirred the reaction mixture at 100^{o}C until starting material was consumed (monitored by TLC). The reaction mixture was quenched with ice, and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (54.7 mg, 2.6%) as a red solid.



Physical appearance: Red solid.

Melting Point: 112 – 114 ℃.

R_f: 0.7 (1.0:9.0, EtOAc: Petether).

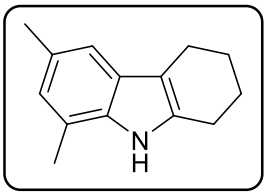
^{1}H NMR (400 MHz, $CDCl_3$): δ 11.44 (s, 1H), 8.11 (d, *J* = 7.6 Hz, 2H), 7.59 (d, *J* = 8.0 Hz, 2H), 7.44 (t, *J* = 8.0 Hz, 1H), 7.20 (t, *J* = 7.6 Hz, 1H), 7.09 (t, *J* = 8.0 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 139.6 (2 × C), 137.8 (2 × C), 127.5 (2 × CH), 126.1 (2 × CH), 124.0 (2 × C), 122.3 (2 × C), 120.4 (2 × CH), 119.7 (2 × CH), 119.3 (2 × CH), 119.1 (2 × CH), 111.4 (2 × CH), 103.2(2 × C).

HRMS (ESI, $M+H^+$): m/z calcd. for $C_{12}H_9BrN$ 245.9903 found 245.9903.

6,8-dimethyl-2,3,4,9-tetrahydro-9H-carbazole:

To a magnetically stirred solution of cyclohexan-1-one (0.921 g, 9.388 mmol) in acetic acid (50 mL) was added 2-(2,4-dimethylphenyl)hydrazin-1-ium chloride (1.621 g, 9.388 mmol), portion-wise, at room temperature. Stirred the reaction mixture at 120 ^{o}C until starting material consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water, and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then product was purified by column chromatography. The product was obtained (1.06 g, 57 %) as a yellow solid.



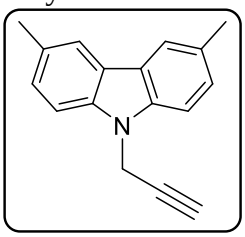
Physical appearance: Yellow solid.

Melting Point: 95-97 ℃.

R_f: 0.7 (1.0:9.0, EtOAc: Petether).

3,6-dimethyl-9-(prop-2-yn-1-yl)-9H-carbazole:

To a magnetically stirred solution of 3,6-dimethyl-9H-carbazole (200 mg, 1.0242 mmol) in DMF (7 mL) KOH pellet (86.18 mg, 1.536 mmol) was added at 0 ^{o}C, and stirred. After 30 minutes, propargyl bromide (171.121 µL, 1.536 mmol) was added, and the reaction mixture was stirred until starting material was fully consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (233.31 mg, 64 %) as a yellow solid.



Physical appearance: Yellow solid.

Melting Point: 130 – 132 ℃.

R_f: 0.6 (1.0:9.0, EtOAc: Petether).

IR (neat): 3298, 3016, 2925, 2867, 1495, 1468, 1430, 1315, 1300, 1264, 1210, 1141, 1059, 1037, 920, 907, 866, 800, 776, 693, 649 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (s, 2H), 7.38-7.34 (m, 4H), 4.98 (d, *J* = 2.4 Hz, 2H), 2.58 (s, 6H), 2.24 (t, *J* = 2.4 Hz, 1H).

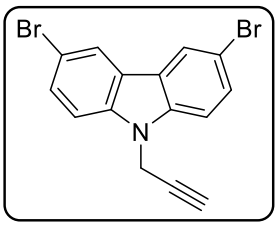
^{13}C NMR (100 MHz, $CDCl_3$): δ 138.6 (2 × C), 128.7 (2 × C), 127.1 (2 × CH), 123.4 (2 × C), 120.5 (2 × CH), 108.5 (2 × CH), 78.19, 72.07, 32.5 (CH_2), 21.5 (2 × CH_3).

HRMS (ESI, M+H^{+}): m/z calcd. for $C_{17}H_{16}N$ 234.1261 found 234.1261.

3,6-dibromo-9-(prop-2-yn-1-yl)-9H-carbazole:

To a magnetically stirred solution of 3,6-dibromo-9H-carbazole (200 mg, 1.0242 mmol) in DMF (3 mL) KOH pellet (52.16 mg, 0.929 mmol) was added at 0 ^{o}C, and stirred. After 30

minutes, propargyl bromide (103.477 µL, 0.929 mmol) was added, and the reaction mixture was stirred until starting material was fully consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (47.20 mg, 21 %) as a white solid.



Physical appearance: White solid.

Melting Point: 194 – 196 ℃

R_f: 0.4 (1.0:9.0, EtOAc: Petether).

IR (neat): 3786, 3277, 2925, 1664, 1473, 1440, 1288, 1213, 1053, 787. 676 cm^{-1}.

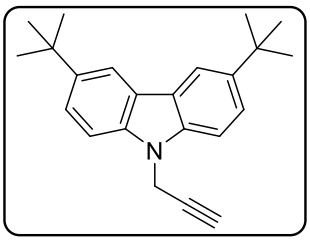
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.12 (s, 2H), 7.58 (dd, *J* = 8.4, 1.6 Hz, 2H), 7.34 (d, *J* = 8.8 Hz, 2H), 4.96 (d, *J* = 2.4 Hz, 2H), 2.284 (t, *J* = 2.8 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 138.9 (2 × C), 129.5 (2 × CH), 124.0 (2 × C), 123.5 (2 × CH), 113.0 (2 × C), 110.6 (2 × CH), 77.0, 73.1, 32.7 (CH_2).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{15}H_{10}Br_2N$ 363.9143 found 363.9143.

3,6-di-tert-butyl-9-(prop-2-yn-1-yl)-9H-carbazole:

To a magnetically stirred solution of 3,6-di-tert-butyl-9H-carbazole (200 mg, 0.7157 mmol) in DMF (10 mL), KOH pellet (60.239 mg, 1.0736 mmol) was added at 0 ^{o}C and stirred. After 30 minutes, propargyl bromide (119.588 µL, 1.0736 mmol) was added, and the reaction mixture was stirred until starting material was fully consumed (monitored by TLC). The reaction mixture was quenched with ice-cold water and the organic layer was extracted with EtOAc (3 × 10 mL) and dried over anhydrous Na_2SO_4. Solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (111 mg, 89 %) as a white solid.



Physical appearance: White solid.

Melting Point: 164 – 166 ℃.

R_f: 0.6 (1.0:9.0, EtOAc: Petether).

IR (neat): 3288, 3054, 2959, 2874, 2125, 1861, 1728, 1623, 1606, 1579, 1476, 1357, 1322, 1298, 1274, 1256, 1219, 1161, 1049, 1036, 929, 898, 802, 758, 676, 654, 616 cm^{-1}.

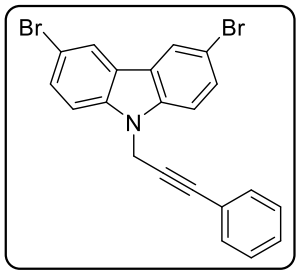
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.13 (d, *J* = 1.6 Hz, 2H), 7.56 (dd, *J* = 8.8, 2.0 Hz, 2H), 7.40 (d, *J* = 8.4 Hz, 2H), 5.00 (d, *J* = 2.4 Hz, 2H), 2.24 (t, *J* = 2.4 Hz, 1H), 1.48 (s, 18H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 142.5 (2 × C), 138.5 (2 × C), 123.7 (2 × CH), 123.3 (2 × C), 116.6 (2 × CH), 108.2 (2 × CH), 78.3, 72.1, 34.8 (2 × C), 32.5 (CH_2), 32.2 (6 × CH_3).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{23}H_{28}N$ 318.2237 found 318.2237.

***3,6-dibromo-9-(3-phenylprop-2-yn-1-yl)-9H-carbazole*:**

To a magnetically stirred solution of 3,6-dibromo-9-(prop-2-yn-1-yl)-9H-carbazole (40 mg, 0.1101 mmol) in $N(CH_2CH_3)_3$ (15 mL) was added iodobenzene (14.737 μL, 0.1322 mmol), followed by $Pd(PPh_3)_3Cl_2$ (3.86 mg, 0.0055 mmol) and CuI (2.09 mg, 0.0110 mmol) at rt. Stirred the reaction mixture up to starting material consumed (monitored by TLC). The solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (42.7 mg, 88%) as a white solid.



Physical appearance: White solid.

Melting Point: 203 – 205 ℃.

R_f: 0.6 (1.0:9.0, EtOAc: Petether).

IR (neat): 3776, 3705, 2922, 2338, 1654, 1468, 1439, 1337, 1288, 1212, 1046, 785, 761, 692 cm^{-1}.

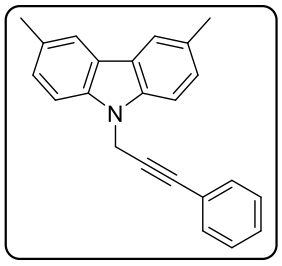
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.13 (d, *J* = 1.8 Hz, 2H), 7.61 (dd, *J* = 1.92, 8.68 Hz, 2H), 7.42 (d, *J* = 8.68 Hz, 2H), 7.38 – 7.36 (m, 2H), 7.32 – 7.28 (m, 3H), 5.18 (s, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 139.0 (2 × C), 131.9 (2 × CH), 129.4 (2 × CH), 128.9 (CH), 128. 4 (2 × CH), 124.0 (2 × C), 123.4 (2 × CH), 122.0 (C), 112.8 (C x 2), 110.7 (2 × CH), 84.8 (C), 82.3 (C), 33.6 (CH_2).

HRMS (ESI, M+H^+): m/z calcd. for $C_{21}H_{14}Br_2N$ 439.9449 found 439.9449.

3,6-dimethyl-9-(3-phenylprop-2-yn-1-yl)-9H-carbazole:

To a magnetically stirred solution of 3,6-dimethyl-9-(prop-2-yn-1-yl)-9H-carbazole (100 mg, 0.4277 mmol) in $N(CH_2CH_3)_3$ (10 mL) was added iodobenzene (57.213 μL, 0.5132 mmol), followed by $Pd(PPh_3)_3Cl_2$ (14.95 mg, 0.0213 mmol) and CuI (8.145 mg, 0.0427 mmol) at rt. Stirred the reaction mixture up to starting material consumed (monitored by TLC). The solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (121.3 mg, 92%) as an orange solid.



Physical appearance: Orange solid.

Melting Point: 118 – 120 ℃.

R_f: 0.7 (1.0:9.0, EtOAc: Petether).

IR (neat): 3016, 2922, 2861, 1612, 1490, 1471, 1332, 1322, 1302, 1266, 1213, 873, 795, 754, 690 cm^{-1}.

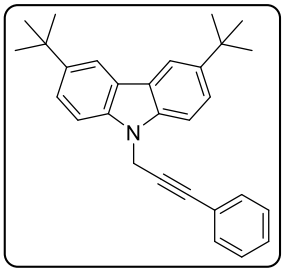
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.90 (s, 2H), 7.44 (d, J = 8.28 2H), 7.37 (dd, *J* = 7.88, 2.24 Hz, 2H), 7.33 (dd, *J* = 8.32, 1.08 Hz, 2H), 7.28 (t, J = 1.84, 2H), 5.21 (s, 2H), 2.57 (s, 6H).

^{13}C NMR (100 MHz, $CDCl_3$, DEPT): δ 138.7 (2 × C), 131.9 (2 × CH), 128.6 (2 × C), 128.5 (CH), 128.3 (2 × CH), 127.1 (2 × CH), 123.3 (2 × C), 122.6 (C), 120.4 (2 × CH), 108.7 (2 × CH), 83.9 (C), 83.7 (C), 33.4 (CH_2), 21.5 (2 × CH_3).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{23}H_{20}N$ 310.1575 found 310.1575.

***3,6-di-tert-butyl-9-(3-phenylprop-2-yn-1-yl)-9H-carbazole*:**

To a magnetically stirred solution of 3,6-di-tert-butyl-9-(prop-2-yn-1-yl)-9H-carbazole (96.2 mg, 0.3030 mmol) in $N(CH_2CH_3)_3$ (20 mL) was added iodobenzene (40.53 μL, 0.3636 mmol), followed by $Pd(PPh_3)_3Cl_2$ (10.59 mg, 0.0151 mmol) and CuI (5.77 mg, 0.0303 mmol) at rt. Stirred the reaction mixture up to starting material consumed (monitored by TLC). The solvent was evaporated in vacuo and then purified by column chromatography. The product was obtained (111.0 mg, 93%) as a yellow solid.



Physical appearance: Yellow solid.

Melting Point: 117 – 119 ℃.

R_f: 0.7 (2.0:8.0, EtOAc: Petether).

IR (neat): 3047, 2952, 2867, 1606, 1479, 1357, 1334, 1322, 1299, 1215, 1159, 1049, 1034, 898, 878, 805, 754, 688, 612, 531 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (s, 2H), 7.62 (d, *J* = 8.64 Hz, 2H), 7.52 (d, *J* = 8.6 Hz, 2H), 7.43 – 7.41 (m, 2H), 7.31 – 7.29 (m, 3H), 5.25 (s, 2H), 1.55 – 1.54 (m, 18H).

^{13}C NMR (100 MHz, $CDCl_3$, DEPT): δ 142.3 (2 × C), 138.7 (2 × C), 131.9 (2 × CH), 128.5 (2 × CH), 128.3 (2 × CH), 123.6 (CH), 123.2 (2 × C), 122.6 (C), 116.5 (2 × CH), 108.4 (2 × CH), 83.8 (2 × CH), 34.8 (2 × C), 33.3 (CH_2), 32.2 (6 × CH_3).

HRMS (ESI, M+H$^+$): m/z calcd. for $C_{29}H_{32}N$ 394.2517 found 394.2517.