Supporting Information

Synthesis of Pyrazoles through Copper-Catalyzed Three-Component Coupling of Aldehydes, Alkynes, and p-Toluenesulfonylhydrazide

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I. General Information

Unless otherwise noted, all reagents were obtained commercially and used without further purification. All reaction mixtures were stirred with a magnetic bar in flame-dried glassware.

Chromatography

Thin layer chromatography (TLC) was performed on Huanghai pre-coated glass-backed TLC plates and visualized by UV lamp (254 nm). Column chromatography on silica gel (300-400 mesh) was carried out using Technical Grade 60-90 °C v/v petroleum ether (distilled prior to use) and Analytical Grade EtOAc (without further purification). Concentration under reduced pressure was performed by rotary evaporation. Purified compounds were further addressed under high vacuum (3-5 mmHg). Yields referred to chromatographically purified compounds.

Nuclear Magnetic Resonance Spectra

$^1$H and $^{13}$C spectra were recorded on a Bruker AV-400 spectrometer. Chemical shifts were reported in ppm. $^1$H-NMR spectra were referenced to TMS in CDCl$_3$ (0 ppm) or DMSO-$d_6$ (2.50 ppm), and $^{13}$C-NMR spectra were referenced to CDCl$_3$ (77.0 ppm) or DMSO-$d_6$ (39.5 ppm). All $^{13}$C-NMR spectra were measured with complete proton decoupling. Peak multiplicities were designated by the following abbreviations: s, singlet; d, doublet; t, triplet; m, multiplet; brs, broad singlet and $J$, coupling constant in Hz.

Melting points

Melting points were measured on a Büchi Melting Point B-540 Apparatus using open glass capillaries and are uncorrected.

IR Spectra

IR spectra were recorded on a Nicolet AVATER FTIR360 spectrometer as thin film. Absorptions were given in wavenumbers (cm$^{-1}$).

Mass Spectroscopy

MS measurements were performed on Bruker Reflex III mass spectrometer.

High resolution mass spectroscopy

Data were obtained via Ultra-high Resolution Hybrid Qh-Fourier Transform Mass Spectrometer (En Apex ultra 7.0 FT-MS) operated by Department of Chemistry, Xiamen University.

II. Spectroscopic Analysis
Because of the dynamic tautomeric forms of the NH-pyrazoles, their $^{13}$C NMR spectra are unusual as normal organic compounds show. They often exhibit concentration and solvent-dependent NMR spectra (see the reference "M. T. Chenon, C. Coupry, D. M. Grant, R. J. Pugmire, *J. Org. Chem.*, 1977, 42, 659." for more details). The biggest effect can be seen in the $^{13}$C NMR spectra is that the C-3, C-5 and α-carbons appears as very broad signals that unresolved from the baseline. In other words, these carbons are missing from the spectra. To circumvent this issue, derivatization such as alkylation has been adopted to provide spectra where all carbons can be found.

![Chemical structures and reaction scheme](attachment:image.png)

The derivatization of 4a and 4f

For example, compound 4a and 4f was treated with KOH and n-BuBr (1-bromobutane) in DMF at room temperature to readily generate the corresponding 1-butyl-3,5-diphenyl-1H-pyrazole (4a'), 1-butyl-3-(4-fluorophenyl)-5-phenyl-1H-pyrazole (4f') and 1-butyl-5-(4-fluorophenyl)-3-phenyl-1H-pyrazole (4f'') in nearly quantitative yield (4f' and 4f'' were produced as a mixture which could not be separated by column chromatography, and the isomers ratio is 3:5). These compounds are well dissolved in CDCl$_3$ (4a and 4f are insoluble in CDCl$_3$), and analyzed by $^{13}$C NMR to give $^{13}$C spectra that provide sharp signals with all of the carbons being found (see the supporting information for more details). The two examples are provided as additional supports for characterization of the pyrazole products via $^{13}$C NMR.

**III. Experimental**

General procedure for the synthesis of pyrazoles: To a flame-dried 5-mL flask equipped with a magnetic bar, aldehyde 1 (0.5 mmol, 1.0 equiv.), *p*-toluenesulfonylhydrazide 2 (0.6 mmol, 1.2 equiv.), alkyne 3 (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were
added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product was purified by column chromatography on silica gel to afford 4.

**IV. Spectral data of Substituted Pyrazoles**

![Image of 3,5-Diphenyl-1H-pyrazole (4a)]

**3,5-Diphenyl-1H-pyrazole (4a):**

To a flame-dried 5-mL flask equipped with a magnetic bar, benzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4a) was purified by column chromatography on silica gel to afford a white solid in 60% yield (mp 190-192 °C).

**^1H-NMR (400 MHz, DMSO): δ 7.17 (s, 1H), 7.31-7.35 (m, 2H), 7.43-7.46 (m, 4H), 7.84 (m, 4H), 13.39 (brs, 1H);**

**^13C-NMR (100 MHz, DMSO): δ 99.6, 125.2, 128.8; IR (film): 3417, 3101, 1610, 1494 cm⁻¹;**

**ESI-MS: calc. for C₁₅H₁₂N₂ [M+H]⁺: m/z = 221.1; found: 221.3.**

![Image of 3-(4-Methylphenyl)-5-phenyl-1H-Pyrazole (4b)]

**3-(4-Methylphenyl)-5-phenyl-1H-Pyrazole (4b):**

To a flame-dried 5-mL flask equipped with a magnetic bar, 4-methylbenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4b) was purified by column chromatography on silica gel to afford a white solid in 61% yield (mp 162-164 °C).

**^1H-NMR (400 MHz, DMSO): δ 2.32 (s, 3H), 7.12 (s, 1H), 7.24-7.45 (m, 5H), 7.72 (d, 2H, J = 6.4 Hz), 7.84 (d, 2H, J = 6.0 Hz), 13.3 (brs, 1H);**

**^13C-NMR (100 MHz, DMSO): δ 20.8, 99.3, 125.1, 125.2, 128.3, 128.8, 129.4; IR (film): 3421, 3021, 1608, 1508 cm⁻¹;**

**ESI-MS: calc. for C₁₆H₁₄N₂ [M+H]⁺: m/z = 235.1; found: 235.3.**
3-(4-Methoxyphenyl)-5-phenyl-1H-pyrazole (4c): To a flame-dried 5-mL flask equipped with a magnetic bar, 4-methoxybenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4c) was purified by column chromatography on silica gel to afford a white solid in 62% yield (mp 145-146 °C). ¹H-NMR (400 MHz, DMSO): δ 3.78 (s, 3H), 7.02 (s, 2H), 7.06 (s, 1H), 7.32-7.43 (m, 3H), 7.71-7.82 (m, 4H), 13.23(brs, 1H); ¹³C-NMR (100 MHz, DMSO): δ 55.6, 99.2, 114.8, 125.5, 126.9, 129.2; IR (film): 3350, 3102, 1613, 1509, 1252 cm⁻¹; ESI-MS: calc. for C₁₆H₁₂N₂O [M+H]⁺: m/z = 251.1; found: 251.3.

3-(4-Bromophenyl)-5-phenyl-1H-Pyrazole (4d): To a flame-dried 5-mL flask equipped with a magnetic bar, 4-bromobenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4d) was purified by column chromatography on silica gel to afford a white solid in 55% yield (mp 217-219 °C). ¹H-NMR (400 MHz, DMSO): δ 7.19 (s, 1H), 7.34-7.45 (m, 3H), 7.56-7.63 (m, 2H), 7.73-7.81 (m, 4H), 13.46(brs, 1H); ¹³C-NMR (100 MHz, DMSO): δ 99.9, 125.2, 127.2, 128.4, 129.0, 129.4, 131.5, 131.7; IR (film): 3345, 3142, 1623, 1512 cm⁻¹; ESI-MS: calc. for C₁₅H₁₁N₂Br [M+H]⁺: m/z = 299.0, 301.0; found: 299.1, 301.2.

3-(4-Chlorophenyl)-5-phenyl-1H-Pyrazole (4e): To a flame-dried 5-mL flask equipped with a
magnetic bar, 4-chlorobenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4e) was purified by column chromatography on silica gel to afford a white solid in 55% yield (mp 216-218 °C). $^1$H-NMR (400 MHz, DMSO): $\delta$ 7.20 (s, 1H), 7.32-7.49 (m, 5H), 7.82-7.86 (m, 4H), 13.44(brs, 1H); $^{13}$C-NMR (100 MHz, DMSO): $\delta$ 99.9, 125.1, 126.8, 128.9; IR (film): 3340, 3143, 1618, 1490 cm$^{-1}$; ESI-MS: calc. for C$_{15}$H$_{11}$N$_2$Cl [M+H]$^+$: m/z = 255.1; found: 255.2.

3-(4-Fluorophenyl)-5-phenyl-1H-Pyrazole (4f):$^{3,4}$ To a flame-dried 5-mL flask equipped with a magnetic bar, 4-fluorobenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4f) was purified by column chromatography on silica gel to afford a white solid in 57% yield (mp 167-169 °C). $^1$H-NMR (400 MHz, DMSO): $\delta$ 7.15 (s, 1H), 7.27-7.37 (m, 4H), 7.43-7.46 (m, 2H), 7.83-7.88 (m, 3H), 13.39(brs, 1H); $^{13}$C-NMR (100 MHz, DMSO): $\delta$ 100.0, 116.2, 125.6, 127.6, 128.0, 129.2, 131.5; IR (film): 3321, 3118, 1606, 1520 cm$^{-1}$; ESI-MS: calc. for C$_{15}$H$_{11}$N$_2$F [M+H]$^+$: m/z = 239.1; found: 239.2.

4-(5-Phenyl-1H-pyrazol-3-yl)benzonitrile (4g):$^5$ To a flame-dried 5-mL flask equipped with a magnetic bar, 4-formylbenzonitrile (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion,
the product (4g) was purified by column chromatography on silica gel to afford a yellow oil in 32% yield. $^1$H-NMR (400 MHz, DMSO): $\delta$ 7.34 (s, 1H), 7.41-7.44 (m, 3H), 7.66-7.87 (m, 5H), 8.04 (s, 1H), 13.65 (brs, 1H);$^{13}$C-NMR (100 MHz, DMSO): $\delta$ 100.8, 110.5, 118.8, 125.3, 125.7, 127.0, 128.3, 128.5, 128.9, 129.9, 132.6, 146.9, 157.8; IR (film): 3335, 3120, 2223, 1608, 1497 cm$^{-1}$; ESI-MS: calc. for C$_{16}$H$_{11}$N$_3$ [M+H]$^+$: m/z (%) = 246.1; found: 246.3.

3-(Furan-2-yl)-5-phenyl-1H-pyrazole (4h):$^2$ To a flame-dried 5-mL flask equipped with a magnetic bar, furan-2-carbaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4h) was purified by column chromatography on silica gel to afford a yellow solid in 30% yield (mp 172-173 °C). $^1$H-NMR (400 MHz, CDCl$_3$): $\delta$ 6.49 (dd, 1H, $J$ = 3.2, 1.6 Hz), 6.67 (d, 1H, $J$ = 3.2 Hz), 6.78 (d, 1H, $J$ = 1.6 Hz), 7.31-7.46 (m, 4H), 7.72 (d, 2H, $J$ = 7.2 Hz); $^{13}$C-NMR (100 MHz, CDCl$_3$): $\delta$ 99.4, 106.6, 111.4, 125.7, 128.4, 128.9, 129.5, 142.1, 146.7, 148.2; IR (film): 3371, 3054, 1609, 1596 cm$^{-1}$; ESI-MS: calc. for C$_{13}$H$_{10}$N$_2$O [M+H]$^+$: m/z (%) = 211.1; found: 211.2.

3-(4-nitrophenyl)-5-phenyl-1H-pyrazole (4i):$^9$ To a flame-dried 5-mL flask equipped with a magnetic bar, 4-nitrobenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), phenylacetylene (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4i) was purified directly by column chromatography on silica gel to afford a white solid in 38% yield (mp 278-279 °C). $^1$H-NMR (400 MHz, DMSO): $\delta$ 7.27-7.60 (m, 4H),
7.84-8.31 (m, 6H), 13.72 (brs, 1H); $^{13}$C-NMR (100 MHz, DMSO): $\delta$ 101.0, 123.2, 124.1, 125.3, 125.2, 125.6, 125.8, 127.0, 128.9, 146.4, 150.7; IR (film): 3190, 2920, 1644, 1515, 1457, 1330, 1299 cm$^{-1}$; ESI-MS: calc. for C$_{15}$H$_{11}$N$_3$O$_2$ [M+H]$^+$: m/z (%) = 265.1; found: 265.2.

![4j](image.png)

5-Butyl-3-phenyl-1H-pyrazole (4j):$^7$ To a flame-dried 25-mL sealed tube equipped with a magnetic bar, benzaldehyde (0.5 mmol, 1.0 equiv.), $p$-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), hex-1-yne (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4j) was purified by column chromatography on silica gel to afford a yellow oil in 51% yield.

$^1$H-NMR (400 MHz, DMSO): $\delta$ 0.91 (t, 3H, $J = 7.6$ Hz), 1.29-1.35 (m, 2H), 1.57-1.61 (m, 2H), 2.59 (t, 2H, $J = 7.6$ Hz), 6.44 (s, 1H), 7.25 (t, 1H, $J = 7.6$ Hz), 7.37 (dd, 2H, $J = 7.6, 7.6$ Hz), 7.75 (t, 2H, $J = 7.6$ Hz); $^{13}$C-NMR (100 MHz, DMSO): $\delta$ 13.7, 21.8, 31.1, 100.3, 127.3, 128.7; IR (film): 3421, 3101, 1620, 1514 cm$^{-1}$; HRMS(ESI): calc. for C$_{13}$H$_{16}$N$_2$ [M+H]$^+$: m/z (%) = 201.1392; found: 201.1384.

![4k](image.png)

5-Butyl-3-p-tolyl-1H-pyrazole (4k): To a flame-dried 25-mL sealed tube equipped with a magnetic bar, 4-methylbenzaldehyde (0.5 mmol, 1.0 equiv.), $p$-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), hex-1-yne (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4k) was purified by column chromatography on silica gel to afford a yellow oil in 56% yield. $^1$H-NMR (400 MHz, CDCl$_3$) $\delta$ 0.90 (t, 3H, $J = 7.6$ Hz), 1.30-1.37 (m, 2H), 1.59-1.63 (m, 2H), 2.36 (s, 3H), 2.59 (t, 2H, $J = 7.6$ Hz), 6.32 (s, 1H), 7.16 (d, 2H, $J = 8.0$ Hz), 7.62 (d, 2H, $J = 8.0$ Hz); $^{13}$C-NMR (100 MHz, CDCl$_3$): $\delta$ 13.7, 21.2, 22.3, 26.1, 31.3, 100.6, 125.6, 129.2,
5-Butyl-3-(4-chlorophenyl)-1H-pyrazole (4I): To a flame-dried 25-mL sealed tube equipped with a magnetic bar, 4-chlorobenzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), hex-1-yn (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4I) was purified by column chromatography on silica gel to afford a colorless crystal in 42% yield (mp 65-66 °C); ¹H-NMR (400 MHz, DMSO): δ 0.90 (t, 3H, J = 7.2 Hz), 1.29-1.34 (m, 2H), 1.56-1.62 (m, 2H), 2.59 (t, 2H, J = 7.2 Hz), 6.46 (s, 1H), 7.41 (d, 2H, J = 8.4 Hz), 7.37 (d, 2H, J = 8.4 Hz), 12.66 (brs, 1H); ¹³C-NMR (100 MHz, DMSO): δ 13.7, 21.8, 31.1, 100.3, 126.7, 128.7; IR (film): 3417, 3116, 1643, 1510 cm⁻¹; ESI-MS: calc. for C₁₄H₁₈N₂[M+H]+: m/z (%) = 215.1548; found: 215.1541.

Methyl 4-(5-butyl-1H-pyrazol-3-yl)benzoate (4m): To a flame-dried 25-mL sealed tube equipped with a magnetic bar, methyl 4-formylbenzoate (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), hex-1-yn (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)₂ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4m) was purified by column chromatography on silica gel to afford a white solid in 35% yield (mp 87-89 °C); ¹H-NMR (400 MHz, CDCl₃): δ 0.87 (t, 3H, J = 7.6 Hz), 1.28-1.33 (m, 2H), 1.55-1.63 (m, 2H), 2.59 (t, 2H, J = 7.6 Hz), 3.91 (s, 3H), 6.39 (s, 1H), 7.78 (d, 2H, J = 8.4 Hz), 8.00 (d, 2H, J = 8.4 Hz); ¹³C-NMR (100MHz, CDCl₃): δ 13.7, 22.2, 25.8, 31.2, 52.0, 101.5, 125.4, 129.0, 130.0, 137.3, 147.4, 149.5,
166.9; \textbf{IR} (film): 3322, 3002, 1772, 1604, 1095 cm$^{-1}$; \textbf{HRMS(ESI)}: calc. for C$_{15}$H$_{18}$N$_2$O$_2$ [M+H]$^+$: m/z (%) = 259.1447; found: 259.1442.

5-Cyclopropyl-3-phenyl-1H-pyrazole (4n):$^8$ To a flame-dried 25-mL sealed tube equipped with a magnetic bar, benzaldehyde (0.5 mmol, 1.0 equiv.), p-toluenesulfonylhydrazide (0.6 mmol, 1.2 equiv.), ethynylcyclopropane (1.5 mmol, 3.0 equiv.), chlorobenzene (3 mL) and Cu (OTf)$_2$ (0.1 mmol) were added successively. The mixture was stirred at rt until the 2 was dissolved, then heated to reflux for an appropriate time, and monitored periodically by TLC. Upon completion, the product (4n) was purified by column chromatography on silica gel to afford a white solid in 45% yield (mp 96-98 °C). \textbf{H-NMR} (400 MHz, CDCl$_3$): $\delta$ 0.72-0.73 (m, 2H), 0.83-0.88 (m, 2H), 1.80-1.87 (m, 1H), 6.16 (s, 1H), 7.23-7.26 (m, 1H), 7.29-7.32 (m, 2H), 7.65-7.67 (m, 2H); \textbf{C-NMR} (100 MHz, CDCl$_3$): $\delta$ 7.7, 7.8, 98.6, 125.7, 127.7, 128.6, 132.2, 149.1, 150.8; \textbf{IR} (film): 3404, 3130, 1600, 1503 cm$^{-1}$; \textbf{ESI-MS}: calc. for C$_{12}$H$_{12}$N$_2$ [M+H]$^+$: m/z (%) = 185.1; found: 185.2.

1-butyl-3,5-diphenyl-1H-pyrazole (4a' ): To a flame-dried flask (10 mL) equipped with a magnetic stirring bar, the pyrazole 4a (1.0 mmol, 1.0 equiv.), KOH (2.0 mmol, 2.0 equiv.), and DMF (5 mL) were successively added. The mixture was stirred at rt for 1 hour. Subsequently, n-BuBr (1-bromobutane) (1.2 mmol, 1.0 equiv) was added dropwise. The mixture was stirred at rt for another hour, and monitored periodically by the TLC. Upon completion of the reaction, the solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel to afford 4a' as a yellow oil in nearly quantitative yield. \textbf{H-NMR} (400 MHz, CDCl$_3$): $\delta$ 0.88 (t, 3H, $J=7.6$ Hz), 1.24-1.32 (m, 2H), 1.83-1.90 (m, 2H), 4.16-4.20 (m,
2H), 6.60 (s, 1H), 7.31-7.34 (m, 1H), 7.41-7.51 (m, 7H), 7.88 (d, 2H, \( J=7.6 \) Hz); \(^{13}\text{C-NMR} (100 MHz, CDCl\textsubscript{3}): \delta 13.6, 19.8, 32.6, 49.4, 103.2, 125.5, 127.4, 128.4, 128.5, 128.6, 128.9, 131.0, 133.6, 144.8, 150.4; \text{IR} (film): 3178, 1610, 1514 cm\(^{-1}\); \text{HRMS} (ESI): calc. for C\textsubscript{19}H\textsubscript{20}N\textsubscript{2} [M+H]\(^+\): m/z (%) = 277.1705; found: 277.1704.

1-butyl-3-(4-fluorophenyl)-5-phenyl-1H-pyrazole(4f') and 1-butyl-5-(4-fluorophenyl)-3-Pheny1-1H-pyrazole(4f''): To a flame-dried flask (10 mL) equipped with a magnetic stirring bar, the pyrazole 4f (1.0 mmol, 1.0 equiv.), KOH (2.0 mmol, 2.0 equiv.), and DMF (5 mL) were successively added. The mixture was stirred at rt for 1 hour. Subsequently, \( n \)-BuBr (1-bromobutane) (1.2 mmol, 1.0 equiv.) was added dropwise. The mixture was stirred at rt for another hour, and monitored periodically by the TLC. Upon completion of the reaction, the solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel to afford 4f' and 4f'' (a mixture of isomers, and the isomers ratio is 3:5) as a yellow oil in nearly quantitative yield. \(^1\text{H-NMR} (400 MHz, CDCl\textsubscript{3}): \delta 0.86 (t, 4.96H, \( J=7.2 \) Hz), 1.25-1.31 (m, 3.26H), 1.83-1.84 (m, 3.61H), 4.10-4.16 (m, 3.42H), 6.52 (s, 1H), 6.55 (s, 0.65H), 7.08-7.12 (m, 2.31H), 7.15-7.19 (m, 1.5H), 7.31-7.48 (m, 8.32H), 7.80-7.86 (m, 3.24H); \(^{13}\text{C-NMR} (100 MHz, CDCl\textsubscript{3}): \delta 13.6, 19.8, 32.7, 49.4, 49.5, 103.1, 103.3, 115.5 (\( ^{2}J_{\text{CF}} = 22 \) Hz), 115.8 (\( ^{2}J_{\text{CF}} = 22 \) Hz), 125.6, 127.2 (\( ^{2}J_{\text{CF}} = 8 \) Hz), 127.6, 128.5, 128.6, 128.7, 128.9, 129.7, 129.9, 130.8 (\( ^{2}J_{\text{CF}} = 8 \) Hz), 131.0, 133.6, 143.8, 145.0, 149.6, 150.5, 162.5 (\( ^{1}J_{\text{CF}} = 244 \) Hz), 162.8 (\( ^{1}J_{\text{CF}} = 244 \) Hz); \text{IR} (film): 3180, 1608, 1509, 1329 cm\(^{-1}\); \text{HRMS} (ESI): calc. for C\textsubscript{19}H\textsubscript{19}FN\textsubscript{2} [M+H]\(^+\): m/z (%) = 295.1611; found: 295.1604.

References
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IV. $^1$H, $^{13}$C-NMR Spectra

4a

[Diagram of NMR spectra]