Indian Journal of Chemistry
Vol. 65, April 2026, pp. 328-336
DOI: 10.56042/ijc.v65i4.21611

Functional vinyl-1,8-naphthyridine copper(I) complex as efficient synergistic catalyst with KI for N-arylation coupling reactions

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Received 15 July 2025; accepted (revised) 6 April 2026

An efficient and novel functional vinyl-1,8-naphthyridine copper(I) complex has been exploited as a synergistic catalyst for the cross-coupling reactions of aryl halides with imidazoles, benzimidazole, or pyrazole, offering a practical approach for C–N bond formation. Remarkably, this catalytic system operates under aerobic conditions with a low catalyst loading (2% molar fraction) and an inexpensive base. The protocol exhibits excellent tolerance towards aryl halides bearing diverse functional groups, including methyl, methoxy, acetyl, fluoro, nitrile, and nitro groups, among others. It consistently furnishes the corresponding coupling products in moderate to high yields. In total, 31 examples have been demonstrated, with the catalytic yields reaching up to 96%.

Keywords: Vinyl-1,8-naphthyridine, Copper (I) complex, Imidazole, Benzimidazole, Pyrazole, Cross-coupling reaction, N-Arylation

Naphthyridines (pyridopyridines, diazanaphthalenes) encompass a set of six isomeric heterocyclic frameworks featuring two fused pyridine rings with distinct relative arrangements of nitrogen atoms. These compounds have been well-documented in previous studies[1,2]. Over the past two decades, among the six isomeric pyridopyridines, 1,8-naphthyridine derivatives have received the most extensive investigation[3-9]. The 1,8-naphthyridine scaffolds are particularly intriguing synthetic targets. This is attributed to the broad array of biological activities they exhibit, such as antibacterial, anti-inflammatory, antitumor, antimalarial, antiproliferative, antihypertensive, and antioxidant properties[10-13]. Moreover, due to their remarkable optical characteristics, certain 1,8-naphthyridine derivatives have been rationally designed and developed as fluorescent dyes and sensors[14-19]. A family of dinucleating 1,8-naphthyridine complex have drawn significant attention from the synthetic chemistry community over the last few decades due to the range of possible reaction pathways that result from close metal−metal contacts[20-24].

On the other hand, N-Aryl imidazoles constitute crucial structural motifs in a vast array of agrochemicals, pharmaceuticals, and biologically active compounds, as reported in references[25,26]. In recent years, Buchwald *et al*.[27] and Taillefer *et al*.[28] discovered that several N-and O-based ligands could significantly promote the copper-catalyzed pathway for the N-arylation of imidazoles. Nevertheless, this method still has some limitations. For instance, the high stoichiometric consumption of the copper reagent or ligand (usually 20% molar fraction) and the relatively long reaction time (generally 24-72 h) are notable drawbacks[29-31].

Therefore, a series of 1,8-naphthyridine derivatives bearing vinyl groups, along with the complex $Cu_2L_1(PPh_3)_2$(PPh_3 = triphenylphosphine), have been rationally designed and synthesized. These compounds were thoroughly characterized by single - crystal X-ray diffraction analysis. Moreover, a comprehensive investigation of their spectroscopic properties, integrating both experimental and theoretical studies, is presented[32]. To the best of our knowledge, there has been no prior report on the utilization of a vinyl-1,8-naphthyridine copper-catalyst in C–N cross-coupling reactions. Based on these considerations, we herein report the synthesis of a novel vinyl-1,8-naphthyridine derivative, along with its first-ever application in the direct copper(I) complex catalyzed N-arylation of imidazoles, benzimidazoles, or pyrazoles. The experimental results are highly satisfactory.

Experimental Section

General Information

All reagents were procured from commercial sources and utilized without further purification. Column chromatography was conducted using silica gel (200–300 mesh). Thin-layer chromatography was carried out on Merck silica gel GF_{254} plates. ^1H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra were recorded in $CDCl_3$. Chemical shifts were referenced to tetramethylsilane (TMS) as the internal standard. Chemical shifts are reported in ppm, and coupling constants (*J*) are given in Hz. Matrix-assisted laser desorption/ionization-time of flight (MALDI-TOF) MS data were acquired on a Bruker Biflex III Model MALDI-TOF mass spectrometer. Elemental analyses for C, H, and N were performed on a Perkin-Elmer 240 analyzer.

Single crystals of **C1** appropriate for X-ray diffraction analysis were obtained *via* the slow diffusion of diethyl ether vapors into a dichloromethane solution. The diffraction data were collected on a Rigaku R-AXIS RAPID IP X-Ray diffractometer, employing a graphite monochromator with MoKα radiation (λ = 0.071073 nm) at 293 K. The structures were determined by direct methods and refined using full-matrix least-squares methods based on all F^2 data with the SHELX-97 software[33]. Non-hydrogen atoms were refined anisotropically. The positions of hydrogen atoms were calculated and refined isotropically. A summary of the crystallographic parameters and data is presented in Figures S3–S6 and Tables S1–S3.

Synthesis and Characterization

2-Acetyl amino1,8-naphthyridine[34], N-(7-formyl-1,8-naphthyridine-2-yl) acetamide (**1a**)[35,36], Methyl 4-(bromomethyl) benzoate (**1b**)[37] and $Cu(CH_3CN)_4BF_4$ (Ref. 38) were synthesized by the reported procedure.

Intermediate **1c**: Methyl 4-(bromomethyl)benzoate (2.36 g, 10.3 mmol), triphenylphosphine (2.97 g, 11.3 mmol), and freshly distilled toluene (60 mL) were combined in a 100 mL flask. The mixture was refluxed with stirring for 4 h under a nitrogen atmosphere, during which a white solid precipitated. After cooling to RT, the solid was collected by filtration, washed with ether, and then dried *in vacuo* at 50°C to afford the desired methyl 4-(bromomethyl)benzoate phosphonium salt (4.2 g, 84%). The obtained methyl 4-(bromomethyl)benzoate phosphonium salt was unstable and was directly used in the subsequent step.

Vinyl-1,8-naphthyridine **L1**: In a 50 mL flask, methyl 4-(bromomethyl)benzoate phosphonium salt (600 mg, 1.22 mmol), anhydrous NaH (30 mg, 0.25 mmol), and 40 mL of freshly distilled toluene were introduced. The mixture was stirred at RT for 4 h. Once the color turned yellow-orange, N-(7-formyl-1,8-naphthyridin-2- yl)acetamide (0.28 g, 1.24 mmol) was added, and the resulting mixture was refluxed under a nitrogen atmosphere for 24 h. After completion of the reaction, it was quenched by the addition of H_2O (10 mL). The aqueous phase was then extracted with CH_2Cl_2 (3 × 10 mL). The combined organic layers were washed with brine (30 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude product was purified by silica gel column chromatography using a CH_2Cl_2:CH_3OH (40:1) eluent system, affording **L1** as a pale-yellow solid with a yield of 49%. ^1H NMR (500 MHz, $CDCl_3$): δ 8.57 (s, 1H NH), 8.51 (d, *J* = 8.8 Hz, 1H Napy-H), 8.19 (d, *J* = 8.8 Hz, 1H Napy-H), 8.15 (s, 1H Napy-H), 8.09 (d, *J* = 8.3 Hz, 2H Ar-H), 8.05 (d, *J* = 16.1 Hz, 1H ethylene proton), 7.71 (d, *J* = 8.3 Hz, 2H Ar-H), 7.57 (d, *J* = 8.2 Hz, 1H Napy-H), 7.43 (d, *J* = 16.0 Hz, 1H ethylene proton), 3.96 (s, 3H OCH_3), 2.31 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 169.36, 66.62, 158.46, 154.65, 153.96, 140.62, 139.08, 137.00, 134.77, 132.14, 130.12, 127.30, 120.57, 119.86, 114.68, 52.09, 24.92; MALDI-TOF MS: *m/z* 348.0$[M+H]^+$, 370.0$[M+Na]^+$. Anal. Calcd for $C_{20}H_{17}N_3O_3$: C, 69.15; H, 4.93; N, 12.10; O, 13.82. Found: C, 69.19; H, 4.96; N, 13.53%.

Complex **C1**: Under a nitrogen atmosphere, vinyl-1,8-naphthyridine **L1** (0.072 g, 0.2 mmol) and $Cu(CH_3CN)_4BF_4$ (0.063 g, 0.2 mmol) were mixed with stirring in dichloromethane (25 mL). A yellow precipitate formed during the reaction. After stirring at RT for 3 h, PPh_3 (0.105 g, 0.4 mmol) was added, causing the yellow suspension to gradually dissolve. The resulting solution was further stirred for 2 h and then filtered. The filtrate was concentrated under vacuum, and the crude product was recrystallized from a CH_2Cl_2/diethyl ether mixture to yield a yellow solid. Yellow crystals were obtained by slow diffusion of diethyl ether into a dichloromethane solution of the solid. The yellow crystalline solid was characterized by elemental analysis and X-ray crystallography. Yield: 39%. MALDI-TOF MS: *m/z* 936.45$[M+H]^+$. Anal. Calcd for $C_{56}H_{46}CuN_3O_3P_2$: C, 71.98; H, 4.96; Cu, 6.80; N, 4.50; O, 5.14; P, 6.63. Found: C,71.94; H, 4.94; N, 4.45%.

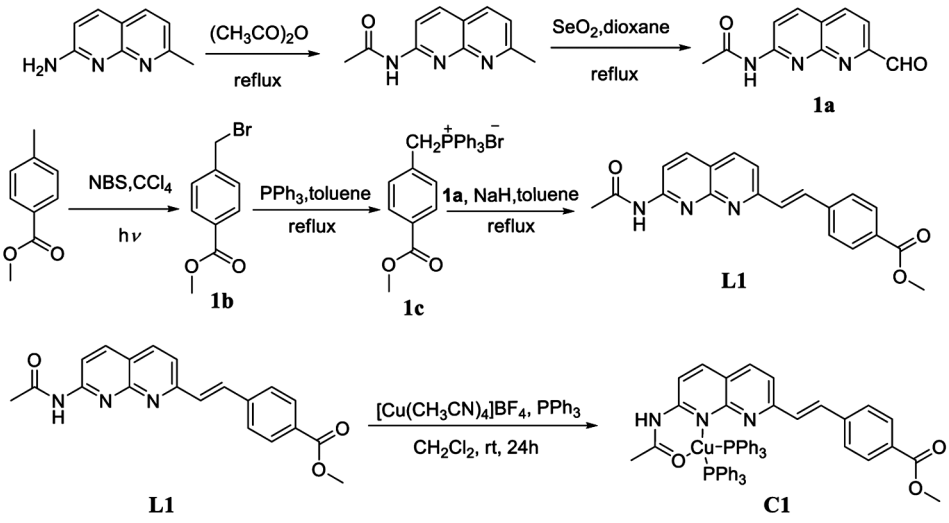
General procedure for the catalysis of N-arylation coupling reactions

In a sealed tube, catalyst **C1** (18.7 mg, 0.02 mmol), imidazole, benzimidazole or pyrazole (1.0 mmol), aryl halide (1.0 mmol), KOH (112 mg, 2.0 mmol), KI (6.6 mg, 0.04 mmol), and dimethyl sulfoxide (DMSO, 5 mL) were added. The reaction mixture was stirred at 100°C for 4 h and subsequently cooled to RT. After the addition of 5 mL of H_2O, the solution was extracted with ethyl acetate. The organic layer was then dried over anhydrous Na_2SO_4, and the solvent was removed under reduced pressure. Finally, the N-arylated product was obtained *via* column chromatography on silica gel.

Results and Discussion

Synthesis and structures

As depicted in Scheme 1, the vinyl-1,8-naphthyridine derivative (**L1**) was synthesized *via* a Wittig reaction in toluene under a nitrogen atmosphere at 110°C. The structure of **L1** was comprehensively characterized by multinuclear NMR spectroscopy, mass spectrometry, and elemental analyses (Figures S1–S2). Moreover, the mass spectrum and elemental analyses confirmed that compound **L1** is a vinyl-1,8- naphthyridine derivative, which is also corroborated by the crystal structure of **C1**. The crystal structure of **C1** is presented in Fig. 1, and the detailed crystallographic data are summarized in Table S1. The bond lengths, angles, torsion angles,



Scheme 1 — Synthetic route and chemical structures of vinyl-1,8-naphthyridine derivatives **L1** and its copper(I) complex **C1**

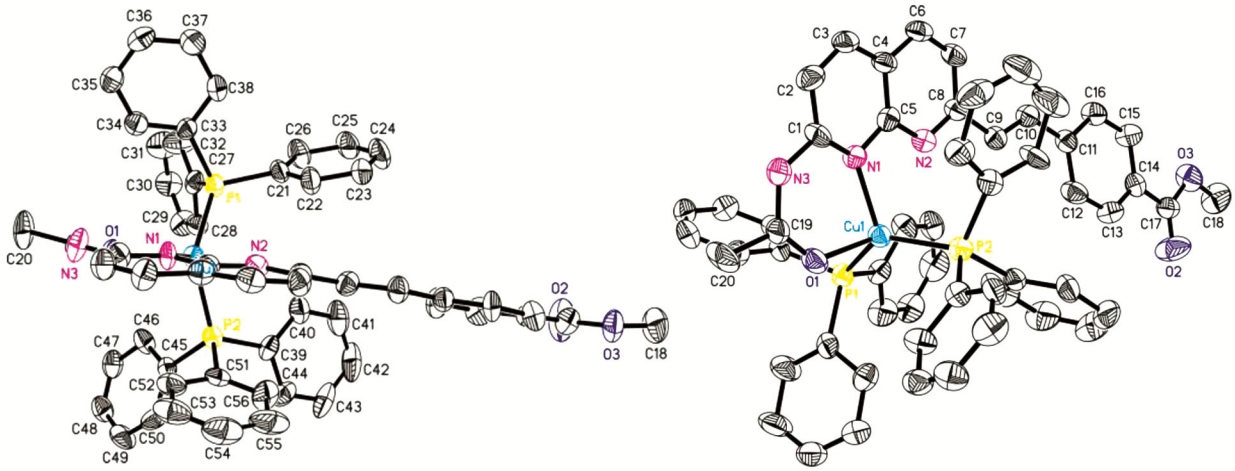


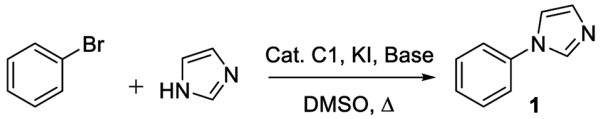
Fig. 1 — ORTEP diagrams for C1 showing 30% probability ellipsoids. All H-atoms are omitted for clarity.

and crystal packing diagram are shown in Tables S2, S3 and Figures S3–S6. The copper(I) complex (**C1**) crystallizes in the triclinic space group *P-1*. The two PPh_3 groups are positioned on either side of the planar vinyl-1,8-naphthyridine moiety. The structure reveals a distorted tetrahedral geometry around the Cu(I) ions, which are coordinated to one N-atom and one O-atom from **L1**, as well as two P-atoms from PPh_3. In the vinyl-1,8-naphthyridine unit, the groups around the C–C double bond adopt a trans-configuration. The molecules stack along the *Z*-axis to form a layer structure with only partial overlap (Figures S3 and S6). The inter-planar distance is 3.450 Å, similar to that in graphite (3.35 Å), indicating a medium-intensity π–π stacking system in the crystal (the larger volume of PPh_3 leads to greater repulsion), as shown in the diagrams and tables of bond lengths and angles (Figure S4 and Table S2). The distances of Cu(1)–N(1), Cu(1)–O(1), Cu(1)–P(1), and Cu(1)–P(2) are 2.057, 2.217, 2.239, and 2.260 Å, respectively. The bond angles N(1)–Cu(1)–O(1), N(1)–Cu(1)–P(1), O(1)–Cu(1)–P(1), N(1)–Cu(1)–P(2), O(1)–Cu(1)–P(2), and P(1)–Cu(1)–P(2) around the copper atom are 83.6°, 118.7°, 97.2°, 105.4°, 102.9°, and 133.21°, respectively. The angle between the naphthyridine and benzene rings at both ends of the vinyl group is 12.94°. The coordination mode is consistent with the literature report[32].

N-Arylation Coupling Reactions

We initially focused on the N-arylation of imidazole because 1-arylimidazoles are crucial motifs present in a series of medicinally significant compounds and have been utilized as key building blocks for the synthesis of N-heterocyclic carbenes[39-41]. To optimize the reaction conditions, the catalytic N-arylation was conducted with bromobenzene (1.0 mmol) and imidazole (1.0 mmol) in the presence of complex **C1** (0.02 mmol), a base (2.0 mmol), and KI as a synergistic catalyst (0.04 mmol) in dimethyl sulfoxide. As presented in Table 1, in the absence of

Table 1 — Screening of reaction conditions for vinyl-1,8-naphthyridine copper (I) complex **C1** catalyzed N-arylation of imidazole with bromobenzene [a]



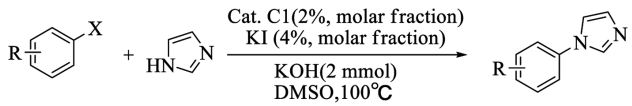
Entry	Base	Solvent	Synergistic Catalyst	Time/h	Temperature (°C)	Yield[b] (%)
1	NaOH	DMSO	–	4	100	<10
2	KOH	DMSO	–	4	100	<10
3	K_2CO_3	DMSO	–	12	100	<10
4	Na_2CO_3	DMSO	–	12	100	<10
5	Cs_2CO_3	DMSO	–	12	100	<10
6	Et_3N	DMSO	–	24	100	<10
7	Pyridine	DMSO	–	24	100	<10
8	NaOH	DMSO	KI	4	100	90
9	KOH	DMSO	KI	4	100	93
10	K_2CO_3	DMSO	KI	12	100	52
11	Na_2CO_3	DMSO	KI	12	100	56
12	Cs_2CO_3	DMSO	KI	12	100	65
13	Et_3N	DMSO	KI	24	100	<10
14	Pyridine	DMSO	KI	24	100	<10
15	KOH	DMF	KI	4	100	83
16	KOH	Toluene	KI	12	110	75
17	KOH	Xylene	KI	12	110	80
18	KOH	THF	KI	12	80	53
19	KOH	DMSO	KI	4	80	80
20	KOH	DMSO	KI	6	100	95
21	KOH	DMSO	KI	2	100	66
22 [c]	KOH	DMSO	KI	4	100	73
23 [d]	KOH	DMSO	KI	4	100	70

(a) Reaction conditions: bromobenzene (1.0 mmol), imidazole (1.0 mmol), base (2.0 mmol), complex **C1** (0.02 mmol), solvent (5 mL), air atmosphere; (b) isolated yield; (c) 1.0% (molar fraction) catalyst was used. (d) 2.0% (molar fraction) KI was used. "–" shows no KI was used.

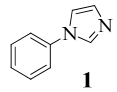
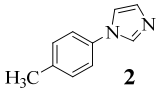
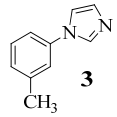
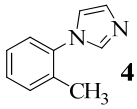
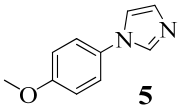
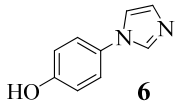
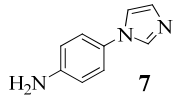
KI as a co-catalyst, all isolated yields were below 10% (Entries 1-7). However, the isolated yields were significantly improved after the addition of KI (Entries 8-14). Among the different bases tested under the same reaction conditions, KOH afforded the highest isolated yield of approximately 93%, and NaOH gave the second-highest isolated yield of around 90% after a 4-h reaction (Entries 8 and 9). Other inorganic bases, such as Na_2CO_3, K_2CO_3, and Cs_2CO_3, were less effective than NaOH, requiring a longer reaction time of 12 h (Entries 10-12). In contrast, only a trace amount of the product was detected when organic bases, like triethylamine or pyridine, were employed (Entries 13 and 14). The solvent is another crucial factor influencing the catalysis. Other solvents, including DMF, toluene, xylene, and THF, were less effective than DMSO, necessitating a longer reaction time of 12 h (Entries 15-18). DMSO was highly efficient for the catalysis, providing the product in a yield of 93%. Moreover, a lower temperature slowed down the reaction rate. When the reaction was carried out at 80°C, only an 80% yield was obtained (Entry 19). Further investigation revealed that 4 h was sufficient for the reaction to reach completion. When the reaction time was reduced to 2 h, the yield decreased to 66% (Entry 21). When the reaction time was extended to 6 h, the yield remained at 95% (Entry 20). Reducing the catalyst loading to 1.0% (molar fraction) led to a drop in the reaction yield to 73% (Entry 22). Similarly, reducing the loading of the synergistic catalyst (KI) to 2.0% (molar fraction) caused the reaction yield to decline to 70% (Entry 23).

Armed with the optimized reaction conditions, a more extensive investigation was carried out. The coupling reactions between imidazole and substituted aryl bromides as well as certain aryl iodides were examined. In general, under identical reaction conditions, substituted aryl iodides afforded higher yields than substituted aryl bromides (Table 2, Products **1**, **2**, **10**, **12**, **14**). We are pleased to note that all the combinations yielded moderate to excellent

Table 2 — N-Arylation of imidazole with different aryl halides catalyzed by complex **C1** [a]

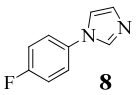
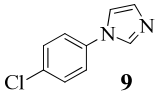
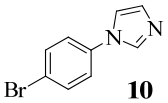
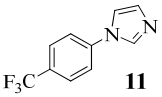
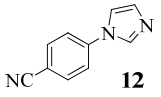
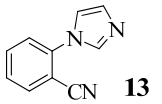
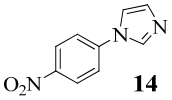
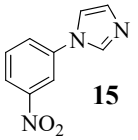
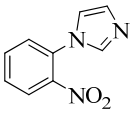
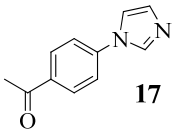
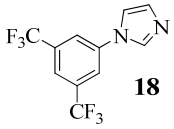
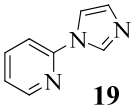


X=I, Br 1-19

Entry	Aryl halide	Product	Yield [b](%)
1	X=I, R=*p*-H	 **1**	96
2	X=Br, R=*p*-H		93
3	X=I, R=*p*-CH_3	 **2**	87
4	X=Br, R=*p*-CH_3		82
5	X=Br, R=*m*-CH_3	 **3**	80
6	X=Br, R=*o*-CH_3	 **4**	75
7	X=Br, R=*p*-OCH_3	 **5**	85
8	X=Br, R=*p*-OH	 **6**	81
9	X=Br, R=*p*-NH_2	 **7**	78

(*Contd.*)

Table 2 — N-Arylation of imidazole with different aryl halides catalyzed by complex **C1** [a]

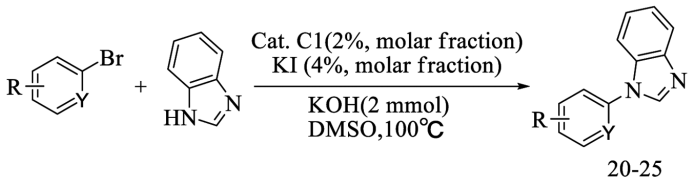
Entry	Aryl halide	Product	Yield [b](%)
10	X=Br, R=*p*-F	 **8**	91
11	X=Br, R=*p*-Cl	 **9**	89
12	X=I, R=*p*-Br	 **10**	90
13	X=Br, R=*p*-Br		87
14	X=Br, R=*p*-CF_3	 **11**	95
15	X=I, R=*p*-CN	 **12**	94
16 [c]	X=Br, R=*p*-CN		92
17	X=Br, R=*o*-CN	 **13**	84
18	X=I, R=*p*-NO_2	 **14**	96
19	X=Br, R=*p*-NO_2		91
20	X=Br, R=*m*-NO_2	 **15**	86
21	X=Br, R=*o*-NO_2	 **16**	82
22	X=Br, R=*p*-$COCH_3$	 **17**	83
23	X=Br, R= 3,5-Bis(trifluoromethyl)	 **18**	93
24 [c]	X=Br, R=H	 **19**	89

(a) Reaction conditions: aryl halide (1.0 mmol), imidazole (1.0 mmol), KOH (2.0 mmol), complex **C1** (0.02 mmol), KI (0.04 mmol), DMSO (3 mL) at 100°C in air; (b) isolated yields; (c) the aryl halide is 2-bromopyridine.

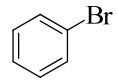
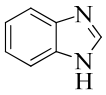
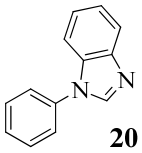
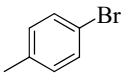
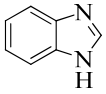
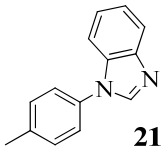
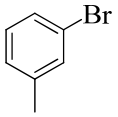
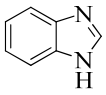
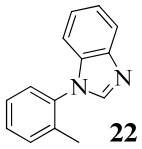
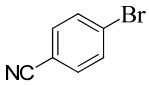
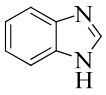
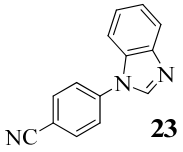
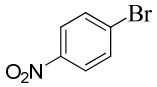
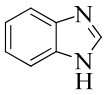
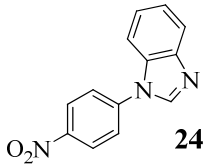
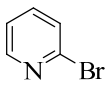
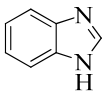
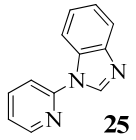
results, with yields ranging from 75% to 96%. Notably, the strong sensitivity to electron effects observed for electron-poor substrates is particularly intriguing, as such substrates are typically more challenging to handle in transition-metal-catalyzed reactions, as reported in previous studies[42,43].

Furthermore, the catalytic system demonstrated remarkable tolerance towards a diverse range of functionalized aryl halides during the reaction, such as those bearing *p*-methyl, *m*-methyl, *o*-methyl, nitrile, *p*-nitro, *m*-nitro, *o*-nitro, acetyl, and ether groups (Table 2, Products **2**–**5**, **12**–**17**). Notably, the reaction

Table 3 — Complex **C1** catalyzed N-arylation of aryl halides with benzimidazole [a]



20-25

Entry	Aryl halide	Benzimidazole	Product	Yield [b] (%)
1			 **20**	88
2			 **21**	82
3			 **22**	80
4			 **23**	85
5			 **24**	86
6			 **25**	76

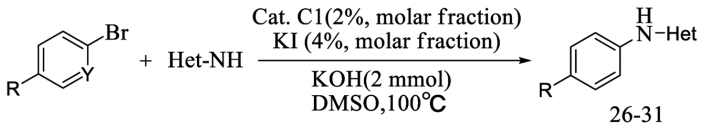
(a) Reaction conditions: aryl bromide (1.0 mmol), benzimidazole (1.0 mmol), KOH (2.0 mmol), complex **C1** (0.02 mmol), KI (0.04 mmol), DMSO (3 mL) at 100°C in air; (b) isolated yields.

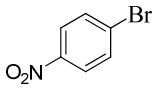
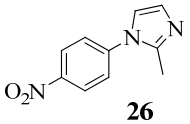
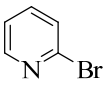
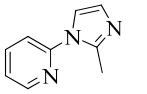
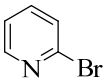
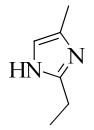
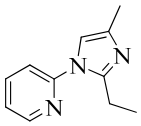
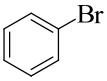
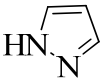
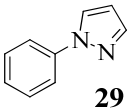
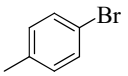
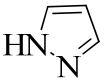
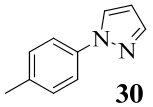
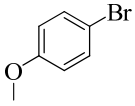
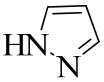
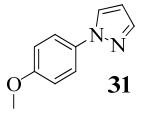
exhibited high chemoselectivity. For instance, imidazole could be selectively arylated with aryl halides containing amino or hydroxyl groups, affording the desired products in good yields without the formation of diaryl ethers, diarylamines, or other coupling side-products (Products **6** and **7**). In contrast, according to previous reports[44,45], these functional groups had to be protected prior to the catalytic reaction.

Subsequently, we successfully extended the optimized reaction conditions to the reaction between benzimidazole and aryl bromides. The results are presented in Table 3. To our delight, under the optimized conditions, most benzimidazole substrates selectively furnished the corresponding products **20**–**25** in good to excellent yields (76%–88%). Remarkably, even the heterocyclic compound pyridine could participate in the selective N-arylation reaction with benzimidazole, affording the corresponding 2-(1H-imidazol-1-yl)pyridine **25** in a yield of 76%.

In an attempt to broaden the scope of this methodology, the newly developed catalytic system was employed for a diverse range of imidazole

Table 4 — Complex **C1** catalyzed N-arylation of aryl halides with other imidazoles and pyrazoles [a]



Entry	Aryl halide	Het-NH	Product	Yield [b] (%)
1			 **26**	85
2			 **27**	79
3			 **28**	74
4			 **29**	86
5			 **30**	81
6			 **31**	76

(a) Reaction conditions: aryl bromide (1.0 mmol), imidazole derivative (1.0 mmol), KOH (2.0 mmol), complex **C1** (0.01 mmol), KI (0.04 mmol), DMSO (3 mL) at 100°C in air; (b) isolated yields.

derivatives (such as 2 -methylimidazole and 2-ethyl-4-methylimidazole) and pyrazole derivatives. To our great satisfaction, under the optimized reaction conditions, most of these imidazole and pyrazole derivatives selectively yielded the corresponding products in good to excellent yields (76–86%). Notably, the sterically hindered 2-methylimidazole could undergo selective N-arylation with 4-nitrobromobenzene and 2-bromopyridine, affording yields of 85% and 79%, respectively (Table 4, Entries 1–2). The sterically hindered 2-ethyl-4-methylimidazole was also able to participate in the selective N-arylation with 2-bromopyridine, giving the corresponding 2-(2-ethyl-4-methyl-1H-imidazol-1-yl)pyridine (**28**) in a yield of 74%. Moreover, the sterically hindered pyrazole could selectively react in N-arylation with bromobenzene, 4-methylbromobenzene, and 4-methoxybromobenzene, resulting in yields of 86%, 81%, and 76%, respectively (Table 4, Entries 4–6). To our pleasure, compared with Ullmann-type condensations, this reaction was less sensitive to the steric hindrance of imidazoles.

Conclusions

In summary, we have developed an efficient functional vinyl-1,8-naphthyridine copper(I) complex. This complex has been successfully synthesized and serves as a synergistic catalyst for the N-arylation cross-coupling reactions of imidazoles, benzimidazoles, or pyrazoles. Remarkably, the reaction can proceed under aerobic conditions with a low catalyst loading (2% molar fraction) and an inexpensive base. A total of 31 examples were demonstrated, with the catalytic yields reaching up to

96%. The present methodology is highly attractive due to its simple experimental procedure, the ease of catalyst availability and synthesis, and its excellent tolerance towards diverse functional groups. Further exploration of the application of this catalyst in other reactions or the synthesis of biologically important molecules is currently underway.

Supplementary Information

Supplementary information is available in the website https://nopr.niscpr.res.in/handle/123456789/58776.

Acknowledgement

This work was financially supported by the Basic Research Foundation for Young Talents of Education Department of Yunnan Province, China (No. 2024J1019); the Applied Basic Research Foundation of Yunnan Province (No. 202501AT070389); the Yunnan Province International Joint Laboratory of Green Food (China-Vietnam) (No. 202403AP140032); the College Students' Innovative Entrepreneurial Training Plan Program (CX2024073); the Key Laboratory of Honghe State ethnic medicinal research and Development of Yunnan Province; the Yunnan Provincial Department of Education Honghe Prefecture Ethnic Medicine Innovation and Research and Development Engineering Center.

References

1 Litvinov V P, Roman S V & Dyachenko V D, *Russ Chem Rev*, 69 (2000) 201.
2 Desnoyer A N, Nicolay A, Rios P, Ziegler M S & Tilley T D, *Acc Chem Res*, 53 (2020)1944.
3 Multem A J H, Delaney A R, Kroeger A A, Coote M L & Colebatch A L, *Chem Asian J*, 19 (2024) e202301071.
4 Van Beek C B, Van Leest N P, Lutz M, Vos S D D, Klein Gebbink R J M, Bruin B D & Broere D L J, *Chem Sci*, 13 (2022) 2094.
5 Stevens M A, Lim L F, Pham L N, Cox N, Coote M L & Colebatch A L, *Dalton Trans*, 53 (2024) 1284.
6 Wu J, Stevens M A, Gardiner M G & Colebatch A L, *Dalton Trans*, 53 (2024) 18037.
7 He Y, Souza C P, Weiser J, Dietz M, Krummenacher I, Dewhurst R D, Braunschweig H, Fantuzzi F & Cui J, *Eur J Inorg Chem*, 27 (2024) e202400422.
8 Patrick E A, Erickson J D, Bullock R M & Tran B L, *Organometallics*, 44 (2024) 373.
9 Gou G Z, Zhou B, Yan H P, Hong Y, Liu W, Chi S M & Mang C Y, *J Chem Sci*, 128 (2016) 1813.
10 Gou G Z, Zhou B, Chen X B, Wang X Q, Mang C Y, Liu W & Chi S M, *Indian J Chem A*, 56A (2017) 211.
11 Fairuz S, Ang C W, Tan K W, Mraiche F, Chow S C & Goh J K, *J Mol Struc*, 1327 (2025) 141202.
12 Alshaye N A, Badran A-S & Ibrahim M A, *Molecules*, 29 (2024) 4496.
13 Fu L, Lin W, Hu M H, Liu X C, Huang Z B & Shi D Q, *ACS Comb Sci*, 16 (2014) 238.
14 Banevičius D, Kreiza G, Klioštoraitis R, Juršėnas S, Javorskis T, Vaitkevičius V, Orentas E & Kazlauskas K, *J Mater Chem C*, 10 (2022) 4813.
15 Mahalingam M, Mohan P S, Gayathri K, Gomathi R & Subhapriya P, *J Chem Sci*, 125 (2013) 1015.
16 Kota T P & Kollipara M R, *J Chem Sci*, 126 (2014) 1143.
17 Hao H-C, Zhang G, Sun R, Xu Y-J & Ge J-F, *J Mater Chem B*, 11 (2023) 7134.
18 Franceschini S Z, Kappenberg Y G, Luz F M, Vieira J CB, Martins M AP, Zanatta N, Frizzo C P, Iglesias B A & Bonacorso H G, *Dyes Pigments*, 218 (2023) 111514.
19 Umeno T, Muroi L, Kayama Y, Usui K, Hamada K, Mizutani A & Karasawa S, *Bioconjugate Chem*, 34 (2023) 1439.
20 Maity A K, Kalb A E, Zeller M & Uyeda C A, *Angew Chem Int Edit*, 60 (2021) 1897.
21 Deolka S, Govindarajan R, Khaskin E, Fayzullin R R, Roy M C & Khusnutdinova J R, *Angew Chem Int Edit*, 60 **(**2021**)** 24620.
22 Hu P, Xu K L, Wang X R, Chen Z Y, Zhang W H, Zhou Y, Zhang W J & Liu X L, *Org Chem Front*, 11 (2024) 2600.
23 Julie H & David B, *ACS Cat*, 12 (2022) 4744.
24 See M S, Ríos P & Tilley T D, *Organometallics*, 43 (2024) 1180.
25 Kison C & Opatz T, *Chem-Eur J*, 15 (2009) 843.
26 Wang Y, Wu Z, Wang L, Li Z & Zhou X, *Chem-Eur J*, 15 (2009) 8971.
27 Klapars A, Antilla J C, Huang X & Buchwald S L, *J Am Chem Soc*, 123 (2001) 7727.
28 Cristau H J, Cellier P P, Spindler J F & Taillefer M, *Eur J Org Chem*, 2004 (2004) 695.
29 Wang Y, Gao J, Zhao M & Li J M, *Chem Res Chinese U*, 31 (2015) 549.
30 Zhou L, Lang W, Jiang X, Huang Q & Yin M, *Chin J Org Chem*, 35 (2015) 2340.
31 Huang Q, Zhou L, Jiang X, Qi X, Wang Z & Lang W, *Chinese J Cat*, 35 (2014) 1818.
32 Fu W F, Jia L F, Mu W H, Gan X, Zhang J B & Liu P H, *Inorg Chem*, 49 (2010) 4524.
33 Sheldrich G M, *SHELX-97*, *Program for the Refinement of Crystal Structures*, (University of Gottingen, Germany), 1997.
34 Gou G Z, Ma R, Zhou Q D & Chi S M, *Acta Crystal E*, 69 (2013) o489.
35 Duan Y L, Shi Y G, Chen J H, Wu X H, Wang G K, Zhou Y & Zhang J F, *Tetrahedron Lett*, 53 (2012) 6544.
36 Li Z, Liu X, Zhao W, Wang S, Zhou W & Wei L H, *Anal Chem*, 86 (2014) 2521.
37 Yathirajan H S, Bindya S, Sarojini B K, Narayana B & Bolte M, *Acta Crystallogra E*, 63 (2007) o1334.
38 Kubas G, Monzyk B & Crumbliss A, *Inorg Synth*, 19 (1979) 90.
39 Campeau L C & Fagnou K, *Chem Soc Rev*, 36 (2007) 1058.
40 Wiglenda T & Gust R, *J Med Chem*, 50 (2007) 1475.
41 Kison C & Opatz T, *Chem-Eur J*, 15 (2009) 843.
42 Wang Z, Skerlj R T & Bridger G J, *Tetrahedron Lett*, 40 (1999) 3543.
43 Mann G & Hartwig J F, *Tetrahedron Lett*, 38 (1997) 8005.
44 Wolter M, Nordmann G, Job G E & Buchwald S L, *Org Lett*, 4 (2002) 973.
45 Nordmann G & Buchwald S L, *J Am Chem Soc*, 125 (2003) 4978.