Organic & Biomolecular Chemistry

PAPER

View Article Online
View Journal | View Issue

Cite this: *Org. Biomol. Chem.*, 2018, **16**, 8629

Palladium catalyzed carbonylative annulation of the C(sp^2)–H bond of *N*,1-diaryl-1*H*-tetrazol-5-amines and *N*,4-diaryl-4*H*-triazol-3-amines to quinazolinones†

Attoor Chandrasekhar, Venkatachalam Ramkumar and Sethuraman Sankararaman *

Pd(II) catalyzed direct C–H carbonylative annulation of *N*,1-diaryl-1*H*-tetrazol-5-amines and *N*,4-diaryl-4*H*-1,2,4-triazol-3-amines gave the corresponding triazole and tetrazole fused quinazolinones in good yields. This methodology offers a convenient method for the synthesis of these important heterocyclic scaffolds in a highly atom economical process. On the mechanistic aspect weakly nucleophilic triazole and tetrazole moieties function as both directing as well as intramolecular nucleophiles. The catalytically active C–H activated intermediate dimeric Pd complex was isolated and characterized which on exposure to CO gas gave the corresponding tetrazole fused quinazolinone derivative. On the basis of isolation of the intermediate and observed kinetic isotope effects, a mechanism has been proposed for the C–H activated direct carbonylative annulation reaction.

Received 11th October 2018,
Accepted 25th October 2018

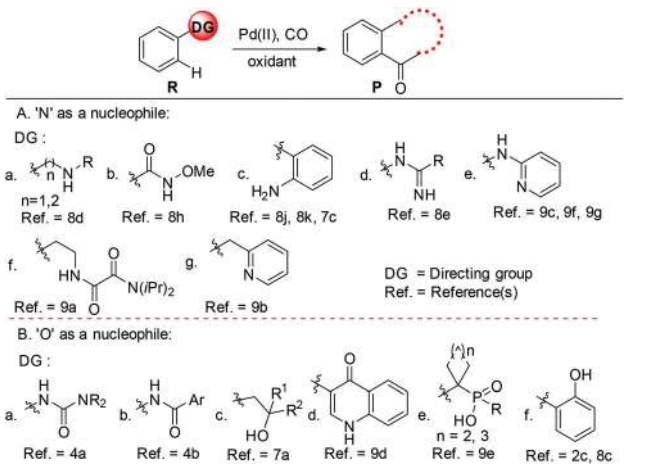
DOI: 10.1039/c8ob02516a

rsc.li/obc

Introduction

Since the seminal work of Heck, transition metal catalyzed carbonylation of organic halides and pseudo halides using carbon monoxide as a carbonyl source has become a powerful method for the synthesis of carboxylic acid and its derivatives and a wide variety of carbonylated heterocyclic compounds.[1] More recently the direct carbonylation of a C–H bond has resulted in the development of a more straightforward and atom economical approach.[2] The first direct oxidative carbonylation of arenes was introduced by Fujiwara in 1980 which involved an electrophilic attack on the arene by palladium(II).[3] Since then the focus has been on transition metal catalyzed regioselective arene C–H carbonylation.[4–7] In order to achieve selectivity various directing groups (DG) such as amides,[4] nitrogen containing heterocycles,[4c] carboxylic acids,[5] amidines[8e] and *tert*-amines[6] have been deployed, and often these directing groups also act as in-built nucleophiles.[9] Examples of directing groups in Pd(II) catalyzed intramolecular oxidative carbonylation of arenes are shown in Scheme 1. Derivatives of aminotriazole and aminotetrazole are important in medicinal chemistry.[10] Quinazolinone is an important scaffold found in nature and exhibits a wide range of biological activities including antibacterial, anti-inflammatory, antifungal and anti-cancer activities.[11]

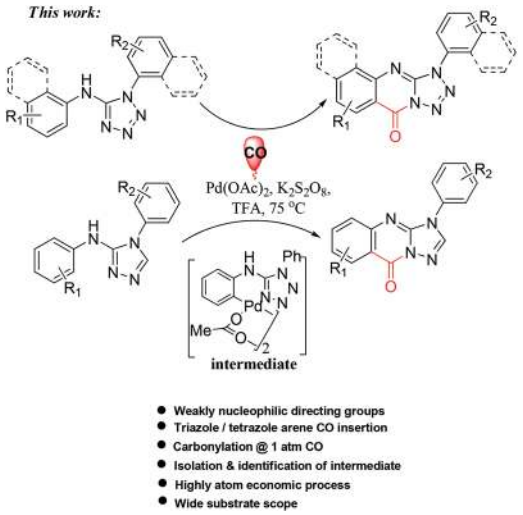
While fused triazoloquinazolinone is well known and prevalent, the fused tetrazoloquinazolinone scaffold is still rare and both are potential candidates in medicinal chemistry due to their wide biological activities. Copper catalyzed oxidative annulation of arylacetamides is known to give fused quinazolinones.[11h] Triazole and tetrazole fused quinazolinones are gen-



Scheme 1 Intramolecular C–H carbonylation of arenes.

Department of Chemistry, Indian Institute of Technology Madras, Chennai 600036, India. E-mail: sanka@iitm.ac.in

†Electronic supplementary information (ESI) available. CCDC 1832713, 1834321–1834323. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c8ob02516a



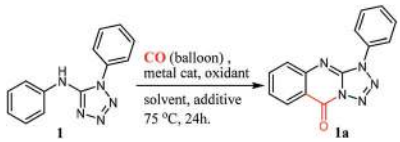
Scheme 2 Pd(II) catalyzed carbonylative annulation of *N*,1-diaryl-1*H*-tetrazol-5-amines and *N*,4-diaryl-4*H*-triazol-3-amines.

erally synthesized in multiple steps often with limitations on the substrate scope.[11h,12,13] Herein we report a straightforward method involving Pd(II) catalyzed oxidative carbonylative annulation of suitably substituted aminotetrazole and aminotriazole moieties, acting both as directing groups as well as in-built nucleophiles. This atom economical process involves the addition of CO and loss of only protons from the starting molecule and offers a wide substrate scope. We also report the isolation and characterization of a catalytically active intermediate of the reaction and a plausible mechanism of the reaction. This is the first report of aminotetrazole and aminotriazole moieties being used as directing groups as well as internal nucleophiles in carbonylative annulation reactions (Scheme 2).

Results and discussion

All the preliminary reactions were carried out on a 0.5 mmol scale of **1** under 1 atm of CO (balloon pressure) and using 10 mol% of Pd(II) source as the catalyst at 75 °C as there was no reaction at room temperature. The reaction of **1** in DMF with CuO as the oxidant yielded the desired product **1a** in 31% yield (Table 1, entry 1). When *p*-benzoquinone (BQ) was used as an oxidant in DMF and 1,4-dioxane as the solvent **1a** was obtained in 38 and 32% yield, respectively (entries 2 and 6). Additives such as trifluoroacetic acid (TFA) and KI in DMF along with BQ did not improve the yield of **1a** (entries 4 and 5). When the reaction was carried out under Fujiwara conditions[3b] using TFA as a solvent and potassium persulfate as an oxidant the yield of **1a** improved to 63%. Other palladium sources such as $PdCl_2(NCCH_3)_2$ and $PdCl_2(PPh_3)_2$ were not effective as catalysts (entries 8 and 9). The reaction did not proceed when nickel salts were used as catalysts instead of $Pd(OAc)_2$ (entries 11 and 12). The reaction did not proceed

Table 1 Optimization of reaction conditions for Pd catalyzed carbonylation of diarylaminotetrazole (**1**)



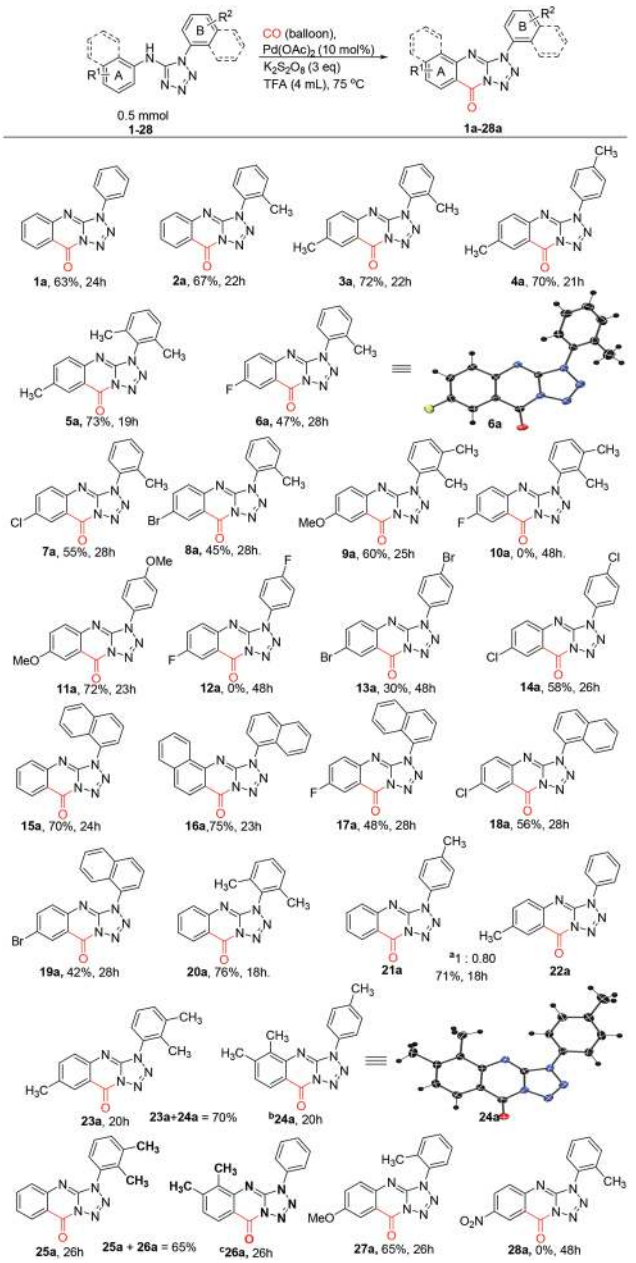
Entry	Metal cat.	Solvent	Additive[a]	Oxidant	Yield[b] (%)
1	$Pd(OAc)_2$	DMF	—	CuO	31
2	$Pd(OAc)_2$	DMF	—	BQ	38
3	$Pd(OAc)_2$	DMF	—	$Cu(OAc)_2$	NR
4	$Pd(OAc)_2$	DMF	TFA	BQ	40
5	$Pd(OAc)_2$	DMF	KI	BQ	37
6	$Pd(OAc)_2$	Dioxane	—	BQ	32
7	**$Pd(OAc)_2$**	**TFA**	**—**	**$K_2S_2O_8$**	**63**
8	$PdCl_2(CH_3CN)_2$	TFA	—	$K_2S_2O_8$	NR
9	$PdCl_2(PPh_3)_2$	TFA	—	$K_2S_2O_8$	NR
10	$Pd(OAc)_2$	TfOH	—	$K_2S_2O_8$	NR
11	$Ni(OTf)_2$	TFA	—	$K_2S_2O_8$	NR
12	$Ni(OAC)_2{\cdot}4H_2O$	TFA	—	$K_2S_2O_8$	NR

Reaction conditions: **1** (0.5 mmol), cat. (10 mol%), oxidant (3 eq.), solvent (4 mL). NR = no reaction. [a] 1 eq. of additive. [b] Isolated yields.

when a stronger acid, namely trifluoromethanesulfonic acid (TfOH) was used (entry 10).

From Table 1 the conditions corresponding to entry 7, which gave the maximum yield of product **1a**, were chosen for studying the substrate scope of the reaction and the results are summarized in Scheme 3. Electron donating (methyl and methoxy) substituents (Scheme 3, **3a–5a**, **9a**, **11a**) on either of the aryl rings favored the reaction and gave the corresponding quinazolinone in good yields. Although chloro and bromo substituents on either of the aryl rings are well tolerated, only moderate yields of the corresponding quinazolinone are obtained (**7a**, **8a**, **13a**, **14a**). Reactions of dichloro (**14a**) and dibromo (**13a**) derivatives proceeded smoothly and are noteworthy. Mono- and di-naphthyl substituted amino tetrazoles reacted to give CO annulated products (**15a–19a**) in good yields. Substrates substituted with strongly electron withdrawing groups such as fluoro (**10a**, **12a**) and nitro (**28a**) did not react at all. In these cases starting materials were fully recovered. On the basis of substituent effects on the reaction it was concluded that the aryl C–H bond is activated by an electrophilic mechanism with Pd(II) acting as an electrophilic species. Substrates **21–22**, **23–24** and **25–26** were prepared and used as a mixture of inseparable regio isomers. However the CO annulated products **23a–24a** and **25a–26a** were separated by column chromatography. The ratio of **21a–22a** was determined by the ^{1}H NMR spectrum of the crude product.

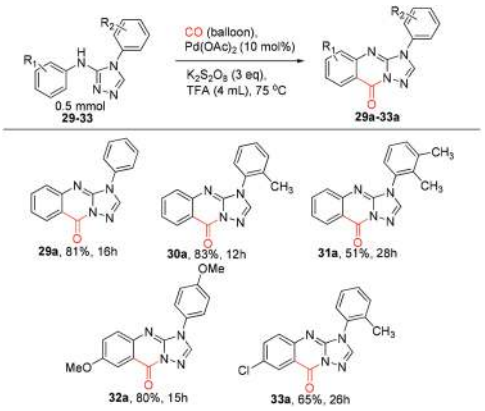
All the products were thoroughly characterized by spectroscopic methods. In addition, structures of **6a** and **24a** were established unequivocally by single crystal XRD data. The methodology developed was applied to the carbonylative annulation of *N*,4-diaryl-4*H*-1,2,4-triazol-3-amines (Scheme 4, **29–33**). The triazole derivatives were found to be more reactive than the tetrazole derivatives and the corresponding 3-aryl-[1,2,4]triazolo



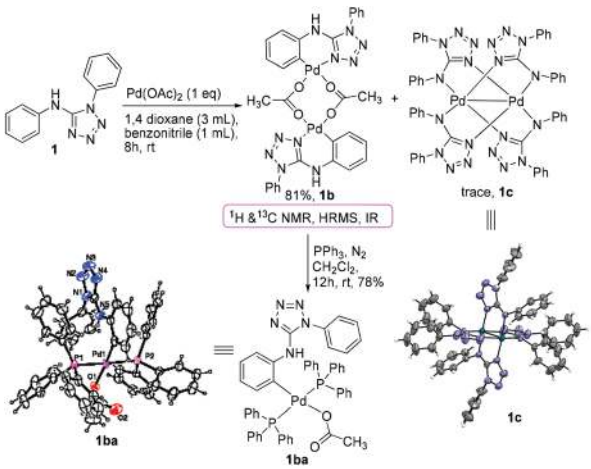
Scheme 3 Substrate scope of Pd catalyzed *ortho* C–H carbonylation of diarylaminotetrazoles to tetrazole fused quinazolinones. [a] Ratio (by ^{1}H NMR) of **21a** and **22a**. [b] 0.11 mmol (**24**) was used, [c] 0.1 mmol (**26**) was used.

[5,1-*b*]quinazolin-9(3*H*)-ones (**29a–33a**) were obtained in high yields, presumably due to higher nucleophilicity of the 1,2,4-triazole moiety in comparison to the tetrazole moiety.

To gain insight into the mechanism of the reaction we attempted to isolate the proposed C–H activated cyclopalladated intermediate (Scheme 5) by reacting **1** with stoichiometric amounts of $Pd(OAc)_2$ in 1,4-dioxane and benzonitrile as a solvent mixture. To our pleasant surprise the anticipated intermediate **1b** was isolated from the reaction mixture as a pale yellow solid (81%) (Scheme 5). Along with **1b**, a trace



Scheme 4 Pd catalyzed *ortho* C–H carbonylation of diarylaminotriazole to triazole fused quinazolinones.

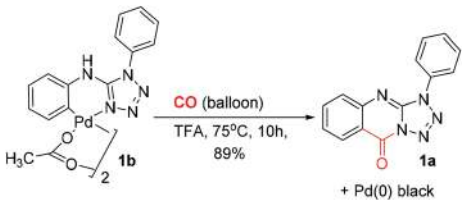


Scheme 5 Isolation and characterization of catalytically active intermediate palladium complex (**1b**).

amount (3%) of tetra-ligated dinuclear complex **1c** was also isolated from this reaction. Complex **1c** was characterized by single crystal XRD data. Attempts to obtain single crystals of **1b** were unsuccessful. It was thoroughly characterized by various spectroscopic methods.

In addition, complex **1b** was treated with Ph_3P in CH_2Cl_2 under an N_2 atm to obtain complex **1ba** which was characterized by single crystal XRD data. The acetate bridged bimetallic complex **1b** underwent ligand substitution with Ph_3P to give mononuclear complex **1ba** in 78% yield. In order to establish the involvement of **1b** in carbonylative annulation reaction, it was treated with carbon monoxide in TFA. The reaction of **1b** with CO proceeded smoothly and cleanly to yield **1a** in 89% yield along with palladium(0) black (Scheme 6) lending support to the hypothesis that **1b** might be involved as an active intermediate in the catalytic cycle.

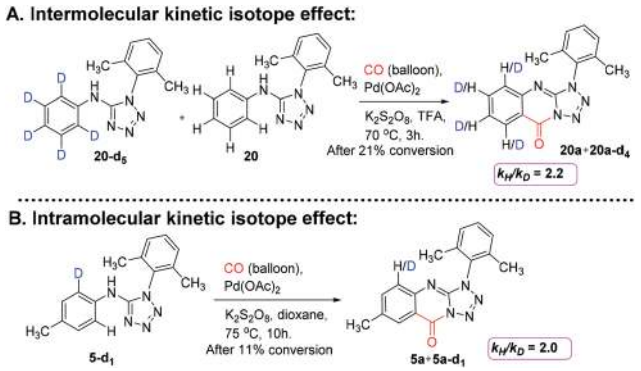
To understand the nature of C–H bond activation in the conversion of **1** to **1a** intra and intermolecular kinetic isotope effects (KIEs) were investigated.[10e,14] For the intermolecular



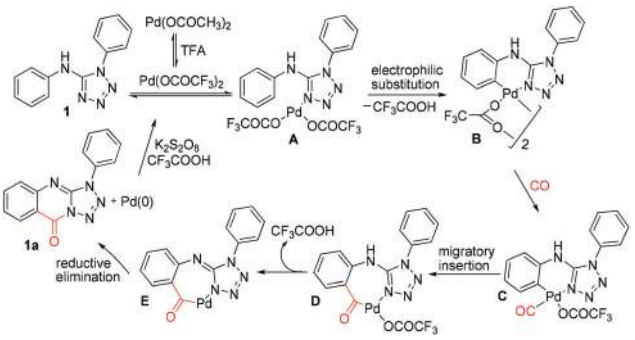
Scheme 6 Carbonylative annulation of intermediate palladium complex **1b**.

KIE a 1 : 1 mixture of **20-d$_5$** and **20** was reacted under standard reaction conditions. After 3 h, 21% conversion was observed (Scheme 7). For the intramolecular KIE **5-d$_1$** was reacted in dioxane for 10 h (11% conversion). Both of these reaction mixtures were analyzed by ^{1}H NMR spectroscopy. On the basis of integration of various peaks in the ^{1}H NMR spectra the KIE k_H/k_D values of 2.2 (intermolecular KIE) and 2.0 (intramolecular KIE) were obtained. On the basis of the KIE values it is concluded that the C–H bond is most likely activated in a rate determining step.

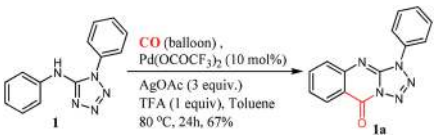
On the basis of these mechanistic studies we propose a plausible mechanism for the carbonylative annulation of **1** to **1a** (Scheme 8). In TFA medium $Pd(OCOCF_3)_2$ is most likely the electrophilic palladium source. Coordination of $Pd(OCOCF_3)_2$ to the tetrazole nitrogen gives **A** which on electrophilic substitution at the *ortho* position followed by loss of CF_3COOH leads to the formation of trifluoroacetate bridged binuclear complex **B** in the rate determining step. Complex **B** is the trifluoroacetate ligated version of complex **1b** which was isolated and characterized (Scheme 5). The reaction of **B** with CO gives intermediate **C** which on carbonyl migratory insertion gives intermediate **D**. The loss of CF_3COOH from **D** gives **E** which on reductive elimination gives **1a**. The Pd(0) species formed in the reductive elimination step is re-oxidized by $K_2S_2O_8$ in TFA back to $Pd(OCOCF_3)_2$ completing the catalytic cycle. Isolation of intermediate **1b** (Scheme 5) that is akin to intermediate **B**, formed in the stoichiometric reaction with $Pd(OAc)_2$ and its ability to undergo carbonylation (Scheme 6) lends support to the proposed mechanism. The



Scheme 7 Determination of inter- and intramolecular kinetic isotope effect.



Scheme 8 Plausible mechanism for aminotetrazole (**1**) directed Pd catalyzed C–H carbonylation to **1a**.

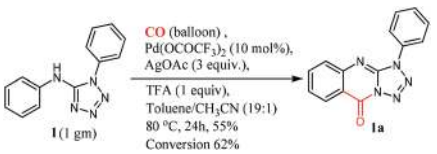


Scheme 9 Synthesis of 3-phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one in toluene.

heterocyclic moiety plays a dual role as a directing group as well as an internal nucleophile resulting in the annulation reaction.

Despite developing an atom economical method for the carbonylative annulation of the substrates under study, we were concerned about the use of TFA as the solvent for this reaction. Therefore we tried the reaction in other solvents. Among the solvents such as toluene, 1,4-dioxane and acetonitrile, toluene was found to be suitable for this transformation (for results see the ESI†). A maximum yield (67%) of quinazolin-9(3*H*)-one (**1a**) was observed when *N*,1-diphenyl-1*H*-tetrazol-5-amine (**1**) was treated with CO in the presence of $Pd(OCOCF_3)_2$ as a catalyst, AgOAc as an oxidant and 1 equiv. of TFA as an additive under a balloon pressure of carbon monoxide in toluene at 80 °C (Scheme 9).

To test the efficiency of carbonylative annulation on a gram scale, 1 gram of *N*,1-diphenyl-1*H*-tetrazol-5-amine (**1**) was treated with CO under the reaction conditions shown in Scheme 9. The reaction proceeded to 62% conversion and gave a 55% isolated yield of quinazolin-9(3*H*)-one (**1a**) (Scheme 10).



Scheme 10 Synthesis of 3-phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one in gram scale reaction.

Conclusion

We have developed a Pd(II) catalyzed oxidative carbonylative annulation strategy for the synthesis of 3-aryltetrazolo[5,1-*b*]quinazolin-9(3*H*)ones and 3-aryl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)-ones from the corresponding *N*,1-diaryl-1*H*-tetrazol-5-amines and *N*,4-diaryl-4*H*-1,2,4-triazol-3-amines. The tetrazole and triazole moieties act both as directing groups as well as internal nucleophiles. The method is highly atom economical as there is only hydrogen loss from the starting material with the insertion of CO. The method is applicable to substrates bearing electron donating substituents on either of the aromatic rings. Isolation and characterization of intermediate **1b** lends support to the proposed mechanism. On the basis of the isolation of a C–H activated cyclopalladated intermediate **1b** and the observed KIE effects a plausible mechanism has been proposed for this reaction involving electrophilic activation of the C–H bond followed by carbonyl insertion.

Experimental section

Starting materials, aminotetrazoles (**1–28**, **5-d$_1$**, **20-d$_5$**) and aminotriazoles (**29–33**), were synthesized by literature procedures with minor changes and were thoroughly characterized by various spectroscopic methods. 2-Deutero-*p*-toluidine (*p*-toluidine-d$_1$) was prepared from *p*-toluidine (see the ESI†).

General procedure for the synthesis of 3-aryltetrazolo[5,1-*b*]quinazolin-9(3*H*)-ones and 3-aryl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)-ones

To a 10 mL oven dried Schlenk round bottom flask were added *N*,1-diaryl-1*H*-tetrazol-5-amine or *N*,4-diaryl-4*H*-1,2,4-triazol-3-amine (0.5 mmol) and $K_2S_2O_8$ (3 eq.) followed by $Pd(OAc)_2$ (10 mol%). Then TFA (4 mL) was added. The reaction mixture was flushed thrice with carbon monoxide from a balloon and stirred at 75 °C under a CO atmosphere. The progress of the reaction was monitored by TLC. After stirring for a required time period (Scheme 3) the reaction mixture was cooled to room temperature and saturated aqueous $NaHCO_3$ was added and then extracted with EtOAc (20 mL) twice. The organic layer was separated and washed with brine solution. It was dried over Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography.

Spectral data for 3-aryltetrazolo[5,1-*b*]quinazolin-9(3*H*)-ones

3-Phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (1a). White solid, yield 63% (83 mg), mp: 151–153 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45 (dd, J = 8.0, 1.2 Hz, 1H), 8.29–8.26 (m, 2H), 7.85–7.81 (m, 1H), 7.76–7.74 (m, 1H), 7.64–7.60 (m, 2H), 7.51–7.43 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.7, 149.9, 141.1, 136.0, 134.3, 129.9, 128.8, 127.9, 126.9, 125.0, 120.3, 116.8; IR (KBr) (cm^{-1}): 1719, 1627; HRMS (ESI, m/z) calcd for $C_{14}H_9N_5ONa$ 286.0705 (M + Na), found 286.0699.

3-*o*-Tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (2a). White solid, yield 67% (93 mg), mp: 206–208 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.48 (dd, J = 8.5, 1.5 Hz, 1H), 7.81–7.78 (m, 1H), 7.66 (d, J = 8.0 Hz, 1H), 7.55–7.52 (m, 2H), 7.49–7.43 (m, 3H), 2.33 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 155.0, 150.2, 142.2, 135.9, 135.6, 132.1, 131.5, 131.3, 127.9, 127.5, 127.3, 126.7, 124.8, 116.6, 18.27; IR (KBr) (cm^{-1}): 1728, 1630; HRMS (ESI, m/z) calcd for $C_{15}H_{11}N_5ONa$ 300.0861 (M + Na), found 300.0880.

7-Methyl-3-*o*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*) one (3a). White solid, yield 72% (104 mg), mp: 198–201 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.26 (s, 1H), 7.63–7.42 (m, 6H), 2.50 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.0, 148.2, 137.6, 135.6, 134.9, 132.1, 131.6, 131.2, 127.5, 127.3, 127.0, 126.5, 116.3, 21.2, 18.2; IR (KBr) (cm^{-1}): 1731, 1632; HRMS (ESI, m/z) calcd for $C_{16}H_{13}N_5ONa$ 314.1018 (M + Na), found 314.1003.

7-Methyl-3-*p*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (4a). White solid, yield 70% (102 mg), mp: 180–182 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (s, 1H), 8.09 (d, J = 8.4 Hz, 2H), 7.63 (s, 2H), 7.39 (d, J = 8.0 Hz, 2H), 2.49 (s, 3H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.7, 147.9, 140.7, 139.0, 137.6, 135.0, 131.9, 130.3, 126.9, 126.7, 120.3, 116.4, 21.3, 21.2; IR (KBr) (cm^{-1}): 1727, 1625; HRMS (ESI, m/z) calcd for $C_{16}H_{14}N_5O$292.1198 (M + H), found 292.1218.

With the addition of Eu(fod)$_3$ shift reagent (2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.43 (s, 1H), 8.13 (d, J = 8.4 Hz, 2H), 7.70 (d, J = 8.8 Hz, 1H), 7.67 (dd, J = 8.8, 1.6 Hz, 1H), 7.41 (d, J = 8.4 Hz, 2H), 2.51 (s, 3H), 2.46 (s, 3H).

3-(2,6-Dimethylphenyl)-7-methyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (5a). White solid, yield 73% (111 mg), mp: 196–198 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.27 (s, 1H), 7.61 (dd, J = 8.4, 2.0 Hz, 1H), 7.55 (d, J = 8.4, Hz, 1H), 7.43 (t, J = 8.0 Hz, 1H), 7.28 (d, J = 7.6, Hz, 2H), 2.50 (s, 3H), 2.14 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.1, 148.4, 141.7, 137.6, 137.0, 134.8, 131.5, 130.5, 129.3, 129.2, 127.0, 126.9, 126.5, 116.3, 21.2, 21.1, 18.0, 17.9; IR (KBr) (cm^{-1}): 1735, 1633; HRMS (ESI, m/z) calcd for $C_{17}H_{16}N_5O$ 306.1355 (M + H), found 306.1346.

7-Fluoro-3-*o*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (6a). White crystalline solid, yield 47% (70 mg), mp: 233–235 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.09 (dd, J = 8.4, 2.4 Hz, 1H), 7.68–7.65 (m, 1H), 7.56–7.44 (m, 5H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.6, 158.2, 154.2, 146.8, 141.9, 135.6, 132.1, 131.4, 129.0, 128.9, 127.5, 127.2, 125.0, 124.8, 117.5, 117.4, 112.3, 112.0, 18.2; IR (KBr) (cm^{-1}): 1698, 1634; HRMS (ESI, m/z) calcd for $C_{15}H_{10}N_5OFNa$ 318.0767 (M + Na), found 318.0768.

7-Chloro-3-*o*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (7a). White solid, yield 55% (86 mg), mp: 218–220 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.42 (d, J = 2.4 Hz, 1H), 7.72 (dd, J = 9.2, 2.8 Hz, 1H), 7.60 (d, J = 8.8 Hz, 1H), 7.57–7.43 (m, 4H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.9, 148.7, 142.4, 136.4, 135.6, 132.1, 131.4, 131.3, 130.4, 128.3, 127.5, 127.2, 126.8, 117.5, 18.2; IR (KBr) (cm^{-1}): 1728, 1627; HRMS (ESI, m/z) calcd for $C_{15}H_{11}N_5OCl$ 312.0652 (M + H), found 312.0674.

7-Bromo-3-*o*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (8a). White solid, yield 45% (79 mg), mp: 208–210 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.58 (s, 1H), 7.84 (d, J = 8.8 Hz, 1H),

7.54–7.45 (m, 5H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.8, 149.1, 142.4, 139.0, 135.6, 132.1, 131.4, 131.3, 130.0, 128.5, 127.5, 127.2, 118.0, 117.8, 18.2; IR (KBr) (cm^{-1}): 1730, 1629; HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{11}N_5OBr$ 356.0147 (M + H), found 356.0149.

3-(2,3-Dimethylphenyl)-7-methoxytetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (9a). Yellow solid, yield 60% (96 mg), mp: 214–216 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.79 (d, J = 3 Hz, 1H), 7.59 (d, J = 9 Hz, 1H), 7.43–7.40 (m, 2H), 7.35–7.32 (m, 2H), 3.94 (s, 3H), 2.42 (s, 3H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.9, 154.8, 145.0, 141.3, 139.5, 134.4, 132.8, 131.5, 128.2, 127.1, 126.8, 125.1, 117.0, 106.1, 56.0, 20.5, 14.8; IR (KBr) (cm^{-1}): 1710, 1637; HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{15}N_5O_2Na$344.1123 (M + Na), found 344.1129.

7-Methoxy-3-(4-methoxyphenyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (11a). Pale yellow solid, yield 72% (116 mg), mp: 205–207 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.10 (d, J = 8.8 Hz, 2H), 7.76 (d, J = 2.8 Hz, 1H), 7.67 (d, J = 9.2 Hz, 1H), 7.44 (dd, J = 9.2, 2.8 Hz, 1H), 7.10 (d, J = 9.2 Hz, 2H), 3.94 (s, 3H), 3.89 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.8, 157.0, 154.6, 144.8, 128.3, 127.3, 127.1, 122.3, 117.1, 115.0, 106.1, 56.0, 55.8; IR (KBr) (cm^{-1}): 1708, 1630; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{13}N_5O_3Na$ 346.0916 (M + Na), found 346.0911.

7-Bromo-3-(4-bromophenyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (13a). White solid, yield 30% (63 mg), mp: 232–234 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.57 (d, J = 2.4 Hz, 1H), 8.20 (AA^lBB^l pattern J = 8.8 Hz, 2H), 7.90 (dd, J = 8.8, 2.4 Hz, 1H), 7.75 (AA^lBB^l pattern J = 8.8 Hz, 2H), 7.64 (d, J = 8.8 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 153.4, 148.6, 141.0, 139.3, 133.2, 133.1, 130.2, 128.7, 122.7, 121.6, 118.4, 118.2; IR (KBr) (cm^{-1}): 1722, 1631; HRMS (ESI, *m*/*z*) calcd for $C_{14}H_7N_5OBr_2Na$ 441.8915 (M + Na), found 441.8904.

7-Chloro-3-(4-chlorophenyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (14a). White solid, yield 58% (96 mg), mp: 207–209 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ8.40 (d, J = 1.6 Hz, 1H), 8.25 (AA^lBB^l pattern J = 9.0 Hz, 2H), 7.77 (dd, J = 8.5, 2.5 Hz, 1H), 7.70 (d, J = 9.0 Hz, 1H), 7.60 (AA^lBB^l pattern J = 9.0 Hz, 2H), ^{13}C NMR (125 MHz, $CDCl_3$): δ 153.6, 148.2, 141.0, 136.6, 134.8, 132.7, 131.0, 130.1, 128.5, 127.0, 121.3, 117.8; IR (KBr) (cm^{-1}): 1719, 1630; HRMS (ESI, *m*/*z*) calcd for $C_{14}H_7N_5OCl_2Na$ 353.9925 (M + Na), found 353.9950.

3-(1-Naphthyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (15a). White solid, yield 70% (109 mg), mp: 234–236 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.51(dd, J = 8.5, 1.5 Hz, 1H), 8.15 (d, J = 8.0 Hz, 1H), 8.04–8.02 (m, 1H), 7.82–7.76 (m, 2H), 7.72–7.69 (m, 1H), 7.65–7.57 (m, 4H), 7.48–7.44 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 155.0, 150.1, 142.9, 136.0, 134.7, 131.9, 128.9, 128.8, 128.6, 128.3, 128.0, 127.5, 126.8, 125.8, 125.3, 124.9, 122.1, 116.7; IR (KBr) (cm^{-1}): 1728, 1630; HRMS (ESI, *m*/*z*) calcd for $C_{18}H_{12}N_5O$ 314.1042 (M + H), found 314.1062.

11-(1-Naphthyl)benzo[*h*]tetrazolo[5,1-*b*]quinazolin-7(11*H*)-one (16a). White solid, yield 75% (136 mg), mp: 224–226 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.73 (dd, J = 8.4, 0.4 Hz, 1H), 8.35 (d, J = 8.3 Hz, 1H), 8.19 (d, J = 8.4 Hz, 1H), 8.07 (d, J = 8.0 Hz, 1H), 7.93–7.88 (m, 2H), 7.79–7.73 (m, 3H), 7.70–7.64 (m, 2H), 7.62–7.58 (m, 1H), 7.54–7.50 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.9, 150.0, 142.9, 136.9, 134.6, 131.8, 130.1, 129.5, 128.87, 128.81, 128.7, 128.6, 128.2, 127.9, 127.5, 126.8, 125.9, 125.5, 125.3, 122.4, 122.2, 112.4; IR (KBr) (cm^{-1}): 1732, 1637; HRMS (ESI, *m*/*z*) calcd for $C_{22}H_{13}N_5ONa$386.1018 (M + Na), found 386.1033.

7-Fluoro-3-(1-naphthyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (17a). Pale yellow solid, yield 48% (79 mg), mp: 360–365 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.16–8.11 (m, 2H), 8.03 (d, J = 7.6 Hz, 1H), 7.80 (d, J = 7.2 Hz, 1H), 7.72–7.68 (m, 1H), 7.66–7.57 (m, 4H), 7.54–7.50 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.7, 158.2, 154.2, 146.8, 134.7, 132.0, 129.1, 129.0, 128.8, 128.5, 128.4, 127.5, 125.8, 125.3, 125.1, 124.8, 122.0, 117.7, 117.6, 112.4, 112.1; IR (KBr) (cm^{-1}): 1725, 1631; HRMS (ESI, *m*/*z*) calcd for $C_{18}H_{10}N_5OFNa$ 354.0767 (M + Na), found 354.0788.

7-Chloro-3-(1-naphthyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (18a). Pale yellow solid, yield 56% (97 mg), mp: 220–222 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45 (d, J = 2.4 Hz, 1H), 8.16 (d, J = 8 Hz, 1H), 8.03 (d, J = 7.6 Hz, 1H), 7.80 (dd, J = 7.2, 1.2 Hz, 1H), 7.72–7.68 (m, 2H), 7.66–7.57 (m, 3H), 7.55 (d, J = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.9, 148.7, 143.0, 136.4, 134.6, 132.0, 130.5, 128.87, 128.82, 128.4, 127.5, 126.9, 125.8, 125.35, 125.31, 122.0, 117.7; IR (KBr) (cm^{-1}): 1729, 1635; HRMS (ESI, *m*/*z*) calcd for $C_{18}H_{11}N_5OCl$ 348.0652 (M + H), found 348.0677.

7-Bromo-3-(1-naphthyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (19a). White solid, yield 42% (82 mg), mp: 224–226 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.61 (d, J = 1.6 Hz, 1H), 8.15 (d, J = 8.4 Hz, 1H), 8.03 (d, J = 7.6 Hz, 1H), 7.84–7.79 (m, 2H), 7.70 (t, J = 8 Hz, 1H), 7.66–7.57 (m, 3H), 7.48 (d, J = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.8, 149.0, 143.1, 139.1, 134.6, 132.1, 130.1, 128.87, 128.80, 128.5, 128.4, 127.5, 125.8, 125.3, 122.0, 118.1, 117.9; IR (KBr) (cm^{-1}): 1731, 1627; HRMS (ESI, *m*/*z*) calcd for $C_{18}H_{11}N_5OBr$ 392.0147 (M + H), found 392.0128.

3-(2,6-Dimethylphenyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (20a). White solid, yield 76% (110 mg), mp: 197–199 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.48 (dd, J = 8, 1.2 Hz, 1H), 7.81–7.77 (m, 1H), 7.65 (dd, J = 8.4, 0.8 Hz, 1H), 7.46–7.42 (m, 2H), 7.27 (d, J = 9.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.0, 150.4, 142.2, 137.0, 135.9, 131.6, 130.5, 129.2, 127.9, 126.8, 124.7, 116.6, 18.0; IR (KBr) (cm^{-1}): 1729, 1635; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{13}N_5OK$ 330.0757 (M + K), found 330.0734.

3-*p*-Tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (21a) & 7-methyl-3-phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (22a). The ratio (by ^{1}H NMR) of the starting material mixture (**21** and **22**) – 1 (**21**) : 0.83 (**22**).

An inseparable mixture of **21a** and **22a** (ratio 1 : 0.80): white solid, yield 71% (98 mg), mp: 123–125 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45 (d, J = 8.0 Hz, 1H), 8.28–8.26 (m, 1.67H), 8.22 (s, 0.78H), 8.10 (d, J = 8.4 Hz, 1.96H), 7.83–7.80 (m, 1H), 7.76–7.73 (m, 1H), 7.64–7.59 (m, 3.34H), 7.50–7.42 (m, 1.71H), 7.40 (d, J = 8.0 Hz, 2.23H), 2.49 (s, 2.42H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 154.7, 150.0, 147.8, 139.1, 137.7, 137.6, 136.0, 135.9, 135.2, 134.4, 131.8, 130.3, 129.8, 128.8, 128.7,

127.8, 126.9, 126.7, 125.0, 124.9, 120.4, 120.2, 120.1, 116.7, 21.6, 21.2; IR (KBr) (cm^{-1}): 1715 (broad peak), 1630, 1603; HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{12}N_5O$ 278.1042 (M + H), found 278.1022.

3-(2,3-Dimethylphenyl)-7-methyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (23a). White solid, yield 84 mg, mp: 219–221 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.25 (dd, J = 1.2, 0.8 Hz, 1H), 7.62–7.60 (m, 1H), 7.56 (d, J = 8.4 Hz, 1H), 7.43–7.41 (m, 1H), 7.34–7.32 (m, 2H), 2.50 (s, 3H), 2.42 (s, 3H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.0, 148.2, 142.1, 139.5, 137.6, 134.8, 134.4, 132.8, 131.5, 126.9, 126.8, 126.5, 125.2, 116.2, 21.2, 20.5, 14.8; IR (KBr) (cm^{-1}): 1736, 1638; HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{16}N_5O$ 306.1355 (M + H), found 306.1352.

5,6-Dimethyl-3-*p*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (24a). White solid, yield 22 mg, mp: 222–224 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (d, J = 8.4 Hz, 3H), 7.43 (d, J = 8 Hz, 2H), 7.27 (d, J = 8 Hz, 1H), 2.59 (s, 3H), 2.49 (s, 3H), 2.48 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 155.1, 148.3, 145.2, 140.1, 138.6, 132.8, 132.3, 130.3, 127.2, 124.6, 119.6, 114.5, 21.4, 21.3, 13.7; IR (KBr) (cm^{-1}): 1720, 1630; HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{16}N_5O$ 306.1355 (M + H), found 306.1366. The isolated combined yield of **23a** and **24a** is 70%. The ratio of **23a** : **24a** is 1 : 0.26

3-(2,3-Dimethylphenyl)tetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (25a). White solid, yield 77 mg, mp: 217–219 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.48 (d, J = 7.6 Hz, 1H), 7.81–7.77 (m, 1H), 7.66 (d, J = 8.4 Hz, 1H), 7.47–7.43 (m, 2H), 7.37–7.33 (m, 2H), 2.43 (s, 3H), 2.15 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 155.0, 150.2, 142.5, 139.5, 135.9, 134.4, 132.8, 131.4, 127.9, 126.8, 126.7, 125.2, 124.7, 116.5, 20.5, 14.8; IR (KBr) (cm^{-1}): 1730, 1635; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{13}N_5ONa$ 314.1018 (M + Na), found 314.0993.

5,6-Dimethyl-3-phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (26a). White solid, yield 18 mg, mp: 189–192 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.37–8.35 (m, 2H), 8.21 (d, J = 8.4 Hz, 1H), 7.31 (t, J = 8.0 Hz, 2H), 7.48 (t, J = 7.6 Hz, 1H), 7.27 (d, J = 8.0 Hz, 1H), 2.59 (s, 3H), 2.48 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 155.0, 148.2, 145.3, 140.1, 134.8, 132.8, 129.8, 128.4, 127.4, 124.6, 119.6, 114.6, 21.4, 13.7; IR (KBr) (cm^{-1}): 1728, 1633; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{13}N_5ONa$ 314.1018 (M + Na), found 314.1045. The isolated combined yield of **25a** and **26a** is 65%. The ratio of **25a** : **26a** is 1 : 0.23.

7-Methoxy-3-*o*-tolyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one (27a). White solid, yield 65% (98 mg), mp: 207–209 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, J = 2.8 Hz, 1H), 7.60 (d, J = 9.2 Hz, 1H), 7.54–7.51 (m, 2H), 7.47 (d, J = 7.2 Hz, 1H), 7.44–7.90 (m, 2H), 3.94 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.0, 154.7, 144.9, 141.0, 135.6, 132.1, 131.6, 131.2, 128.2, 127.5, 127.2, 127.1, 117.0, 106.2, 56.0, 18.2; IR (KBr) (cm^{-1}): 1730, 1638; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{13}N_5O_2Na$ 330.0967 (M + Na), found 330.0943.

Spectral data for 3-aryl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)-ones

3-Phenyl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)one (29a). White solid, yield 81% (106 mg), mp: 234–236 °C, ^{1}H NMR (500 MHz, DMSO-d_6): δ 9.29 (s, 1H), 8.24 (d, J = 8.0 Hz, 1H), 7.94 (d, J = 8.0 Hz, 2H), 7.77 (t, J = 7.5 Hz, 1H), 7.65–7.58 (m, 3H), 7.51 (t, J = 7.5 Hz, 1H), 7.41–7.38 (m, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ 155.7, 148.8, 145.5, 142.5, 134.4, 133.1, 129.6, 128.4, 126.6, 126.0, 123.6, 123.5, 117.1; IR (KBr) (cm^{-1}): 1703, 1629; HRMS (ESI, *m*/*z*) calcd for $C_{15}H_{10}N_4ONa$ 285.0752 (M + Na), found 285.0772.

3-*o*-Tolyl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)one (30a). White solid, yield 83% (114 mg), mp: 264–265 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.46 (dd, J = 8.5, 1.5 Hz, 1H), 8.10 (s, 1H), 7.73–7.69 (m, 1H), 7.61 (t, J = 8.0 Hz, 1H), 7.52–7.37 (m, 5H), 2.29 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.7, 149.3, 145.9, 142.3, 139.6, 134.5, 134.4, 132.2, 131.0, 127.4, 127.0, 126.3, 125.3, 123.9, 117.4, 20.6; IR (KBr) (cm^{-1}): 1710, 1628; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{12}N_4ONa$ 299.0909 (M + Na), found 299.0921.

3-(2,3-Dimethylphenyl)-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)one (31a). White solid, yield 51% (73 mg), mp: 269–271 °C, ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.46 (dd, J = 8.0, 1.0 Hz, 1H), 8.08 (s, 1H), 7.72–7.69 (m, 1H), 7.61 (d, J = 8.5 Hz, 1H), 7.39–7.36 (m, 2H), 7.32–7.29 (m, 1H), 7.23 (d, J = 7.5 Hz, 1H), 2.41 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 156.7, 149.3, 145.9, 142.3, 139.6, 134.5, 134.4, 132.2, 131.0, 127.5, 127.0, 126.4, 125.3, 123.9, 117.5, 20.5, 14.7; IR (KBr) (cm^{-1}): 1711, 1626; HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{15}N_4O$ 291.1246 (M + H), found 291.1262.

7-Methoxy-3-(4-methoxyphenyl)-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)one (32a). White solid, yield 80% (128 mg), mp: 249–251 °C, ^{1}H NMR (500 MHz, DMSO-d_6): δ 9.18 (s, 1H), 7.79 (d, J = 9.0 Hz, 2H), 7.58 (d, J = 3.0 Hz, 1H), 7.53 (d, J = 9.0 Hz, 1H), 7.40 (dd, J = 9.0, 3.0 Hz, 1H), 7.16 (d, J = 9.0 Hz, 2H), 3.86 (s, 3H), 3.84 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6): δ 159.0, 155.4, 155.3, 144.5, 143.5, 142.8, 127.5, 125.8, 125.6, 124.7, 117.2, 114.6, 105.5, 55.6, 55.5; IR (KBr) (cm^{-1}): 1710, 1633; HRMS (ESI, *m*/*z*) calcd for $C_{17}H_{14}N_4O_3Na$ 345.0964 (M + Na), found 345.0946.

7-Chloro-3-*o*-tolyl-[1,2,4]triazolo[5,1-*b*]quinazolin-9(3*H*)one (33a). White solid, yield 65% (100 mg), mp: 268–270 °C, ^{1}H NMR (500 MHz, DMSO-d_6): δ 9.14 (s, 1H), 8.18 (d, J = 2.0 Hz, 1H), 7.76 (dd, J = 9.0, 2.5 Hz, 1H), 7.58–7.55 (m, 2H), 7.53–7.50 (m, 2H), 7.46–7.43 (m, 1H), 2.23 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6): δ 154.9, 147.8, 146.4, 143.9, 135.5, 134.3, 131.3, 130.2, 128.3, 128.1, 127.19, 127.17, 125.2, 118.0, 17.3; IR (KBr) (cm^{-1}): 1719, 1638; HRMS (ESI, *m*/*z*) calcd for $C_{16}H_{12}N_4OCl$311.0700 (M + H), found 311.0674.

Catalytically active C–H activated Pd complexes as intermediates. To a 10 mL oven dried reaction tube were added *N*,1-diphenyl-1*H*-tetrazol-5-amine **1** (1.25 mmol, 296 mg) and $Pd(OAc)_2$ (1 equiv., 280 mg). Then 1,4-dioxane was added (3 mL) followed by benzonitrile (1 mL) as a solvent mixture. The reaction mixture was stirred at room temperature. After 2 h, precipitate formation was observed in the reaction medium. After 8 h, the reaction mixture was filtered through Whatman filter paper and washed with 1,4-dioxane thrice. Pd complex **1b** was collected as a pale yellow solid and dried at room temperature for 24 h and finally dried under high vacuum. The filtrate (mother liquor) was exposed to air for a week upon which

complex **1c** was obtained as a brown crystalline solid (3% yield, 22 mg).

Synthesis of Pd complex 1ba from 1b. To a dried Schlenk reaction tube were added Pd complex **1b** (0.25 mmol, 200 mg) and triphenylphosphine (6 equiv., 395 mg) under an N_2 atmosphere. To this, dry CH_2Cl_2 (3 mL) was added through a syringe. The reaction mixture was degassed with N_2 for 15 min and stirred at room temperature for 12 h under an N_2 atmosphere. Then the reaction mixture was filtered through Whatman filter paper and mother liquor was concentrated on a rotary evaporator. The crude product was washed with anhydrous diethyl ether twice to obtain complex **1ba** as a white crystalline solid in 78% yield (360 mg).

CO insertion and conversion of catalytically active Pd complex 1b to 1a. Complex **1b** (0.25 mmol, 200 mg) was taken in a 10 mL oven dried Schlenk round bottom flask and TFA (3 mL) was added. The reaction mixture was flushed three times with 'CO' from the balloon and stirred at 75 °C under a CO balloon. After 10 h the reaction mixture was cooled to room temperature and saturated aqueous $NaHCO_3$ was added and then extracted with EtOAc twice. The organic layer was separated and washed with brine solution. The organic layer was dried over Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by column chromatography to obtain compound **1a** (89%, 117 mg).

Characterization data for the intermediate palladium complexes

Pd complex (1b). Pale yellow solid, yield 81% (406 mg), mp: 270–275 °C, ^{1}H NMR (400 MHz, DMSO-d_6): δ 9.72 (s, 1H), 7.61–7.59 (m, 3H), 7.27–7.25 (m, 2H), 7.09 (dd, J = 8.0, 1.2 Hz, 1H), 6.81–6.73 (m, 2H), 6.55–6.51 (m, 1H), 2.01 (s, 3H), 1.90 (s, 3H), ^{13}C NMR (100 MHz, DMSO-d_6): δ 179.5, 172.1, 142.6, 135.8, 134.3, 132.0, 130.4, 129.7, 125.4, 124.1, 120.5, 115.5, 115.4, 24.6, 21.1; IR (KBr) (cm^{-1}): 1563, 1461; HRMS (ESI, m/z) calcd for $C_{30}H_{26}N_{10}O_4Pd_2Na$ 825.0106 (M + Na), found 825.0109.

Pd complex (1c). Reddish orange solid, yield 3% (11 mg), mp: 295–300 °C, yield 65% (100 mg), ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.02–6.93 (m, 5H), 6.75 (d, J = 7.2 Hz, 3H), 6.66 (t, J = 6.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.9, 146.5, 134.3, 128.6, 128.4, 128.3, 123.9, 123.3, 122.7; HRMS (ESI, m/z) calcd for $C_{52}H_{41}N_{20}Pd_2$ 1157.1893 (M + H), found 1157.1899.

Pd complex (1ba). White crystalline solid, yield 78% (360 mg), mp: 154–155 °C, ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 (m, 3H), 7.61 (d, J = 8.0 Hz, 1H), 7.46 (s, 1H), 7.40 (d, J = 4.8 Hz, 2H), 7.34–7.30 (m, 6H), 7.21–7.20 (m, 24H), 6.86 (t, J = 7.6 Hz, 1H), 6.71 (d, J = 7.6 Hz, 1H), 6.21 (t, J = 6.8, 7.2 Hz, 1H), 0.89 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.7, 150.0, 137.4, 134.4 (t, 134.5, 134.4, 134.3), 134.3, 133.6, 130.8, 130.4, 129.6, 129.2. 129.0, 128.7, 128.11 (t, 128.15, 128.11, 128.0), 124.4, 124.3, 120.6, 118.9, 23.3; ^{31}P NMR (202 MHz, $CDCl_3$): δ 19.57 (external ref: PPh_3, δ = −6.00); IR (KBr) (cm^{-1}): 1559.

Determination of kinetic isotope effect

Intermolecular kinetic isotope experiment. To a 10 mL oven dried Schlenk round bottom flask were added 1-(2,6-dimethylphenyl)-*N*-phenyl-1*H*-tetrazol-5-amine **20** (0.5 mmol, 132 mg), 1-(2,6-dimethylphenyl)-*N*-(phenyl-d_5)-1*H*-tetrazol-5-amine **20-d_5** (0.5 mmol, 135 mg), and $K_2S_2O_8$ (3 eq.) followed by $Pd(OAc)_2$ (10 mol%). Then TFA (4 mL) was added. The reaction mixture was flushed thrice with carbon monoxide from a balloon and stirred at 75 °C under a CO balloon for 3 h. The reaction mixture was cooled to room temperature and saturated aqueous $NaHCO_3$ was added and then extracted with EtOAc two times. The organic layer was separated and washed with brine. The combined organic solution was dried over Na_2SO_4 and concentrated under reduced pressure. Conversion was calculated by the isolated yield of the recovered starting material. The ratio of deuterated and non-deuterated products was determined by ^{1}H NMR. The deuterium content of the product was determined by the relative integration value of H_{ortho} (8.49 ppm) based on the methyl (2.15 ppm) group. The reported k_H/k_D value is the average of two independent experiments.

Intramolecular kinetic isotope experiment. To a 10 mL oven dried Schlenk round bottom flask were added 1-(2,6-dimethylphenyl)-*N*-(2-deuterio-4-methylphenyl)-1*H*-tetrazol-5-amine **5-d_1** (0.5 mmol, 140 mg) and $K_2S_2O_8$(3 eq.) followed by $Pd(OAc)_2$ (10 mol%). Then 1,4-dioxane (4 mL) was added. The reaction mixture was flushed thrice with carbon monoxide from a balloon and stirred at 75 °C under a CO balloon for 10 h. The reaction mixture was cooled to room temperature and diluted with EtOAc followed by extraction with brine solution. The organic layer was dried over Na_2SO_4 and concentrated under reduced pressure. Conversion was calculated by the isolated yield of the recovered starting material. The ratio of deuterated and non-deuterated products was determined by ^{1}H NMR. The deuterium content of the product was determined by the relative integration value of Ha (7.56 ppm) based on the methyl (2.14 ppm) group. The reported K_H/K_D value is the average of two independent experiments.

Synthesis of 3-phenyltetrazolo[5,1-*b*]quinazolin-9(3*H*)-one in gram scale reaction

To a 50 mL oven dried Schlenk round bottom flask were added *N*,1-diphenyl-1*H*-tetrazol-5-amine (4.2 mmol, 1 g) and AgOAc (3 equiv., 2.1 g) followed by $Pd(OCOCF_3)_2$ (140 mg, 10 mol%). Then toluene (20 mL) and TFA (1 equiv., 480 mg) were added. The reaction mixture was flushed thrice with carbon monoxide from a balloon and stirred at 80 °C under a CO atmosphere for 24 h. The reaction mixture was cooled to room temperature, passed through a Celite pad, and washed with EtOAc (20 mL). The combined filtrate was concentrated under vacuum, and the crude product was purified by column chromatography on silica gel (eluant ethyl acetate/hexane 15 : 85 (vol%)) to obtain **1a** in 55% (609 mg) yield. 380 mg of the starting material (**1**) was also recovered. The yield of **1a** based on the recovery of the starting material is 89%.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

We thank E. Sharmila for the synthesis of aminotriazole derivatives and SAIF, IIT Madras for XRD data of **1ba**, and IIT Madras for financial support. AC thanks the UGC, New Delhi for a fellowship.

References

1 (*a*) R. F. Heck and D. S. Breslow, *J. Am. Chem. Soc.*, 1963, **85**, 2779; (*b*) A. Schoenberg and R. F. Heck, *J. Org. Chem.*, 1974, **39**, 3327; (*c*) M. Beller, Carbonylation of Benzyl- and Aryl-X Compounds, in *Applied Homogeneous Catalysis with Organometallic Compounds*, ed. B. Cornils and W. A. Herrmann, Wiley-VCH, Weinheim, 2nd edn, 2002; (*d*) X.-F. Wu, H. Neumann and M. Beller, *Chem. Soc. Rev.*, 2011, **40**, 4986; (*e*) X.-F. Wu, H. Neumann and M. Beller, *Chem. Rev.*, 2013, **113**, 1; (*f*) A. Chandrasekhar, V. Ramkumar and S. Sankararaman, *Eur. J. Org. Chem.*, 2016, 4041; (*g*) A. Dasgupta, V. Ramkumar and S. Sankararaman, *Eur. J. Org. Chem.*, 2016, 4817; (*h*) A. Chandrasekhar and S. Sankararaman, *J. Org. Chem.*, 2017, **82**, 11487; (*i*) B. Gabriele, Synthesis of heterocycles by palladium catalyzed carbonylative reactions, in *Advances in Transition-Metal Mediated Heterocyclic Synthesis*, ed. D. Sole and I. Fernandez, 2018, ch. 3, pp. 55–127; (*j*) C. Shen and X.-F. Wu, *Chem. – Eur. J.*, 2017, **23**, 2973; (*k*) X.-F. Wu, *RSC Adv.*, 2016, **6**, 83831; (*l*) S. T. Gadge and B. M. Bhanage, *RSC Adv.*, 2014, **4**, 10367; (*m*) S. Sumino, A. Fusano, T. Fukuyama and I. Ryu, *Acc. Chem. Res.*, 2014, **47**, 1563; (*n*) A. Brunnführer, H. Newmann and M. Beller, *Angew. Chem., Int. Ed.*, 2009, **48**, 4114.

2 (*a*) Z.-H. Guan, M. Chen and Z.-H. Ren, *J. Am. Chem. Soc.*, 2012, **134**, 17490; (*b*) Y. Du, T. K. Hyster and T. Rovis, *Chem. Commun.*, 2011, **47**, 12074; (*c*) T. Lee, J. Jayakumar, C.-H. Cheng and S.-C. Chuang, *Chem. Commun.*, 2013, **49**, 11797; (*d*) J.-R. Chen, X.-Q. Hu, L.-Q. Lu and W.-J. Xiao, *Chem. Rev.*, 2015, **115**, 5301; (*e*) X. Li, L. Li and N. Jiao, *J. Am. Chem. Soc.*, 2015, **137**, 9246; (*f*) M.-N. Zhao, L. F. Ran, M. Chen, Z.-H. Ren, Y.-Y. Wang and Z.-H. Guan, *ACS Catal.*, 2015, **5**, 1210; (*g*) L. Wang and A. Lei, *Angew. Chem., Int. Ed.*, 2014, **53**, 5657; (*h*) W. Li, Z. Duan, X. Zhang, H. Zhang, M. Wang, R. Jiang, H. Zeng, C. Liu and A. Lei, *Angew. Chem., Int. Ed.*, 2015, **54**, 1893; (*i*) W. Li, Z. Duan, R. Jiang and A. Lei, *Org. Lett.*, 2015, **17**, 1397; (*j*) M. Chen, Z.-H. Ren, Y.-Y. Wang and Z.-H. Guan, *J. Org. Chem.*, 2015, **80**, 1258; (*k*) S. Li, F. Li, J. Gong and Z. Yang, *Org. Lett.*, 2015, **17**, 1240; (*l*) L. Zeng, S. Tang, D. Wang, Y. Deng, J.-L. Chen, J.-F. Lee and A. Lei, *Org. Lett.*, 2017, **19**, 2170; (*m*) Y. He, F. Wang, X. Zhang and X. Fan, *Chem. Common.*, 2017, **53**, 4002; (*n*) K. Sasano, J. Takaya and N. Iwasawa, *J. Am. Chem. Soc.*, 2013, **135**, 10954; (*o*) J. Wen, S. Tang, F. Zhang, R. Shi and A. Lei, *Org. Lett.*, 2017, **19**, 94; (*p*) S. T. Gadge, P. Gautam and B. M. Bhanage, *Chem. Rec.*, 2016, **16**, 835; (*q*) Q. Liu, H. Zhang and A. Lei, *Angew. Chem., Int. Ed.*, 2011, **50**, 10788.

3 (*a*) Y. Fujiwara, T. Kawauchi and H. Taniguchi, *J. Chem. Soc., Chem. Commun.*, 1980, 220; (*b*) W. Lu, Y. Yamaoka, Y. Taniguchi, T. Kitamura, K. Takaki and Y. Fujiwara, *J. Organomet. Chem.*, 1999, **580**, 290; (*c*) X.-F. Wu, H. Neumann and M. Beller, *ChemSusChem*, 2013, **6**, 229; (*d*) B. Gabriele, R. Mancuso and G. Salerno, *Eur. J. Org. Chem.*, 2012, 6825; (*e*) Q. Liu, H. Zhang and A. Lei, *Angew. Chem., Int. Ed.*, 2011, **50**, 10788; (*f*) B. Gabriele, Oxidative Carbonylation, in *Top. Organomet. Chem, Catalytic Carbonylation Reactions*, ed. M. Beller, Springer, 2006, vol. 18, p. 239; (*g*) B. Gabriele, G. Salerno, M. Costa and G. P. Chiusoli, *Curr. Org. Chem.*, 2004, **8**, 919.

4 (*a*) C. E. Houlden, M. Hutchby, C. D. Bailey, J. G. Ford, S. N. Tyler, S. M. Gagné, G. C. Lloyd-Jones and K. I. Booker-Milburn, *Angew. Chem., Int. Ed.*, 2009, **48**, 1830; (*b*) R. Giri, J. K. Lam and J.-Q. Yu, *J. Am. Chem. Soc.*, 2010, **132**, 686; (*c*) Z.-H. Guan, Z.-H. Ren, S. M. Spinella, S. Yu, Y.-M. Liang and X. Zhang, *J. Am. Chem. Soc.*, 2009, **131**, 729.

5 R. Giri and J.-Q. Yu, *J. Am. Chem. Soc.*, 2008, **130**, 14082.

6 H. Li, G.-X. Cai and Z.-J. Shi, *Dalton Trans.*, 2010, **39**, 10442.

7 (*a*) Y. Lu, D. Leow, X. Wang, K. Engle and J.-Q. Yu, *Chem. Sci.*, 2011, **2**, 967; (*b*) M. Chen, Z.-H. Ren, Y.-Y. Wang and Z.-H. Guan, *Angew. Chem., Int. Ed.*, 2013, **52**, 14196; (*c*) D. Liang, Z. Hu, J. Peng, J. Huang and Q. Zhu, *Chem. Commun.*, 2013, **49**, 173.

8 (*a*) J. Ferguson, F. Zeng, N. Alwis and H. Alper, *Org. Lett.*, 2012, **14**, 5602; (*b*) K. Inamoto, J. Kadokawa and Y. Kondo, *Org. Lett.*, 2013, **15**, 3962; (*c*) S. Luo, F.-X. Luo, X.-S. Zhang and Z.-J. Shi, *Angew. Chem., Int. Ed.*, 2013, **52**, 10598; (*d*) K. Orito, A. Horibata, T. Nakamura, H. Ushito, H. Nagasaki, M. Yuguchi, S. Yamashita and M. Tokuda, *J. Am. Chem. Soc.*, 2004, **126**, 14342; (*e*) B. Ma, Y. Wang, J. Peng and Q. Zhu, *J. Org. Chem.*, 2011, **76**, 6362; (*f*) B. Haffemayer, M. Gulias and M. J. Gaunt, *Chem. Sci.*, 2011, **2**, 312; (*g*) N. Hasegawa, V. Charra, S. Inoue, Y. Fukumoto and N. Chatani, *J. Am. Chem. Soc.*, 2011, **133**, 8070; (*h*) J. W. Wrigglesworth, B. Cox, G. C. Lloyd-Jones and K. I. Booker-Milburn, *Org. Lett.*, 2011, **13**, 5326; (*i*) J. Ferguson, F. Zeng, N. Alwis and H. Alper, *Org. Lett.*, 2013, **15**, 1998; (*j*) V. Rajeshkumar, T.-H. Lee and S.-C. Chuang, *Org. Lett.*, 2013, **15**, 1468; (*k*) Z. Liang, J. Zhang, Z. Liu, K. Wang and Y. Zhang, *Tetrahedron*, 2013, **69**, 6519; (*l*) W. Li, C. Liu, H. Zhang, K. Ye, G. Zhang, W. Zhang, Z. Duan, S. You and A. Lei, *Angew. Chem., Int. Ed.*, 2014, **53**, 2443.

9 (*a*) L. Zhang, C. Wang, J. Han, Z.-B. Huang and Y. Zhao, *J. Org. Chem.*, 2016, **81**, 5256; (*b*) Z. Xie, S. Luo and Q. Zhu, *Chem. Commun.*, 2016, **52**, 12873; (*c*) J. Chen, J.-B. Feng, K. Natte and X.-F. Wu, *Chem. – Eur. J.*, 2015, **21**, 16370; (*d*) F. Ji, X. Li, W. Wu and H. Jiang, *J. Org. Chem.*, 2014, **79**, 11246; (*e*) S. Shin, Y. Jeong, W. H. Jeon and P. H. Lee, *Org. Lett.*, 2014, **16**, 2930; (*f*) D. Liang, Y. He and Q. Zhu, *Org. Lett.*, 2014, **16**, 2748; (*g*) G. Yan and J. E. Golden, *Org. Lett.*, 2018, **20**, 4393.

10 (*a*) R. E. Ford, P. Knowles, E. Lunt, S. M. Marshall, A. J. Penrose, C. A. Ramsden, A. J. H. Summers, J. L. Walker and D. E. Wright, *J. Med. Chem.*, 1986, **29**, 538; (*b*) N. P. Peet, L. E. Baugh, S. Sunder, J. E. Lewis, E. H. Matthews, E. L. Olberding and D. N. Shah, *J. Med. Chem.*, 1986, **29**, 2403; (*c*) B. Blank, D. M. Nichols and F. D. Vaidya, *J. Med. Chem.*, 1972, **15**, 694; (*d*) J.-L. Fauchere, J.-C. Ortuno, J. Duhault, J. A. Boutin and N. Levens, *European Patent* EP1044970, 2000; (*e*) P. Sadhu, S. K. Alla and T. Punniyamurthy, *J. Org. Chem.*, 2015, **80**, 8245.

11 (*a*) J. P. Michael, *Nat. Prod. Rep.*, 2004, **21**, 650; (*b*) S. B. Mhaske and N. P. Argade, *Tetrahedron*, 2006, **62**, 9787; (*c*) J. B. Jiang, D. P. Hesson, B. A. Dusak, D. L. Dexter, G. J. Kang and E. Hamel, *J. Med. Chem.*, 1990, **33**, 1721; (*d*) H.-J. Zhang, P. Jin, S.-B. Wang, F.-N. Li, L.-P. Guan and Z.-S. Quan, *Arch. Pharm. Chem. Life Sci.*, 2015, **348**, 564; (*e*) Y. Zhuang, X. Teng, Y. Wang, P. Liu, G. Li and W. Zhu, *Org. Lett.*, 2011, **13**, 1130; (*f*) I. Khan, A. Ibrar, W. Ahmed and A. Saeed, *Eur. J. Med. Chem.*, 2015, **90**, 124; (*g*) Z. Yin, Z. Wang and X.-F. Wu, *Org. Lett.*, 2017, **19**, 6232; (*h*) J. Sun, Q. Jan, W. Yang, B. Liu and B. Xu, *Adv. Synth. Catal.*, 2014, **356**, 388.

12 (*a*) D. J. Connolly, D. Cusack, T. P. O. Sullivan and P. J. Guiry, *Tetrahedron*, 2005, **61**, 10153; (*b*) J. Yu, H. Yang, Y. Jiang and H. Fu, *Chem. – Eur. J.*, 2013, **19**, 4271; (*c*) Z.-W. Zhou, F.-C. Jia, C. Xu, S.-F. Jiang, Y.-D. Wu and A.-X. Wu, *Chem. Commun.*, 2017, **53**, 1056; (*d*) D. N. Rao, S. K. Rasheed and P. Das, *Org. Lett.*, 2016, **18**, 3142; (*e*) J. Chen, K. Natte, A. Spannenberg, H. Neumann, P. Langer, M. Beller and X.-F. Wu, *Angew. Chem., Int. Ed.*, 2014, **53**, 7579; (*f*) M. Costa, N. D. Ca, B. Gabriele, C. Massera, G. Salerno and M. Soliani, *J. Org. Chem.*, 2004, **69**, 2469.

13 K. Kottke, K. Hans, L. Hellmut and W. Helmut, *German patent* DD206995, 1984.

14 For similar kinetic isotope effect studies, see: (*a*) M. Tobisu, Y. Ano and N. Chatani, *Org. Lett.*, 2009, **11**, 3250; (*b*) M. Gòmez-Gallego and M. A. Sierra, *Chem. Rev.*, 2011, **111**, 4857.

