Tetrahedron xxx (xxxx) xxx

Contents lists available at ScienceDirect

Tetrahedron

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

N-heterocyclic carbene-Pd(II)-1-methylimidazole complex-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids

Zhen Bao, Zhi-Yuan Zhou, Ye-Ting Mao, Li-Xiong Shao*

College of Chemistry and Materials Engineering, Wenzhou University, Chashan University Town, Wenzhou, Zhejiang Province, 325035, People's Republic of China

ARTICLE INFO

Article history:
Received 9 July 2020
Received in revised form
12 August 2020
Accepted 24 August 2020
Available online xxx

Keywords:
N-heterocyclic carbene-palladium complex
Suzuki-Miyaura coupling
2-Chloro-4-aminoquinazolines
Arylboronic acids
Synthetic method

ABSTRACT

The Suzuki-Miyaura coupling between 2-chloro-4-aminoquinazolines and arylboronic acids catalyzed by the well-defined *N*-heterocyclic carbene-$PdCl_2$-1-methylimidazole complex was performed at room temperature, giving the desired products in good to high yields. Through this methodology, a variety of 2-aryl-4-aminoquinazoline derivatives with potential pharmaceutical activities can be achieved under mild reaction conditions.

1. Introduction

2-Aryl-4-aminoquinazolines are interesting compounds in biological and pharmaceutical chemistry [1]. For example, 4-((2-phenylquinazolin-4-yl)amino)benzonitrile **I** was found to show high inhibitory activities toward the ATP-binding cassette transport proteins [1c,1e]. *N*-(3-Nitrophenyl)-2-phenylquinazolin-4-amine **II** was reported to be potential inhibitor for breast cancer resistance protein [1d]. *N*-4-Tolyl-2-(3,4,5-trimethoxyphenyl)quinazolin-4-amine **III** was found to be a good inhibitor for the proliferation of T cells from human peripheral bond mononuclear cells and Jurkat cells (Fig. 1) [1g].

Consequently, some different methods have been developed for the synthesis of 2-aryl-4-aminoquinazolines. For example, such compounds can be obtained by the cyclization of *N*,*N*′-disubstituted thioureas under ultraviolet light irradiation (Scheme 1, route a) [2]. *N*-Arylamino-1,3-diazabuta-1,3-dienes are also reported as the starting materials for the synthesis of 2-aryl-4-aminoquinazolines via electrocyclication (Scheme 1, route b) [3]. The reactions of 2-aryl-4-chloroquinazolines, usually prepared from the 4-oxo derivatives, with amines under normal heating or microwave irradiation are the most popular pathway for the synthesis of 2-aryl-4-aminoquinazolines (Scheme 1, route c) [1a-g,4]. The palladium-phosphine system-catalyzed Suzuki-Miyaura coupling reactions of 2-chloro-4-aminoquinazolines with arylboronic acids was also used for the synthesis of 2-aryl-4-aminoquinazolines (Scheme 1, route d) [1h,5]. It seems that the palladium-catalyzed Suzuki-Miyaura coupling between 2-chloro-4-aminoquinazolines and arylboronic acids is an interesting alternative due to its broad substrate tolerance. However, the reported methods still suffer from the drawbacks of harsh reaction conditions such as high temperature and complicated procedure. Therefore, much room still remains for such method especially under mild conditions and easy operation. In the present work, a well-defined and easily available *N*-heterocyclic carbene-Pd(II)-1-methylimidazole [NHC-Pd(II)-Im] complex **1** catalyzed Suzuki-Miyaura coupling [6] of 2-chloro-4-aminoquinazolines **2** [7] with arylboronic acids **3** was reported, which can be performed at room temperature, with good to high yields for a variety of starting materials.

2. Results and discussion

First, initial studies were carried out using 2-chloro-4-

* Corresponding author.
E-mail address: Shaolix@wzu.edu.cn (L.-X. Shao).

https://doi.org/10.1016/j.tet.2020.131548
0040-4020/

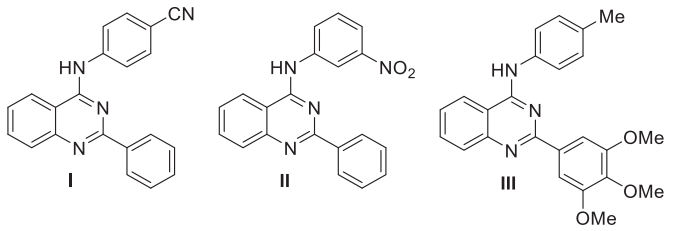
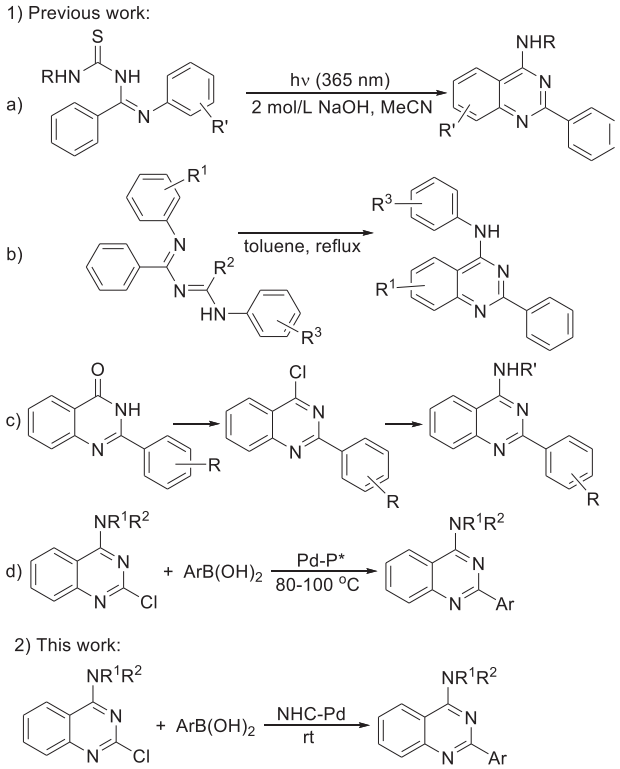


Fig. 1. Representative structure of 2-aryl-4-amino-quinozalines having pharmaceutical activities.

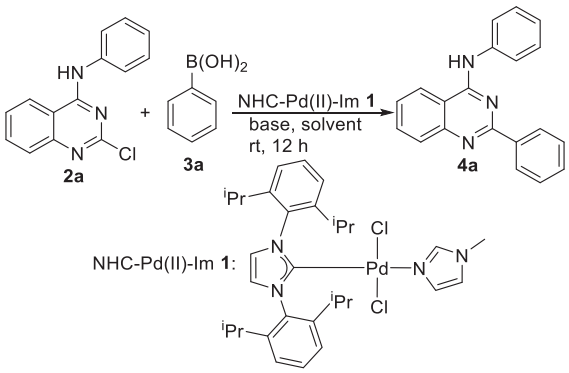


Scheme 1. Synthesis of 2-aryl-4-aminoquinazolines.

anilinoquinazoline **2a** (0.4 mmol) and phenylboronic acid **3a** (0.5 mmol) as the substrates, NHC-Pd(II)-Im complex **1** (1.0 mol%) as the catalyst, EtOH (2.0 mL) as the solvent at room temperature for 12 h to test some conventional inorganic bases (2.0 equiv). High yields were observed when NaOH, K_2CO_3 and KOH were used (Table 1, entries 1–3). Moderate to good yields can also be obtained if KO^{t}Bu, Cs_2CO_3, $K_3PO_4 \cdot 3H_2O$ and LiOH were tested (Table 1, entries 4–7). When weak bases such as Na_2CO_3, KOAc, $NaHCO_3$ and $KHCO_3$ were used, very low yields (<10%) were found. Using KOH as the base, some common solvents were then investigated. In these cases, ^{n}PrOH gave the best result, giving product **4a** in 98% yield (Table 1, entry 9). In ^{i}PrOH and MeOH, 31 and 48% yields were observed, respectively (Table 1, entries 8 and 10). In all other solvents such as dioxane, DMSO, ^{t}BuOH and H_2O, almost no reaction occurred or very low yields (<5%) were given. Considering the cost and easy availability, the optimal conditions were then established using KOH (2.0 equiv) as the base and EtOH (2.0 mL) as the solvent (Table 1, entry 3).

Since 2-(3,4,5-trimethoxyphenyl)quinazolin-4-amine derivatives had some activity in the inhibition of the proliferation of T cells [1g], the reactions between a variety of 2-chloro-4-

Table 1
Optimization for the NHC-Pd(II)-Im complex **1**-catalyzed reaction of 2-chloro-4-anilinoquinazoline **2a** with phenylboronic acid **3a**.



Entry[a]	Base	Solvent	Yield (%)[b]
1	NaOH	EtOH	91
2	K_2CO_3	EtOH	96
3	KOH	EtOH	95
4	KO^{t}Bu	EtOH	83
5	Cs_2CO_3	EtOH	73
6	$K_3PO_4 \cdot 3H_2O$	EtOH	77
7	LiOH	EtOH	58
8	KOH	^{i}PrOH	31
9	KOH	^{n}PrOH	98
10	KOH	MeOH	48

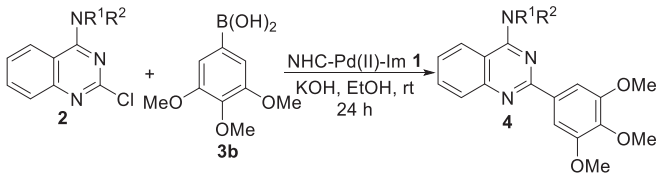
[a] All reactions were carried out using **2a** (0.4 mmol), **3a** (0.5 mmol), NHC-Pd(II)-Im **1** (1.0 mol%), base (2.0 equiv) in solvent (2.0 mL) at rt for 12 h.
[b] Isolated yields.

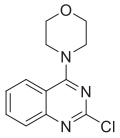
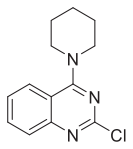
aminoquinazolines **2** and 3,4,5-trimethoxyphenylboronic acid **3b** were first investigated under the optimal conditions. The results are shown in Table 2. All reactions performed well to give the desired products in good to high yields. Substituents on the amino group have some effect on the reactions. For instance, for the anilino-substituted substrates **2**, the best yield was achieved when the electron-poor fluorine atom was attached on the *para*-position (Table 2, entry 5), and better yields were obtained when the electron-rich methyl and methoxy groups were used (Table 2, entries 2–4). Finally, the worst yield was found when the electron-neutral aniline substituted **2a** was used as the substrate (Table 2, entry 1). To our pleasure, once the free NH was replaced by methyl group, high yield can be still achieved (Table 1, entries 6 *vs* 1). Alkyl amino-substituted substrates **2g-j** are also suitable for such coupling reaction, giving the desired products **4h-k** in 73–96% yields (Table 2, entries 7–10). It may be noted here that compared to the previous method performed in refluxing mixture solvent of ethylene glycol dimethyl ether/water [1h], the current one can take place at room temperature with higher yields.

Based on the above results, the reactions of kinds of 2-chloro-4-aminoquinazolines **2** and arylboronic acids **3** were further carried out to test the limitation and scope of such methodology. As can be seen from Table 3, all reactions performed smoothly under the optimal conditions to give products **4** in good to high yields. In these cases, it seems that substituents on both substrates do not affect the reactions significantly. For instance, for all substituents shown in Table 3, such as electron-rich, -neutral, -poor and sterically-hindered ones on the anilino-groups of substrates **2** and on the phenyl rings of arylboronic acids **3**, are all tolerated under the reaction conditions, giving products **4** in 80–99% yields (Table 3, entries 1–10). In addition, alkyl amino-substituted substrates **2** are also good partners with various arylboronic acids **3**, giving the corresponding products **4v-4ac** in 81–99% yields

Please cite this article as: Z. Bao et al., *N*-heterocyclic carbene-Pd(II)-1-methylimidazole complex-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids, Tetrahedron, https://doi.org/10.1016/j.tet.2020.131548

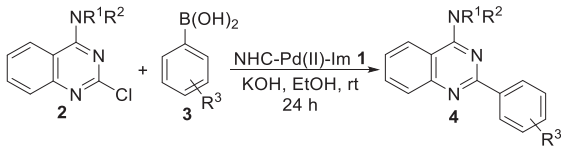
Table 2
NHC-Pd(II)-Im complex **1**-catalyzed reactions of 2-chloro-4-aminoquinazolines **2** with 3,4,5-trimethoxyphenylboronic acid **3b**.

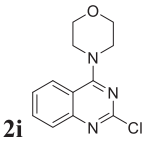


Entry[a]	2 (R^1/R^2)	Yield (%)[b]
1	**2a** (H/C_6H_5)	**4b**, 76
2	**2b** (H/2-MeC_6H_4)	**4c**, 93
3	**2c** (H/4-MeC_6H_4)	**4d**, 89
4	**2d** (H/4-MeOC_6H_4)	**4e**, 80
5	**2e** (H/4-FC_6H_4)	**4f**, 97
6	**2f** (Me/C_6H_5)	**4g**, 95
7	**2g** (Me/benzyl)	**4h**, 82
8	**2h** (Et/Et)	**4i**, 96
9	 **2i**	**4j**, 73
10	 **2j**	**4k**, 88

[a] All reactions were carried out using **2** (0.4 mmol), **3b** (0.5 mmol), NHC-Pd(II)-Im **1** (1.0 mol%), KOH (2.0 equiv) in EtOH (2.0 mL) at rt for 24 h.
[b] Isolated yields.

Table 3
NHC-Pd(II)-Im complex **1**-catalyzed reactions of 2-chloro-4-aminoquinazolines **2** with arylboronic acids.

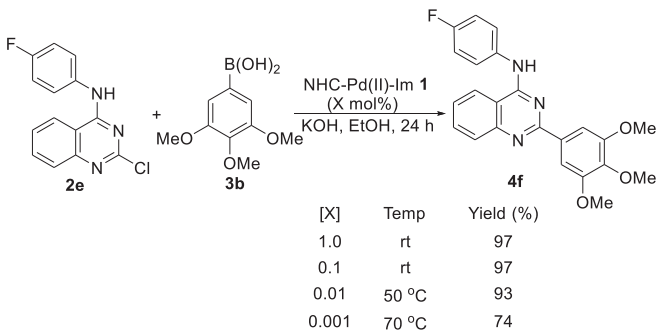


Entry[a]	2 (R^1/R^2)	3 (R^3)	Yield (%)[b]
1	**2a** (H/C_6H_5)	**3c** (3-F)	**4l**, 98
2	**2c** (H/4-MeC_6H_4)	**3a** (H)	**4m**, 90
3	**2c**	**3d** (4-Me)	**4n**, 87
4	**2d** (H/4-MeOC_6H_4)	**3d**	**4o**, 99
5	**2e** (H/4-FC_6H_4)	**3d**	**4p**, 97
6	**2e**	**3f** (2-Me)	**4q**, 97
7	**2e**	**3g** (3-MeO)	**4r**, 83
8	**2e**	**3h** (4-MeO)	**4s**, 80
9	**2f** (Me/C_6H_5)	**3d**	**4t**, 91
10	**2k** (H/2-FC_6H_4)	**3e** (3,5-Me_2)	**4u**, 93
11	**2g** (Me/benzyl)	**3a**	**4v**, 82
12	**2h** (Et/Et)	**3c**	**4w**, 96
13	**2h**	**3d**	**4x**, 95
14	**2h**	**3f**	**4y**, 99
15	**2h**	**3i** (4-F)	**4z**, 98
16	**2h**	**3j** (3-NH_2)	**4aa**, 81
17	 **2i**	**3a**	**4ab**, 95
18	**2j** (H/benzyl)	**3f**	**4ac**, 86

[a] All reactions were carried out using **2** (0.4 mmol), **3** (0.5 mmol), NHC-Pd(II)-Im **1** (1.0 mol%), KOH (2.0 equiv) in EtOH (2.0 mL) at rt for 24 h.
[b] Isolated yields.

(Table 3, entries 11–18). It should be noted here that for the reactions involving arylboronic acids bearing strongly electron-poor groups such as ester group, nitro group and acetyl group, no desired product was given.

To further investigate the applicability of this methodology, the model reaction of 2-chloro-*N*-(4-fluorophenyl)quinazolin-4-amine **2e** with 3,4,5-trimethoxyphenylboronic acid **3b** was performed under identical conditions at lower catalyst loadings. As can be seen from Scheme 2, the same yield was obtained under the same reaction conditions when the catalyst loading decreased from 1.0 to 0.1 mol%. Comparable high yield can still be achieved at elevated temperature (50 °C) when 0.01 mol% NHC-Pd(II)-Im **1** was used. To our pleasure, once the reaction was performed at 70 °C, moderate yield can still be observed when only 0.001 mol% catalyst was added, implying its potential application toward synthetic medicinal chemistry.



[X]	Temp	Yield (%)
1.0	rt	97
0.1	rt	97
0.01	50 °C	93
0.001	70 °C	74

Scheme 2. Reaction of **2e** with **3b** at varied catalyst loading.

3. Conclusion

In conclusion, an easily available NHC-Pd(II)-Im complex **1** has been used as an efficient catalyst in the Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids. All reactions took place well enough at room temperature, giving the desired coupling products in good to high yields. By this methodology, a variety of 2-aryl-4-aminoquinazolines having previously reported or potential pharmaceutical activities can be achieved under mild reaction conditions.

4. Experimental section

4.1. General remarks

NMR spectra were recorded at 400 or 500 MHz (for ^{1}H NMR) or 125 MHz (for ^{13}C NMR), respectively. ^{1}H and ^{13}C NMR spectra recorded in $CDCl_3$ solutions were referenced to TMS (0.00 ppm) and the residual solvent peak (77.0 ppm), respectively. *J*-values are given in Hz. All solvents were dried by standard methods. The mass analyzer type for the high resolution mass spectra (HRMS) is Q-TOF. Flash column chromatography was performed on silica gel (300–400 mesh).

Please cite this article as: Z. Bao et al., *N*-heterocyclic carbene-Pd(II)-1-methylimidazole complex-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids, Tetrahedron, https://doi.org/10.1016/j.tet.2020.131548

4.2. Experimental procedure

4.2.1. General procedure for the NHC-Pd(II)-Im complex 1-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines 2 with arylboronic acids 3

Under a N_2 atmosphere, KOH (0.8 mmol), 2-chloro-4-aminoquinazolines **2** (0.40 mmol), arylboronic acids **3** (0.50 mmol), NHC-Pd(II)-Im complex **1** (1.0 mol%) and EtOH (2.0 mL) were successively added into a Schlenk reaction tube. The mixture was stirred vigorously at room temperature for 24 h. Then the solvent was removed under reduced pressure and the residue was purified by flash column chromatography (SiO_2) to give the corresponding products.

4.2.1.1. Compound ***4a*** *[1f]: white solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.55 (d, J = 6.5 Hz, 2H), 8.00 (d, J = 8.5 Hz, 1H), 7.91–7.87 (m, 3H), 7.80 (t, J = 7.5 Hz, 1H), 7.54–7.46 (m, 7H), 7.20 (t, J = 7.5 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.4, 157.3, 151.1, 138.7, 132.9, 130.3, 129.4, 129.0, 128.5, 128.4, 126.1, 124.1, 121.3, 120.2, 113.8.

4.2.1.2. Compound ***4b*** *[1h]: white solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.00 (d, J = 8.0 Hz, 1H), 7.91–7.88 (m, 5H), 7.80 (t, J = 7.5 Hz, 1H), 7.54–7.51 (m, 2H), 7.43 (t, J = 7.5 Hz, 2H), 7.19 (t, J = 7.5 Hz, 1H), 4.00 (s, 6H), 3.93 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.7, 157.2, 153.1, 151.2, 140.1, 138.7, 134.0, 132.9, 129.3, 128.7, 126.0, 124.2, 121.7, 120.2, 113.7, 105.6, 60.9, 56.0.

4.2.1.3. Compound ***4c****: white solid. m.p. 160.2–161.4 °C.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.06 (d, J = 8.0 Hz, 1H), 7.98 (d, J = 8.5 Hz, 1H), 7.86 (d, J = 8.5 Hz, 1H), 7.79–7.76 (m, 3H), 7.48 (t, J = 8.0 Hz, 1H), 7.38 (s, 1H), 7.29–7.25 (m, 2H), 7.15 (t, J = 7.5 Hz, 1H), 3.92 (s, 6H), 3.90 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.5, 157.6, 152.9, 151.1, 140.0, 136.8, 133.9, 132.8, 131.1, 130.5, 129.1, 126.2, 125.8, 125.2, 124.5, 120.4, 113.7, 105.4, 60.8, 55.9, 18.0. IR (neat) ν 2978, 2900, 1550, 1517, 1453, 1410, 1371, 1220, 1127, 1063, 1009, 898, 798, 773, 751 cm^{-1}. HRMS (ESI) Calcd for $C_{24}H_{24}N_3O_3$ [M + H$^+$] 402.1812, found 402.1808.

4.2.1.4. Compound ***4d*** *[1h]: white solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.98 (d, J = 8.0 Hz, 1H), 7.89–7.86 (m, 3H), 7.81–7.78 (m, 3H), 7.51 (t, J = 7.5 Hz, 1H), 7.45 (s, 1H), 7.23 (d, J = 8.0 Hz, 2H), 4.01 (s, 6H), 3.93 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.7, 157.2, 153.1, 150.9, 136.1, 134.1, 133.9, 132.8, 129.3, 125.9, 121.7, 120.2, 113.7, 105.6, 60.9, 56.0, 20.9.

4.2.1.5. Compound ***4e*** *[1h]: white solid.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.97 (d, J = 8.4 Hz, 1H), 7.88–7.86 (m, 3H), 7.80–7.75 (m, 3H), 7.51–7.47 (m, 2H), 6.96 (d, J = 8.8 Hz, 2H), 3.98 (s, 6H), 3.92 (s, 3H), 3.84 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.7, 157.4, 156.6, 153.0, 151.0, 140.1, 134.0, 132.8, 131.7, 129.0, 125.8, 123.7, 120.4, 113.9, 113.6, 105.6, 60.9, 56.0, 55.5.

4.2.1.6. Compound ***4f****: white solid. m.p. 163.9–165.0 °C.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.95 (d, J = 8.5 Hz, 1H), 7.89 (d, J = 8.0 Hz, 1H), 7.83–7.71 (m, 6H), 7.44 (t, J = 7.5 Hz, 1H), 7.07 (t, J = 8.5 Hz, 2H), 3.94 (s, 6H), 3.92 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.3, 159.5, 158.4, 157.3, 153.0, 151.0, 140.1, 134.7, 134.6, 133.9, 132.9, 129.0, 125.9, 123.75, 123.68, 120.4, 115.3, 115.1, 113.5, 105.5, 60.9, 55.9. IR (neat) ν 2928, 2846, 1614, 1557, 1510, 1432, 1364, 1439, 1292, 1213, 1152, 1120, 952, 826, 791, 762 cm^{-1}. HRMS (ESI) Calcd for $C_{23}H_{21}FN_3O_3$ [M + H$^+$] 406.1561, found 406.1564.

4.2.1.7. Compound ***4g****: white solid. m.p. 180.5–181.6 °C.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.95 (s, 2H), 7.91 (d, J = 8.0 Hz, 1H), 7.57 (t, J = 7.0 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.29 (d, J = 7.5 Hz, 1H), 7.22 (d, J = 7.5 Hz, 2H), 7.06 (d, J = 8.0 Hz, 1H), 7.00 (t, J = 7.5 Hz, 1H), 4.03 (s, 6H), 3.94 (s, 3H), 3.77 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.9, 159.2, 153.2, 152.6, 148.7, 134.3, 131.9, 130.0, 128.7, 126.2, 125.9, 124.4, 115.4, 105.7, 60.9, 56.2, 42.3. IR (neat) ν 2934, 1683, 1615, 1547, 1509, 1410, 1365, 1217, 1126, 1099, 1027, 1001, 921, 804, 773, 751 cm^{-1}. HRMS (ESI) Calcd for $C_{24}H_{24}N_3O_3$ [M + H$^+$] 402.1812, found 402.1808.

4.2.1.8. Compound ***4h:*** *white solid. m.p. 190.0 °C (decomposed).* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.95 (dd, J = 8.4, 2.8 Hz, 2H), 7.83 (s, 2H), 7.68 (t, J = 7.6 Hz, 1H), 7.42–7.36 (m, 4H), 7.33–7.27 (m, 2H), 5.03 (s, 2H), 3.92 (s, 6H), 3.91 (s, 3H), 3.39 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.4, 152.7, 149.7, 138.9, 135.7, 130.9, 128.8, 127.8, 126.2, 125.0, 116.9, 51.9, 34.6, 31.3. IR (neat) ν 2942, 1566, 1520, 1456, 1403, 1350, 1259, 1213, 1122, 1069, 1012, 902, 857, 770, 743, 705 cm^{-1}. HRMS (ESI) Calcd for $C_{25}H_{26}N_3O_3$ [M + H$^+$] 416.1969, found 416.1977.

4.2.1.9. Compound ***4i****: white solid. m.p. 94.8–96.2 °C.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.92 (t, J = 6.8 Hz, 2H), 7.88 (s, 2H), 7.69 (t, J = 7.6 Hz, 1H), 7.36 (t, J = 7.6 Hz, 1H), 4.01 (s, 6H), 3.92 (s, 3H), 3.82 (q, J = 7.2 Hz, 4H), 1.48 (t, J = 7.2 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.1, 159.0, 153.1, 152.8, 140.1, 134.4, 132.2, 128.8, 125.1, 124.5, 115.5, 105.7, 60.9, 56.2, 51.0, 26.0, 24.9. IR (neat) ν 2972, 1562, 1513, 1460, 1406, 1342, 1293, 1217, 1118, 1061, 1005, 898, 861, 758, 747, 686 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{26}N_3O_3$ [M + H$^+$] 368.1969, found 368.1967.

4.2.1.10. Compound ***4j****: white solid. m.p. 135.1–136.2 °C.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.00 (t, J = 8.0 Hz, 1H), 7.92–7.87 (m, 3H), 7.76 (t, J = 7.5 Hz, 1H), 7.45 (t, J = 7.5 Hz, 1H), 4.03–3.93 (m, 13H), 3.86 (t, J = 4.5 Hz, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.0, 159.0, 153.2, 152.8, 140.4, 134.0, 132.5, 129.1, 125.0, 124.6, 115.3, 105.8, 66.7, 60.9, 56.2, 50.4. IR (neat) ν 2978, 2900, 1578, 1471, 1403, 1263, 1231, 1056, 862, 816 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{23}N_3NaO_4$ [M + Na$^+$] 404.1581, found 404.1594.

4.2.1.11. Compound ***4k*** *[8]: white solid.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.94 (d, J = 8.4 Hz, 1H), 7.89–7.87 (m, 3H), 7.71 (t, J = 7.6 Hz, 1H), 7.40 (t, J = 7.6 Hz, 1H), 4.02 (s, 6H), 3.92 (s, 3H), 3.80–3.79 (m, 4H), 1.85–1.82 (m, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.1, 159.0, 153.1, 152.8, 140.1, 134.4, 132.2, 128.8, 125.1, 124.5, 115.5, 105.7, 60.9, 56.2, 51.0, 26.0, 24.9.

4.2.1.12. Compound ***4l*** *[1f]: white solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.32 (d, J = 7.5 Hz, 1H), 8.23 (d, J = 10.5 Hz, 1H), 7.97 (d, J = 8.5 Hz, 1H), 7.84 (d, J = 8.0 Hz, 3H), 7.79 (t, J = 7.5 Hz, 1H), 7.53–7.42 (m, 5H), 7.20 (t, J = 7.5 Hz, 1H), 7.15 (t, J = 7.5 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.1 (d, $J_{C\text{-}F}$ = 242.75 Hz), 159.2, 157.4, 151.0, 141.2 (d, $J_{C\text{-}F}$ = 7.625 Hz), 138.5, 133.0, 129.7 (d, $J_{C\text{-}F}$ = 7.875 Hz), 129.4, 129.0, 126.4, 124.3, 124.1 (d, $J_{C\text{-}F}$ = 2.625 Hz), 121.4, 120.2, 117.0 (d, $J_{C\text{-}F}$ = 21.25 Hz), 115.3 (d, $J_{C\text{-}F}$ = 22.875 Hz), 113.9.

4.2.1.13. Compound ***4m*** *[1c]: pale yellow solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.53 (d, J = 7.0 Hz, 2H), 7.95 (d, J = 8.0 Hz, 1H), 7.77–7.71 (m, 4H), 7.49–7.39 (m, 5H), 7.22 (d, J = 8.0 Hz, 2H), 2.37 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.4, 157.3, 151.0, 138.7, 136.0,

Please cite this article as: Z. Bao et al., *N*-heterocyclic carbene-Pd(II)-1-methylimidazole complex-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids, Tetrahedron, https://doi.org/10.1016/j.tet.2020.131548

133.7, 132.7, 130.2, 129.4, 129.2, 128.5, 128.3, 125.9, 121.4, 120.2, 113.8, 20.9.

4.2.1.14. Compound ***4n*** *[9]: pale yellow solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.44 (d, J = 8.5 Hz, 2H), 7.97 (d, J = 9.5 Hz, 1H), 7.85 (d, J = 10.0 Hz, 1H), 7.78–7.76 (m, 3H), 7.49 (t, J = 9.5 Hz, 1H), 7.41 (br, 1H), 7.31–7.26 (m, 4H), 2.43 (s, 3H), 2.40 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.5, 157.3, 151.1, 140.3, 136.1, 136.0, 133.6, 132.7, 129.4, 129.2, 129.1, 128.5, 125.7, 121.3, 120.2, 113.8, 21.5, 20.9.

4.2.1.15. Compound ***4o*** *[8]: yellow solid.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.41 (d, J = 8.0 Hz, 2H), 7.96 (d, J = 8.0 Hz, 1H), 7.84 (d, J = 9.2 Hz, 1H), 7.79–7.75 (m, 3H), 7.48 (td, J = 8.0, 0.8 Hz, 1H), 7.37 (br, 1H), 7.29 (d, J = 8.0 Hz, 2H), 7.00 (d, J = 9.2 Hz, 2H), 3.87 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.5, 157.5, 156.4, 151.0, 140.3, 136.0, 132.7, 131.7, 129.1, 128.5, 125.7, 123.3, 120.2, 114.2, 113.7, 55.6, 21.5.

4.2.1.16. Compound ***4p****: white solid. m.p. 177.0–179.0* °C. ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.38 (d, J = 8.0 Hz, 2H), 7.93 (d, J = 8.0 Hz, 1H), 7.79–7.71 (m, 4H), 7.44–7.41 (m, 2H), 7.27 (d, J = 8.0 Hz, 2H), 7.10 (t, J = 8.5 Hz, 2H), 2.40 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.3, 159.3 (d, $J_{C\text{-}F}$ = 242.0 Hz), 157.3, 151.0, 140.4, 135.8, 134.6, 132.8, 129.1, 128.4, 125.8, 123.2 (d, $J_{C\text{-}F}$ = 7.75 Hz), 120.1, 115.5 (d, $J_{C\text{-}F}$ = 22.375 Hz), 113.6, 21.4. IR (neat) ν 2978, 2903, 1679, 1607, 1575, 1503, 1442, 1399, 1360, 1317, 1213, 1063, 837, 755 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{17}FN_3$ [M + H$^+$] 330.1401, found 330.1396.

4.2.1.17. Compound ***4q****: white solid. m.p. 165.7–166.5* °C. ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.97 (d, J = 8.0 Hz, 1H), 7.88 (d, J = 8.5 Hz, 1H), 7.85 (d, J = 7.0 Hz, 1H), 7.79 (t, J = 8.0 Hz, 1H), 7.71 (dd, J = 7.0, 5.0 Hz, 2H), 7.55–7.50 (m, 2H), 7.32–7.25 (m, 3H), 7.05 (t, J = 8.5 Hz, 2H), 2.55 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.4, 159.4 (d, $J_{C\text{-}F}$ = 242.25 Hz), 157.2, 150.7, 139.3, 137.2, 134.5, 132.9, 131.1, 130.4, 129.2, 128.9, 126.2, 125.7, 123.5 (d, $J_{C\text{-}F}$ = 7.875 Hz), 120.2, 115.5 (d, $J_{C\text{-}F}$ = 22.375 Hz), 113.0, 21.2. IR (neat) ν 2982, 2896, 1625, 1568, 1510, 1424, 1403, 1353, 1224, 1152, 1052, 952, 837, 805, 758, 733 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{17}FN_3$ [M + H$^+$] 330.1401, found 330.1409.

4.2.1.18. Compound ***4r****: yellow solid. m.p. 165.3–167.2* °C. ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.12–8.10 (m, 2H), 8.00 (d, J = 8.4 Hz, 1H), 7.88–7.79 (m, 4H), 7.53 (t, J = 7.2 Hz, 1H), 7.42 (br, 1H), 7.39 (d, J = 7.6 Hz, 1H), 7.16 (t, J = 8.8 Hz, 2H), 7.03 (dd, J = 7.6, 1.6 Hz, 1H), 3.92 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.1, 159.8, 159.4 (d, $J_{C\text{-}F}$ = 242.75 Hz), 157.4, 151.1, 140.1, 134.6, 132.9, 129.4 (d, $J_{C\text{-}F}$ = 8.625 Hz), 126.1, 123.5 (d, $J_{C\text{-}F}$ = 7.75 Hz), 121.0, 120.1, 117.0, 115.6 (d, $J_{C\text{-}F}$ = 22.375 Hz), 113.7, 113.0, 55.3. IR (neat) ν 2978, 2903, 1564, 1521, 1424, 1353, 1224, 1063, 1041, 902, 869, 816, 758, 737 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{17}FN_3O$ [M + H$^+$] 346.1350, found 346.1365.

4.2.1.19. Compound ***4s****: yellow solid. m.p. 173.6–175.3* °C. ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.45 (d, J = 8.8 Hz, 2H), 7.94 (d, J = 8.4 Hz, 1H), 7.83–7.74 (m, 4H), 7.45 (t, J = 8.0 Hz, 1H), 7.41 (br, 1H), 7.14 (t, J = 8.8 Hz, 2H), 7.00 (d, J = 8.8 Hz, 2H), 3.87 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.6, 160.1, 159.4 (d, $J_{C\text{-}F}$ = 242.0 Hz), 157.3, 151.2, 134.6, 132.9, 131.2, 130.0, 129.1, 125.6, 123.3 (d, $J_{C\text{-}F}$ = 7.75 Hz), 120.1, 115.6 (d, $J_{C\text{-}F}$ = 22.375 Hz), 113.7, 113.4, 55.3. IR (neat) ν 2989, 2900, 1611, 1568, 1532, 1507, 1449, 1414, 1356, 1220, 1170, 1056, 1027, 948, 862, 826, 758 cm^{-1}. HRMS (ESI) Calcd for $C_{21}H_{17}FN_3O$ [M + H$^+$] 346.1350, found 346.1355.

4.2.1.20. Compound ***4t****: yellow solid. m.p. 159.2–160.1* °C. ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.52 (d, J = 8.0 Hz, 2H), 7.90 (d, J = 8.4 Hz, 1H), 7.58–7.53 (m, 1H), 7.38 (t, J = 8.0 Hz, 2H), 7.32 (d, J = 8.0 Hz, 2H), 7.28–7.20 (m, 3H), 7.06–7.04 (m, 1H), 7.00–6.95 (m, 1H), 3.76 (s, 3H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.9, 159.7, 152.7, 148.8, 140.2, 136.1, 131.7, 129.8, 129.0, 128.7, 128.4, 126.2, 126.1, 125.8, 124.2, 115.5, 42.3, 21.4. IR (neat) ν 2989, 2903, 1611, 1564, 1539, 1482, 1442, 1389, 1356, 1288, 1170, 1074, 927, 837, 766, 698 cm^{-1}. HRMS (ESI) Calcd for $C_{22}H_{20}N_3$ [M + H$^+$] 326.1652, found 326.1664.

4.2.1.21. Compound ***4u****: white solid. m.p. 132.7–133.4* °C. ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.91 (d, J = 8.4, 6.8 Hz, 1H), 8.16 (s, 2H), 8.01 (d, J = 8.0 Hz, 1H), 7.88 (d, J = 8.0 Hz, 1H), 7.81 (td, J = 8.4, 1.2 Hz, 1H), 7.72 (br, 1H), 7.54 (td, J = 8.0, 0.8 Hz, 1H), 7.29–7.10 (m, 4H), 2.44 (s, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.6, 156.9, 153.3 (d, $J_{C\text{-}F}$ = 241.25 Hz), 151.1, 138.4, 137.8, 132.9, 132.1, 129.3, 127.4, 126.4, 126.2, 124.3 (d, $J_{C\text{-}F}$ = 3.5 Hz), 123.6 (d, $J_{C\text{-}F}$ = 7.625 Hz), 122.7, 120.1, 114.8 (d, $J_{C\text{-}F}$ = 19.25 Hz), 114.0, 21.5. IR (neat) ν 2993, 2900, 1628, 1568, 1535, 1503, 1482, 1449, 1417, 1353, 1260, 1177, 1113, 1066, 894, 859, 787, 751, 669 cm^{-1}. HRMS (ESI) Calcd for $C_{22}H_{19}FN_3$ [M + H$^+$] 344.1558, found 344.1571.

4.2.1.22. Compound ***4v*** *[10]: white solid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.56 (dd, J = 7.2, 1.6 Hz, 2H), 7.97 (d, J = 8.4 Hz, 1H), 7.94 (d, J = 8.4 Hz, 1H), 7.69 (t, J = 7.6 Hz, 1H), 7.50–7.40 (m, 7H), 7.36–7.28 (m, 2H), 5.07 (s, 2H), 3.38 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.9, 159.3, 153.1, 132.1, 130.0, 128.83, 128.81, 128.4, 127.4, 127.3, 124.9, 124.4, 114.8, 56.9, 39.4.

4.2.1.23. Compound ***4w****: yellow solid. m.p. 87.5–88.7* °C. ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.34 (d, J = 7.6 Hz, 1H), 8.24 (dd, J = 9.2, 1.2 Hz, 1H), 7.92 (d, J = 8.4 Hz, 2H), 7.71–7.67 (m, 1H), 7.46–7.41 (m, 1H), 7.38–7.35 (m, 1H), 7.14 (td, J = 8.4, 2.8 Hz, 1H), 3.82 (q, J = 7.2 Hz, 4H), 1.45 (t, J = 7.2 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.1 (d, $J_{C\text{-}F}$ = 242.375 Hz), 162.6, 158.0 (d, $J_{C\text{-}F}$ = 3.125 Hz), 153.0, 141.7 (d, $J_{C\text{-}F}$ = 7.625 Hz), 131.9, 129.6 (d, $J_{C\text{-}F}$ = 7.875 Hz), 129.0, 124.7, 124.4, 123.9 (d, $J_{C\text{-}F}$ = 2.625 Hz), 116.6 (d, $J_{C\text{-}F}$ = 21.375 Hz), 115.2 (d, $J_{C\text{-}F}$ = 4.125 Hz), 115.0. 45.1, 13.1. IR (neat) ν 2971, 2896, 1600, 1560, 1514, 1471, 1410, 1378, 1346, 1288, 1213, 1145, 1063, 1013, 859, 755, 726 cm^{-1}. HRMS (ESI) Calcd for $C_{18}H_{19}FN_3$ [M + H$^+$] 296.1558, found 296.1568.

4.2.1.24. Compound ***4x*** *[11]: white solid.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 8.44 (d, J = 8.4 Hz, 2H), 7.90 (t, J = 8.4 Hz, 2H), 7.68–7.64 (m, 1H), 7.35–7.31 (m, 1H), 7.28 (d, J = 8.0 Hz, 2H), 3.80 (q, J = 7.2 Hz, 4H), 2.42 (s, 3H), 1.44 (t, J = 7.2 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.6, 159.3, 153.1, 139.8, 136.4, 131.7, 128.9, 128.8, 128.3, 124.6, 123.9, 115.1, 45.0, 21.4, 13.1.

4.2.1.25. Compound ***4y****: white solid. m.p. 91.1–91.6* °C. ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.94 (d, J = 8.5 Hz, 1H), 7.91 (d, J = 8.5 Hz, 1H), 7.87–7.85 (m, 1H), 7.69 (t, J = 7.5 Hz, 1H), 7.39 (t, J = 7.5 Hz, 1H), 7.30–7.28 (m, 3H), 3.79 (q, J = 7.0 Hz, 4H), 2.59 (s, 3H), 1.41 (t, J = 7.0 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.6, 162.5, 152.7, 139.8, 137.1, 131.8, 130.9, 130.3, 128.9, 128.5, 125.6, 124.7, 124.3, 114.6, 45.0, 21.2, 13.4. IR (neat) ν 2989, 2907, 1603, 1553, 1517, 1381, 1242, 1177, 1070, 869, 823, 794, 762, 733 cm^{-1}. HRMS (ESI) Calcd for $C_{19}H_{22}N_3$ [M + H$^+$] 292.1808, found 292.1817.

4.2.1.26. Compound ***4z****: white solid. m.p. 87.1–89.0* °C. ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.54 (dd, J = 8.5, 5.5 Hz, 2H), 7.90 (d, J = 8.5 Hz, 2H), 7.68 (t, J = 7.0 Hz, 1H), 7.35 (t, J = 7.0 Hz, 1H), 7.15 (t, J = 8.5 Hz, 2H), 3.82 (q, J = 6.5 Hz, 4H), 1.45 (t, J = 6.5 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.3 (d, $J_{C\text{-}F}$ = 247.5 Hz), 162.6, 158.3, 153.0, 135.2, 131.9, 130.3 (d, $J_{C\text{-}F}$ = 8.5 Hz), 128.8, 124.7, 124.1, 115.02 (d, $J_{C\text{-}F}$ = 21.375 Hz), 115.00, 45.1, 13.1. IR (neat) ν 2980, 2919, 1596, 1558, 1505, 1463, 1376, 1353, 1206, 1065, 845, 796, 751, 682 cm^{-1}.

Please cite this article as: Z. Bao et al., *N*-heterocyclic carbene-Pd(II)-1-methylimidazole complex-catalyzed Suzuki-Miyaura coupling of 2-chloro-4-aminoquinazolines with arylboronic acids, Tetrahedron, https://doi.org/10.1016/j.tet.2020.131548

HRMS (ESI) Calcd for $C_{18}H_{19}FN_3$ [M + H^+] 296.1558, found 296.1565.

*4.2.1.27. Compound **4aa**: red liquid.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 7.96–7.89 (m, 4H), 7.69–7.65 (m, 1H), 7.36–7.33 (m, 1H), 7.27 (d, J = 6.5 Hz, 1H), 6.79 (ddd, J = 8.0, 2.5, 1.0 Hz, 1H), 3.81 (q, J = 7.0 Hz, 4H), 1.44 (t, J = 7.0 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.6, 159.2, 152.9, 146.3, 140.1, 131.8, 129.1, 128.8, 124.7, 124.0, 119.1, 116.9, 115.1, 115.0, 45.0, 13.2. IR (neat) ν 3344, 3224, 2976, 2930, 1618, 1560, 1518, 1432, 1344, 1294, 1194, 1076, 998, 904, 836, 764, 732 cm^{-1}. HRMS (ESI) Calcd for $C_{18}H_{20}N_4Na$ [M + Na^+] 315.1580, found 315.1577.

*4.2.1.28. Compound **4ab:** white solid. m.p. 123.3–124.4 °C.* ^{1}H NMR (500 MHz, $CDCl_3$, TMS) δ 8.55 (dd, J = 8.0, 2.0 Hz, 2H), 7.99 (d, J = 8.0 Hz, 1H), 7.88 (d, J = 8.5 Hz, 1H), 7.75–7.71 (m, 1H), 7.51–7.45 (m, 3H), 7.43–7.40 (m, 1H), 3.94 (t, J = 5.0 Hz, 4H), 3.85 (t, J = 5.0 Hz, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.9, 159.4, 152.8, 138.4, 132.5, 130.2, 129.1, 128.4, 128.3, 125.0, 124.6, 115.3, 66.7, 50.3. IR (neat) ν 2978, 2846, 1614, 1564, 1535, 1507, 1449, 1435, 1349, 1267, 1156, 1109, 1070, 1023, 1020, 948, 855, 769, 712 cm^{-1}. HRMS (ESI) Calcd for $C_{18}H_{18}N_3O$ [M + H^+] 292.1444, found 292.1447.

*4.2.1.29. Compound **4ac**[5]: yellow solid.* ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.93 (d, J = 8.0 Hz, 1H), 7.86–7.84 (m, 1H), 7.77–7.70 (m, 2H), 7.46–7.25 (m, 9H), 5.99 (br, 1H), 4.92 (d, J = 5.6 Hz, 2H), 2.56 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.9, 159.1, 150.3, 139.7, 138.5, 137.1, 132.5, 131.0, 130.2, 128.9, 128.75, 128.71, 127.9, 127.6, 125.7, 125.6, 120.4, 112.9, 45.3, 21.2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Zhen Bao thanks the Science and Technology Department of Zhejiang Province (Xinmiao Program) (No. 2019R429018) and College Students' Innovative Entrepreneurial Training Plan Program (No. 202010351021) for financial support.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tet.2020.131548.

References

[1] (a) M.K. Krapf, J. Gallus, A. Spindler, M. Wiese, Eur. J. Med. Chem. 161 (2019) 506–525;
(b) M.K. Krapf, J. Gallus, V. Namasivayam, M. Wiese, J. Med. Chem. 61 (2018) 7952–7976;
(c) M.K. Krapf, M. Wiese, J. Med. Chem. 59 (2016) 5449–5461;
(d) K. Juvale, J. Gallus, M. Wiese, Bioorg. Med. Chem. 21 (2013) 7858–7873;
(e) K. Juvale, M. Wiese, Bioorg. Med. Chem. Lett. 22 (2012) 6766–6769;
(f) M.-J. Hour, J.-S. Yang, T.-L. Chen, K.-T. Chen, S.-C. Kuo, J.-G. Chung, C.-C. Lu, C.-Y. Chen, Y.-H. Chuang, Eur. J. Med. Chem. 46 (2011) 2709–2721;
(g) H. Cope, R. Mutter, W. Heal, C. Pascoe, P. Brown, S. Pratt, P.B. Chen, Eur. J. Med. Chem. 41 (2006) 1124–1143;
(h) I. Sagiv-Barfi, E. Weiss, A. Levitzki, Bioorg. Med. Chem. 18 (2010) 6404–6413.
[2] (a) Z.-Y. Xing, Y. Fu, F. Ye, ARKIVOC ix (2012) 280–286;
(b) Z.-Y. Xing, Y. Fu, F. Ye, J. Heterocycl. Chem. 49 (2012) 1210–1213.
[3] V. Kumar, G. Bhargava, P.D. Dey, M.P. Mahajan, Synthesis (2005) 3059–3062.
[4] M. Staderini, N. Cabezas, M.L. Bolognesi, J. Carlos Menéndez, Tetrahedron 69 (2013) 1024–1030.
[5] X. Zhu, K.S. Van Horn, M.M. Barber, S. Yang, M.Z. Wang, R. Manetsch, K.A. Werbovetz, Bioorg. Med. Chem. 23 (2015) 5182–5189.
[6] For more examples of such complex catalyzed Suzuki-Miyaura coupling, please see: (a) Y.-Q. Tang, J.-M. Lu, L.-X. Shao, J. Organomet. Chem. 696 (2011) 3741–3744;
(b) X.-X. Zhou, L.-X. Shao, Synthesis (2011) 3138–3142;
(c) Z.-Y. Wang, G.-Q. Chen, L.-X. Shao, J. Org. Chem. 77 (2012) 6608–6614;
(d) Z.-Y. Wang, Q.-N. Ma, R.-H. Li, L.-X. Shao, Org. Biomol. Chem. 11 (2013) 7899–7906;
(e) Y. Zhang, M.-T. Feng, J.-M. Lu, Org. Biomol. Chem. 11 (2013) 2266–2272;
(f) H. Lv, L. Zhu, Y.-Q. Tang, J.-M. Lu, Appl. Organometal. Chem. 28 (2014) 27–31;
(g) X.-X. Wang, B.-B. Xu, W.-T. Song, K.-X. Sun, J.-M. Lu, Org. Biomol. Chem. 13 (2015) 4925–4930;
(h) X.-X. Wang, M.-J. Luo, J.-M. Lu, Org. Biomol. Chem. 13 (2015) 11438–11444.
[7] D. Kumar, S.I. Khan, B.L. Tekwani, P. Ponnan, D.S. Rawat, Eur. J. Med. Chem. 89 (2015) 490–502.
[8] E.M. Gedawy, Z. Mahmoud, Pharm. Chem. 7 (2015) 162–171.
[9] K.M. El-Shaieb, H. Hopf, P.G. Jones, ARKIVOC x (2010) 98–109.
[10] S.J. Lee, Y. Konishi, D.T. Yu, T.A. Miskowski, C.M. Riviello, O.T. Macina, M.R. Frierson, K. Kondo, M. Sugitani, J.C. Sircar, K.M. Blazejewski, J. Med. Chem. 38 (1995) 3547–3557.
[11] X. Chen, Q. Yang, Y. Zhou, Z. Deng, X. Mao, Y. Peng, Synthesis 47 (2015) 2055–2062.