A new route towards dithienoquinazoline and benzo[*f*]thieno[3,2-*h*]quinazoline systems using Pd-catalyzed intramolecular cyclization under microwave irradiation

Egor V. Verbitskiy,* Gennady L. Rusinov, Oleg N. Chupakhin, and Valery N. Charushin

Postovsky Institute of Organic Synthesis, Ural Branch of the Russian Academy of Sciences, S. Kovalevskoy Str. 22, Ekaterinburg 620 137, Russia, and: Ural Federal University, Mira Str. 19, Ekaterinburg 620 002, Russia
E-mail: Verbitsky@ios.uran.ru

Dedicated to Professor Renad Z. Sagdeev on the occasion of his 75th anniversary

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Abstract
A novel synthetic route to novel thienoacene systems bearing a fused pyrimidine ring is proposed. The commercially available 5-bromopyrimidine is used as the starting material to obtain various dithienoquinazoline and benzo[*f*]thieno[3,2-*h*]quinazoline systems through the Suzuki cross-coupling, nucleophilic aromatic substitution of hydrogen (the S_N^H reaction), and finally palladium-catalyzed intramolecular cyclization under microwave irradiation. Redox properties of some of the new compounds have been investigated. The data obtained show that these systems have plausible potential for use in organic electronic applications.

Keywords: Pyrimidines, thienoacenes, fused ring systems, intramolecular cyclization, palladium

Introduction

Thanks to their good stability, rich electronic properties, and strong intermolecular interactions, heteroacenes are among the most promising organic semiconductors for application in electronic devices such as organic light-emitting diodes, organic solar cells, and organic field-effect transistors.[1-3] In our previous publications, we have reported the synthesis of a series of dithienoquinazolines and benzo[*f*]thieno[3,2-*h*]quinazolines featuring a pyrimidine core fused with phenyl and thiophene rings, and have described some of their photophysical and electrochemical properties (Figure 1).[4,5] Compounds **I-III** were obtained using oxidative photocyclization over long reaction times (from 20 to 70 hours) under UV irradiation (450 W).

The direct arylation of arenes via C–H bond activation and halogen exchange catalyzed or mediated by transition metals has received significant attention. Palladium-catalyzed formation of carbon–carbon bonds via intramolecular C–X/C–H cross-coupling has emerged as an efficient and straightforward solution for the synthesis of a variety of heterocycles and carbocycles.[6-10] Palladium-catalyzed C–H intermolecular and/or intramolecular arylation offers one of the most efficient and reliable methods for the construction of different polycyclic structures.[11-15]

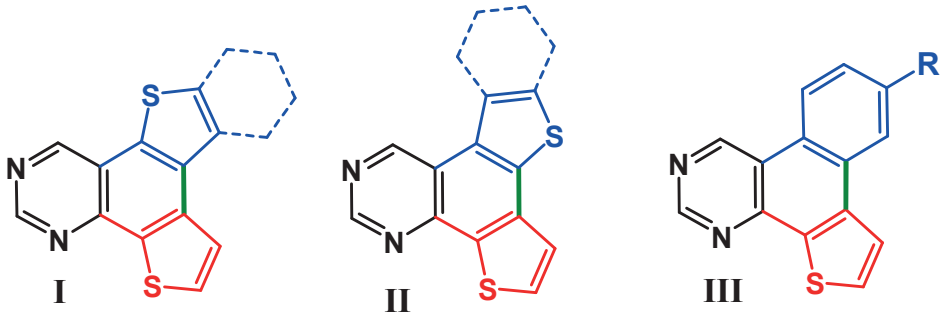


Figure 1. Chemical structures of dithieno[2,3-*f*:3',2'-*h*]quinazolines **(I)**, dithieno[3,2-*f*:3',2'-*h*]-quinazoline **(II)** and benzo[*f*]thieno[3,2-*h*]quinazolines **(III)**.

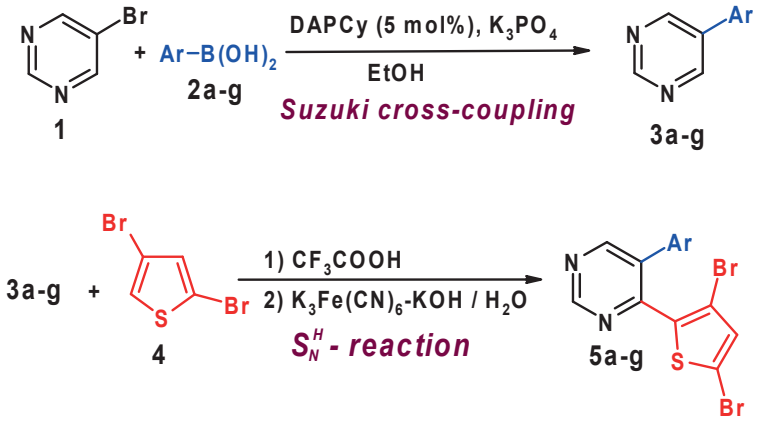
In this communication, we present a new and simple route to dithienoquinazoline and benzo[*f*]thieno[3,2-*h*]quinazoline systems **I-III**, based on Pd-catalyzed intramolecular cyclization, proceeding under microwave irradiation.

Results and Discussion

Based on literature data[16] on palladium-catalyzed intramolecular arylation through C–H bond activation and aryl *ortho*-bromide elimination, we designed an alternative route for the synthesis of the target polycyclic molecules **6a-g** (Schemes 1 and 2). For this purpose, suitable pyrimidine precursors **5a-g** were chosen. A series of 4-(3,5-dibromothiophen-2-yl)-5-(hetero)arylpyrimidines **(5a-g)** were prepared using the consecutive palladium-catalyzed Suzuki cross-coupling reaction and nucleophilic aromatic substitution of hydrogen (the S_NH reaction).[17-23] 5-(Hetero)arylpyrimidines **3a-g** were obtained from 5-bromopyrimidine **(1)** and an arylboronic acid **(2)** [phenylboronic **(2a)**,4-*tert*-butylphenylboronic **(2b)**, 4-(trifluoromethyl)phenylboronic **(2c)**, 2-thienylboronic **(2d)**, 3-thienylboronic **(2e)**, 1-benzothien-2-ylboronic **(2f)** or 1-benzothien-3-ylboronic **(2g)**], using the aerobic Suzuki cross-coupling reaction with a new catalyst, e.g. *trans*-bis(dicyclohexylamine)palladium(II) acetate (DAPCy)[24] (Scheme 1, Table 1). Compounds **3a-g** have further been involved in the S_NH-reactions of 5-(hetero)arylpyrimidines **3a-g** with 2,4-dibromothiophene **(4)** in CF_3COOH, followed by subsequent oxidation of the intermediates, resulting in the formation of 4-(3,5-dibromothiophen-2-yl)-5-(hetero)arylpyrimidines **(5a-g)** in

moderate yields (Scheme 1, Table 1). The structure of compound **5a** was unequivocally established by X-ray crystallography (Fig. 2).

The low yields (41-55%) of S_N^H-products **5a-g** can be explained by the steric hindrance due to the presence of the (hetero)aryl substituent at C(5) of the pyrimidine ring. Thus, incomplete conversion of the starting reagents **3** and **4** into target products **5** was observed even after long reaction times (up to 2 weeks). In all cases, the starting reagent **3a-g** was partially recovered after the reaction was stopped (see Table 1, entries 8-15).



a: Ar= Ph;
b: Ar= 4-t-Bu-C_6H_4; d: Ar= 2-thienyl; f: Ar= 1-benzothien-2-yl;
c: Ar= 4-F_3C-C_6H_4; e: Ar= 3-thienyl; g: Ar= 1-benzothien-3-yl.

Scheme 1. Synthesis of 4-(3,5-dibromothiophen-2-yl)-5-(hetero)arylpyrimidines **(5a-g)**.

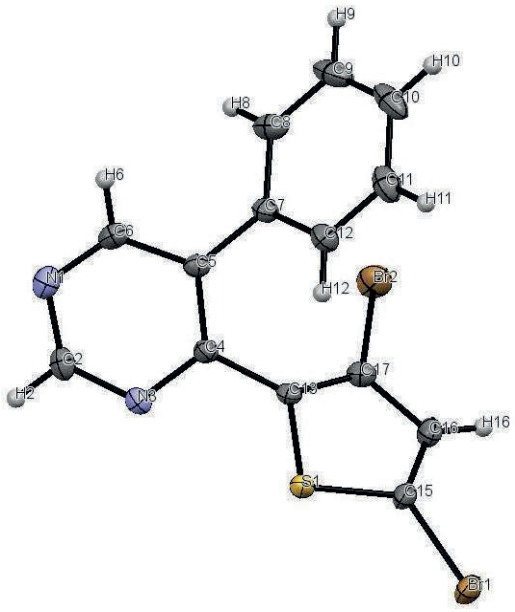


Figure 2. Mercury[25] representation of the X-ray crystal structure of **5a** with thermal ellipsoids of 50% probability.

Table 1. Reaction conditions and yields of compounds **3a-g** and **5a-g**

Entry	Reaction	Time	Reaction mixtures[a] GC-MS (%)	Product – isolated yield (%)
1	**1+2a**	2 hours	**3a** – 95	**3a** – 92
2	**1+2b**	2 hours	**3b –** 82	**3b** – 81
3	**1+2c**	2 hours	**3c** – 89	**3c** – 77
4	**1+2d**	2 hours	n.d.	**3d –** 64
5	**1+2e**	2 hours	n.d.	**3e –** 82
6	**1+2f**	2 hours	n.d.	**3f –** 71
7	**1+2g**	2 hours	n.d.	**3g** – 79
8	**3a+4**	2 weeks	**5a** – 55 **3a** – 38	**5a** – 52 **3a** – 31
9	**3b+4**	2 weeks	**5b** – 38 **4** – 27 **3a** – 28	**5b** – 20 **4** – 11 **3a** – 25
10	**3b+4**	1 month	**5b** – 61 **4** – 2 **3a** – 37	**5b** – 55 **4** – 0 **3a** – 30
11	**3c+4**	2 weeks	**5c** – 58 **3c** – 41	**5c** – 46 **3c** – 31
12	**3d+4**	2 weeks	**5d** – 42 **3d** – 35	**5d** – 45 **3d** – 42
13	**3e+4**	2 weeks	**5e** – 38 **3e** – 57	**5e** – 41 **3e** – 50
14	**3f+4**	1 week	**5f** – 50 **4** – 25 **3f** – 24	**5f** – 41 **4** – 11 **3f** – 20
15	**3g+4**	2 weeks	**5f** – 49 **4** – 23 **3f** – 24	**5f** – 43 **4** – 12 **3f** – 18

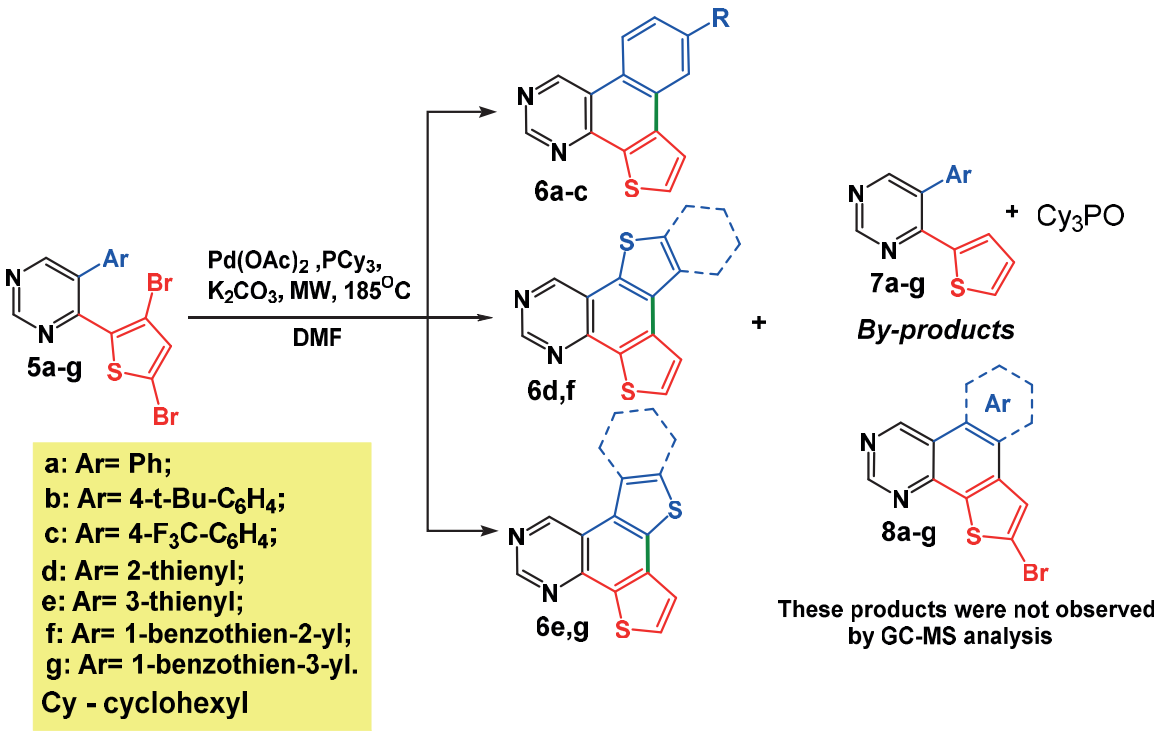
[a] For the reaction mixtures, the solvent was distilled off and the residue was analyzed by GC-MS; n.d. – not determined.

For the synthesis of the desired thienoacene derivatives **6a-g** the best (so far as we are aware) protocol[26] for direct arylation has been used. The reactions proceed in DMF under microwave irradiation at 180 °C in the presence of mixture 10 mol % of $Pd(OAc)_2$ and 20 mol % PCy_3 as catalyst, and 3 equiv of K_2CO_3 as base. All reaction mixtures were analyzed by GC-MS and several by-products were identified (Scheme 2, Table 2). Unfortunately, yields of compounds **6a-g** were

relatively low due to prevailing debromination side reactions. For this reason the formation of bromo-substituted benzo[*f*]thieno[3,2-*h*]quinazolines and dithienoquinazolines **8a-g** could not be observed, and the major by-products proved to be 5-(hetero)aryl-4-(thien-2-yl)pyrimidines **7a-g**. We mention that purification of thienoacenes **6a-g** is a difficult task, because of their poor solubility in common organic solvents.

Table 2. Reaction mixtures and yields of compounds **6a-g**

Entry	Starting compound	Reaction mixtures GC-MS (%)	Product – isolated yield (%)
1	**5a**	**6a** – 6 **7a** – 68 **Cy_3PO** – 18 **Impurities** – 2	**6a** – 4 **7a** – 37
2	**5b**	**6b** – 15 **7b** – 67 **Cy_3PO** – 16 **Impurities** – 2	**6b** – 7 **7b** – 35
3	**5c**	**6c** – 21 **7c** – 18 **Cy_3PO** – 50 **Impurities** – 11	**6c** – 14 **7c** – 10
4	**5d**	**6d** – 13 **7d** – 14 **Cy_3PO** – 78 **Impurities** – 5	**6d** – 12 **7d** – 8
5	**5e**	**6e** – 17 **7e** – 3 **Cy_3PO** – 74 **Impurities** – 6	**6e** – 15 **7e** – 2
6	**5f**	**6f** – 26 **7f** – 9 **Cy_3PO** – 64 **Impurities** – 1	**6f** – 23 **7f** – 6
7	**5g**	**6g** – 28 **7g** – 11 **Cy_3PO** – 59 **Impurities** – 2	**6g** – 25 **7g** – 8



Scheme 2. Synthesis of benzo[*f*]thieno[3,2-*h*]quinazolines (**6a-c**) and dithienoquinazolines (**6d-g**).

Electrochemical and optical properties of dithienoquinazolines **6d-g** are already reported.[4] The electrochemical behavior of heteroacenes **6a-c** was investigated by cyclic voltammetry, revealing their irreversible oxidation processes without reduction waves under the measurement conditions (Figs S1-S3, see *Supporting Information*). Their first oxidation potentials were observed in the following order: **6a** < **6b** < **6c**. Accordingly, the HOMO energy levels of benzo[*f*]thieno[3,2-*h*]quinazolines **(6a-c)** were evaluated, taking into account the first oxidation potentials, in the sequence **6a** (-4.95 eV) < **6b** (-5.00 eV) < **6c** (-5.39 eV). Thus electrochemical characteristics of heteroacenes **6a-c** appear to be similar to those for **6d-g**, suggesting the potential usefulness of the reported polycyclic derivatives for organic electronic applications.

Conclusions

In summary, a new route towards dithienoquinazoline and benzo[*f*]thieno[3,2-*h*]quinazoline systems based on a palladium-catalyzed intramolecular cyclization under microwave irradiation has been suggested. Unfortunately, it gives only moderate to low yields of the target products due to a debrominating side-reaction. Electrochemical studies of the benzo[*f*]thieno[3,2-*h*]quinazolines

have shown that compounds of this family have potential for application in the field of organic electronics.

Experimental Section

General. All reagents and solvents were obtained from commercial sources and dried by using standard procedures before use. *N*,*N*-Dimethylformamide for the microwave-assisted reaction was degassed by bubbling argon for 1h.

^{1}H, ^{19}F, and ^{13}C NMR spectra were recorded on a Bruker DRX-400 and Avance-500 instruments using Me_4Si and C_6F_6 as an internal standards. Elemental analysis was carried on a Eurovector EA 3000 automated analyzer. Melting points were determined on Boetius combined heating stage.

Flash column chromatography was carried out using Alfa Aesar silica gel 0.040-0.063 mm (230–400 mesh), eluting with ethyl acetate-hexane. The progress of reactions and the purity of compounds were checked by TLC on Sorbfil plates (Russia), in which the spots were visualized with UV light (λ 254 or 365 nm).

Semi-preparative HPLC was performed with ZORBAX Eclipse XDB-C18 PrepHT (21.2×150 mm, 5 μm) column, with flow rate 20 mL/min. Mixture of MeCN-H_2O was used as mobile phase.

Microwave heating was carried out in a Discover unimodal microwave system (CEM, USA) with a working frequency of 2.45 GHz and the power of microwave radiation ranged from 0 to 300 W. The reactions were carried out in a 10 mL reaction tube with hermetic Teflon cork. The temperature of the reaction was monitored using an inserted IR sensor by the external surface of the reaction vessel.

A suitable crystal of **5a** was selected and XRD analysis was performed on a Xcalibur diffractometer using standard procedure (MoK_α graphite-monochromated irradiation, ω-scanning with 1º steps). Compound **5a** was solved and refined by using Olex2 program.[27] Non-hydrogen atoms were refined in anisotropic approximation; H-atoms were refined in isotropic approximation in riding model. The X-ray crystallography data for structure **5a** reported in this paper have been deposited with Cambridge Crystallography Data Centre as supplementary publications CCDC no. 1469706 for **5a**. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Cyclic voltammetry was carried out on a Metrohm Autolab PGSTAT128N potentiostat with a standard three-electrode configuration. Typically, a three electrodes cell equipped with a platinum working electrode, a Ag/AgCl reference electrode with two membranes (the interior volume contents KCl saturated water solution; exterior volume 0.1 M $LiClO_4$ in CH_2Cl_2), and a glassy carbon rod counter electrode were employed. The measurements were performed in anhydrous CH_2Cl_2 solution containing the compound (2 mM) and tetrabutylammonium perchlorate (0.1 M) as the supporting electrolyte at a scan rate of 100 mV/s. The potential of reference electrode was calibrated by using the ferrocene/ferrocenium redox couple (Fc/Fc^+), which has a known oxidation

potential of +5.1 eV *vs*. vacuum for ferrocene.[28] The HOMO energy values were estimated from the onset potentials (E_{ox}^{onset}) of the first oxidation event according to the following equations:

$$E_{HOMO}\ (eV) = -\ [E_{ox}^{onset} - E_{1/2}(Fc/Fc^{+}) + 5.1] \qquad (\mathbf{1})$$

where $E_{1/2}(Fc/Fc^{+})$ is the half-wave potential of the Fc/Fc^{+} couple against the Ag/AgCl electrode.

General procedure for the synthesis of 5-(hetero)arylpyrimidines (3a-g). Phenylboronic **(2a)** (1.0 mmol), [or 4-*tert*-butylphenylboronic **(2b)**, 4-(trifluoromethyl)phenylboronic **(2c)**, 2-thienylboronic **(2d)**, 3-thienylboronic **(2e)**, 1benzothien-2-ylboronic **(2f)** or 1-benzothien-3-ylboronic **(2g)**] was added to *trans*-bis(dicyclohexylamine)palladium(II) acetate (29 mg, 0.05 mmol) in EtOH (10 mL). The resulting suspension was kept at reflux for 2 h. EtOH was evaporated under reduced pressure and the residue was suspended in CH_2Cl_2 (20 mL), and then filtered from inorganic salts. Solvent was then distilled off under reduced pressure, and the residue was purified by flash column chromatography on silica gel (hexane/ethyl acetate, 1:3) to afford the desired cross-coupled products **(3a-g)**. Compounds **3d-g** were identified on the basis of their NMR spectra and comparison with authentic materials. For spectral data of compounds **3d-g** synthesized earlier, see ref 21.

5-Phenylpyrimidine (3a).[29] Yield (see Table 1, entry 1), white solid; mp 38-40 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45-7.49 (m, 1H, Ph), 7.51-7.55 (m, 2H, Ph), 7.58-7.60 (m, 2H, Ph), 8.92 (s, 2H, H-4 and H-6), 9.17 (s, 1H, H-2) ppm. GC t_R 15.76 min; MS *m/z* (rel intensity) 156 (M^+, 100). Anal. Calcd for $C_{10}H_8N_2$ (156.19): C, 76.90; H, 5.16; N, 17.94. Found: C, 76.81; H, 5.23; N, 17.87%.

5-(4-*tert*-Butylphenyl)pyrimidine (3b). Yield (see Table 1, entry 2), white solid; mp118-120 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.37 (s, 9H, CH_3), 7.52-7.56 (m, 4H, Ph), 8.95 (s, 2H, H-4 and H-6), 9.19 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 31.23, 34.71, 126.40, 126.65, 131.32, 134.16, 152.31, 154.75, 157.25 ppm. GC t_R 19.90 min; MS *m/z* (rel intensity): 212 (M^+, 100). Anal. Calcd for $C_{14}H_{16}N_2$ (212.30): C 79.21, H 7.60, N, 13.20. Found: C 79.12; H, 7.86; N, 13.07%.

5-(4-Trifluoromethylphenyl)pyrimidine (3c). Yield (see Table 1, entry 3), white solid; mp110-112 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.72 (d, 2H, *J* 8.1 Hz, H-2' and H-6'), 7.80 (d, 2H, *J* 8.1 Hz, H-3' and H-5'), 8.99 (s, 2H, H-4 and H-6), 9.28 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 123.84 (d, $^1J_{C,F}$ 272.3 Hz), 126.40 (q, $^4J_{C,F}$ 3.7 Hz), 127.41, 131.17 (q, $^2J_{C,F}$ 32.8 Hz), 133.10, 137.86 (d, $^4J_{C,F}$ 0.8 Hz), 155.02, 158.24 ppm. ^{19}F NMR (470.5 MHz, $CDCl_3$) 98.98 (s, CF_3) ppm. GC t_R 15.89 min; MS m/z (rel intensity): 224 (M^+, 100). Anal. Calcd for $C_{11}H_7F_3N_2$ (224.19): C 58.93, H 3.15, N, 12.50. Found: C 58.72; H, 3.13; N, 12.64%.

General procedure for synthesis of 4-(3,5-dibromothien-2-yl)-5-(hetero)arylpyrimidines (5a-g) 2,4-Dibromothiophene **(4)** (224 μL, 2.0 mmol) was added to a solution of 5-(hetero)aryl-pyrimidines **(3a-g)** (1.0 mmol) in CF_3COOH (5 mL). The reaction mixture was stirred at room temperature for an appropriate time (see Table 1) and evaporated. The solution of KOH (224 mg, 4.0 mmol, 4 equiv) and $K_3Fe(CN)_6$ (658 mg, 2.0 mmol, 2 equiv) in 10 mL water was added to

residue. The resulting mixture was stirred for 24 h at room temperature, the precipitate or semisolid formed was filtered off, washed with H_2O, and air-dried. The residue was purified by flash column chromatography (hexane/ethyl acetate, 1:3) or by semi-preparative HPLC to afford the desired S_N^H-product **(5a-g)**.

4-(3,5-Dibromothien-2-yl)-5-phenylpyrimidine (5a). Yield (see Table 1, entry 8), yellow semisolid; mp108-110 °C. ^{1}H NMR (500 MHz, DMSO-d_6): δ 7.30 (s, 1H, H-4'), 7.34-7.36 (m, 2H, Ph), 7.40-7.45 (m, 3H, Ph), 8.99 (s, 1H, H-6), 9.28 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, DMSO-d_6): δ 110.58, 115.40, 128.47, 128.74, 128.85, 133.12, 134.16, 134.72, 136.60, 154.93, 156.90, 158.65 ppm. GC t_R 25.74 min; MS *m/z* (rel intensity): 396 (M^+, 100). Anal. Calcd for $C_{14}H_8Br_2N_2S$ (396.11): C 42.45, H 2.04, N, 7.07. Found: C 42.74; H, 1.99; N, 7.05 %.

5-(4-*tert*-Butylphenyl)-4-(3,5-dibromothien-2-yl)pyrimidine (5b). Yield (see Table 1, entries 9 and 10), pale yellow solid; mp55-57 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.34 (s, 9H, CH_3), 6.98 (s, 1H, H-4'), 7.20 (d, 2H, *J* 8.4 Hz, Ph), 7.40 (d, 2H, *J* 8.4 Hz, Ph), 8.83 (s, 1H, H-6), 9.21 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 31.22, 34.67, 110.94, 115.68, 125.89, 128.50, 132.00, 133.30, 134.54, 136.83, 151.87, 155.63, 156.74, 158.65 ppm. GC t_R 27.90 min; MS *m/z* (rel intensity): 452 (M^+, 100). Anal. Calcd for $C_{18}H_{16}Br_2N_2S$ (452.21): C 47.81, H 3.57, N, 6.19. Found: C 47.71, H 3.63, N, 6.23 %.

4-(3,5-Dibromothien-2-yl)-5-(4-trifluoromethylphenyl)pyrimidine (5c). Yield (see Table 1, entry 11), beige solid; mp110-112 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.90 (s, 1H, H-4'), 7.42 (d, 2H, *J* 8.1 Hz, Ph), 7.67 (d, 2H, *J* 8.1 Hz, Ph), 8.84 (s, 1H, H-6), 9.28 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 111.16, 116.45, 123.83 (d, $^1J_{C,F}$ 272.4 Hz), 125.93 (q, $^4J_{C,F}$ 3.7 Hz), 129.23, 130.74 (q, $^2J_{C,F}$ 32.9 Hz), 133.28, 133.46, 136.15, 138.92, 155.93, 157.67, 158.49 ppm. ^{19}F NMR (470.5 MHz, $CDCl_3$) 99.00 (s, CF_3) ppm. GC t_R 25.03 min; MS *m/z* (rel intensity): 464 (M^+, 100). Anal. Calcd for $C_{15}H_7Br_2F_3N_2S$ (464.10): C 38.82, H 1.57, N, 6.04. Found: C 38.85; H, 1.74; N, 5.87%.

4-(3,5-Dibromothien-2-yl)-5-thien-2-yl-pyrimidine (5d). Yield (see Table 1, entry 12), yellow solid; mp106-108 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.97 (s, 1H, H-4'), 7.07 (dd, *J* 5.0, 3.7 Hz, 1H, H-4"), 7.11 (dd, *J* 3.7, 0.9 Hz, 1H, H-3"), 7.43 (dd, *J* 5.0, 0.9 Hz, 1H, H-5"), 8.95 (s, 1H, H-6), 9.17 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 111.77, 116.00, 127.90, 127.95, 128.42, 128.75, 133.15, 135.80, 135.97, 155.09, 156.71, 157.85 ppm. GC t_R 26.11 min; MS *m/z* (rel intensity): 402 (M^+, 100). Anal. Calcd for $C_{12}H_6Br_2N_2S_2$ (402.13): C 35.84, H 1.50, N, 6.97. Found: C 35.75, H 1.42, N, 6.64%.

4-(3,5-Dibromothien-2-yl)-5-thien-3-yl-pyrimidine (5e). Yield (see Table 1, entry 13), yellow solid; mp241-243 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.94 (s, 1H, H-4'), 6.95 (dd, *J* 5.1, 1.1 Hz, 1H, H-4"), 7.31 (dd, *J* 2.7, 1.1 Hz, 1H, H-2"), 7.36 (dd, *J* 5.1, 2.7 Hz, 1H, H-5"), 8.89 (s, 1H, H-6), 9.19 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 111.18, 115.82, 124.90, 126.88, 127.21, 129.91, 133.30, 135.25, 136.55, 155.41, 156.80, 158.02 ppm. GC t_R 26.26 min; MS *m/z* (rel intensity): 402 (M^+, 100). Anal. Calcd for $C_{12}H_6Br_2N_2S_2$ (402.13): C 35.84, H 1.50, N, 6.97. Found: C 35.95, H 1.63, N, 6.88%.

5-(1-Benzothien-2-yl)-4-(3,5-dibromothien-2-yl)pyrimidine (5f). Yield (see Table 1, entry 14), yellow solid; mp141-143 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.97 (s, 1H, H-4'), 7.38 (br. m, 3H, benzothienyl), 7.78-7.82 (br. m, 2H, benzothienyl), 9.04 (s, 1H, H-6), 9.22 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 112.30, 116.42, 122.29, 124.22, 124.73, 124.77, 125.29, 128.79, 133.29, 135.78, 136.19, 139.52, 140.90, 155.57, 157.14, 158.29 ppm. GC t_R 30.68 min; MS *m/z* (rel intensity): 452 (M^+, 100). Anal. Calcd for $C_{16}H_8Br_2N_2S_2$ (452.19): C 42.50, H 1.78, N, 6.20. Found: C 42.46, H 2.04, N, 6.05%.

5-(1-Benzothien-3-yl)-4-(3,5-dibromothien-2-yl)pyrimidine (5g). Yield (see Table 1, entry 15), yellow solid; mp74-76 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.84 (s, 1H, H-4'), 7.34-7.41 (br. m, 3H, benzothienyl), 7.54 (d, 1H, *J* 7.7 Hz, benzothienyl), 7.90 (d, 1H, *J* 7.7 Hz, benzo[*b*]thienyl), 8.93 (s, 1H, H-6), 9.31 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 111.66, 116.12, 121.76, 122.98, 124.84, 124.94, 127.40, 128.79, 130.25, 133.47, 136.15, 137.34, 140.08, 156.79, 157.40, 159.01 ppm. GC t_R 29.91 min; MS *m/z* (rel intensity): 452 (M^+, 100). Anal. Calcd for $C_{16}H_8Br_2N_2S_2$ (452.19): C 42.50, H 1.78, N, 6.20. Found: C 42.64, H 2.01, N, 6.07%.

General procedure for the microwave-assisted palladium-catalyzed intramolecular cyclizations. The corresponding 4-(3,5-dibromothien-2-yl)-5-(hetero)arylpyrimidine (5a-g). (**5a**, **5b**, **5c**, **5d**, **5e**, **5f** or **5g**) (0.5 mmol), $Pd(OAc)_2$ (11 mg, 10 mol %), PCy_3 (56 mg, 0.2 mmol), and K_2CO_3 (207 mg, 1.5 mmol) were dissolved in DMF (5 mL). The resulting reaction mixture was deaerated by bubbling argon and irradiated in a microwave apparatus at 185 °C (200 W) for 10 min. After that the solvent was distilled off under reduced pressure, and the residue was purified by flash column chromatography using EtOAc/hexane (from 1:3 to 1:1) as eluent or by semi-preparative HPLC to afford the desired heteroacene (**6a**, **6b**, **6c**, **6d**, **6e**, **6f** or **6g**) and side product (**7a**, **7b**, **7c**, **7d**, **7e**, **7f** or **7g**). Compounds **6a-g** and **7a-g** were identified on the basis of their NMR and MS spectra and comparison with authentic materials.

Benzo[*f*]thieno[3,2-*h*]quinazoline (6a). Yield (see Table 2, entry 1), beige solid; mp199-201 °C. H NMR (500 MHz, $CDCl_3$): δ 7.66-7.79 (m, 2H, Ph), 7.86 (d, 1H, H-2 or H-3, *J* 5.3 Hz), 7.88 (d, 1H, H-2 or H-3, *J* 5.3 Hz), 8.29-8.35 (m, 1H, Ph), 8.63-8.38 (m, 1H, Ph), 9.38 (s, 1H, H-8), 9.99 (s, 1H, H-10) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 120.14, 122.67, 123.14, 124.58, 126.82, 127.33, 128.66, 128.87, 131.30, 135.01, 141.26, 148.61, 153.98, 156.13 ppm. GC t_R 26.09 min; MS *m/z* (rel intensity) 236 (M^+, 100). Anal. Calcd for $C_{14}H_8N_2S$ (236.30): C 71.16, H 3.41, N 11.86. Found: C 71.26, H 3.21, N 11.79%.

7-*tert*-Butylbenzo[*f*]thieno[3,2-*h*]quinazoline (6b). Yield (see Table 2, entry 2), pale yellow solid; mp174-176 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.50 (s, 9H, *t*-Bu), 7.80 (d, 1H, H-6 or H-7, *J* 8.5 Hz), 7.87 (d, 1H, H-2 or H-3, *J* 5.2 Hz), 8.05 (d, 1H, H-2 or H-3, *J* 5.2 Hz), 8.32 (s, 1H, H-4), 8.62 (d, 1H, H-6 or H-7, *J* 8.5 Hz), 9.36 (s, 1H, H-8), 9.98 (s, 1H, H-10) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 31.34, 35.17, 120.15, 120.44, 122.51, 123.11, 124.49, 125.57, 128.81, 131.00, 134.94, 141.55, 148.39, 151.97, 153.82, 155.81 ppm. GC t_R 28.63 min; MS *m/z* (rel intensity) 292 (M^+, 100). Anal. Calcd for $C_{18}H_{16}N_2S$ (292.41): C 73.94, H 5.52, N 9.58. Found C 73.80, H 5.36, N 9.47%.

7-(Trifluoromethyl)benzo[*f*]thieno[3,2-*h*]quinazoline (6c). Yield (see Table 2, entry 3), beige solid; mp248-250 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.95-7.98 (m, 2H, H-6 or H-7 and H-2 or H-3), 8.09 (d, 1H, H-2 or H-3, *J* 5.3 Hz), 8.64 (s, 1H, H-4), 8.85 (d, 1H, H-6 or H-7, *J* 8.7 Hz), 9.46 (s, 1H, H-8), 10.08 (s, 1H, H-10) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ 96.11, 119.28, 121.89 (q, $^{3}J_{C,F}$ 4.0 Hz, CF_3), 122.89, 123.08, 123.36 (q, $^{3}J_{C,F}$ 3.7 Hz, CF_3), 123.61, 125.06, 128.51, 129.21, 130.08, 130.34, 130.60, 132.01, 136.26, 140.62, 149.25, 154.51, 157.06 ppm. ^{19}F NMR (470.5 MHz, $CDCl_3$): δ 99.48 (s, CF_3). GC t_R 25.09 min; MS *m/z* (rel intensity) 304 (M^+, 100). Anal. Calcd for $C_{15}H_7F_3N_2S$ (304.30): C 59.21, H 2.32, N 9.21. Found C 59.11, H 2.49, N 9.10%.

Dithieno[2,3-*f*:3',2'-*h*]quinazoline (6d). Yield (see Table 2, entry 4), pale brown solid; mp224-226 °C. H NMR (500 MHz, DMSO-d_6): 8.14-8.18 (m, 3H, H-6, H-7 and H-9), 8.29 (d, 1H, H-8, *J* 5.2 Hz), 9.37 (s, 1H, H-4), 9.87 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, DMSO-d_6): 118.32, 123.23, 123.92, 129.51, 131.74, 132.86, 133.36, 134.73, 138.80, 145.46, 155.00, 155.14 ppm. GC t_R 25.87 min; MS *m/z* (rel intensity) 242 (M^+, 100). Anal. Calcd for $C_{12}H_6N_2S_2$ (242.32): C 59.48, H 2.50, N 11.56. Found: C 59.22, H 2.31, N 11.57%.

Dithieno[3,2-*f*:3',2'-*h*]quinazoline (6e). Yield (see Table 2, entry 5), pale brown solid; mp238-240 °C. H NMR (500 MHz, DMSO-d_6): 7.93 (d, 1H, *J* 5.3 Hz), 8.10 (d, 1H, *J* 5.3 Hz), 8.32 (d, 1H, *J* 5.3 Hz), 8.45 (d, 1H, *J* 5.3 Hz), 9.38 (s, 1H, H-4), 10.15 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, DMSO-d_6): 118.11, 122.62, 123.06, 127.83, 132.36, 132.54, 133.69, 133.71, 137.41, 145.90, 154.89, 156.16 ppm. GC t_R 25.89 min; MS *m/z* (rel intensity) 242 (M^+, 100). Anal. Calcd for $C_{12}H_6N_2S_2$ (242.32): C 59.48, H 2.50, N 11.56. Found: C 59.63, H 2.47, N 11.34%.

[1]Benzothieno[2,3-*f*]thieno[3',2'-*h*]quinazoline (6f). Yield (see Table 2, entry 6), pale brown solid; mp281-284 °C. H NMR (500 MHz, DMSO-d_6): 7.69-7.77 (m, 2H, H-7 and H-8), 8.33 (d, 1H, H-9, *J* 7.7 Hz), 8.48 (d, 1H, H-10, *J* 5.6 Hz), 8.71 (d, 1H, H-11, *J* 5.6 Hz), 8.90 (d, 1H, H-6, *J* 7.7 Hz), 9.47 (s, 1H, H-4), 9.94 (s, 1H, H-2) ppm. The ^{13}C NMR spectra of **6g** could not be obtained due to the poor solubility of this compound in deuterated solvents. GC t_R 31.52 min; MS *m/z* (rel intensity) 292 (M^+, 100). Anal. Calcd for $C_{16}H_8N_2S_2$ (292.38): C 65.73, H 2.76, N 9.58. Found: C 65.52, H 2.61, N, 9.39%.

[1]Benzothieno[3,2-*f*]thieno[3',2'-*h*]quinazoline (6g). Yield (see Table 2, entry 7), pale brown solid; mp 280-283 °C. H NMR (500 MHz, DMSO-d_6): 7.64-7.72 (m, 2H, H-6 and H-7), 8.00 (d, 1H, H-10, *J* 5.2 Hz), 8.31 (dd, 1H, H-5, *J* 8.0, 0.8 Hz), 8.39 (d, 1H, H-11, *J* 5.2 Hz), 9.09 (d, 1H, H-8, *J* 8.0 Hz), 9.45 (s, 1H, H-4), 10.65 (s, 1H, H-2) ppm. ^{13}C NMR (126 MHz, DMSO-d_6): 119.36, 123.46, 123.87, 124.89, 125.89, 126.00, 126.32, 134.22, 134.82, 135.11, 135.17, 137.33, 138.33, 146.18, 154.19, 154.85 ppm. GC t_R 31.56 min; MS *m/z* (rel intensity) 292 (M^+, 100). Anal. Calcd for $C_{16}H_8N_2S_2$ (292.38): C 65.73, H 2.76, N, 9.58. Found: C 65.59, H 2.68, N 9.45%.

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