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

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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 SNH 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. 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.

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 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_N_H reaction). 5-(Hetero)arylpyrimidines 3a-g were obtained from 5-bromopyrimidine (1) and an arylboronic acid (2) [phenylboronic (2a), 4-tert-butyphenylboronic (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). Compounds 3a-g have further been involved in the S_N_H-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).

![Scheme 1. Synthesis of 4-(3,5-dibromothiophen-2-yl)-5-(hetero)arylpyrimidines (5a-g).](image)

**Figure 2.** Mercury²⁵ 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 | 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           | 5a – 52                      |
|       |          |        | 3a – 38           | 3a – 31                      |
| 9     | 3b+4     | 2 weeks| 5b – 38           | 5b – 20                      |
|       |          |        | 4 – 27            | 4 – 11                       |
|       |          |        | 3a – 28           | 3a – 25                      |
| 10    | 3b+4     | 1 month| 5b – 61           | 5b – 55                      |
|       |          |        | 4 – 2             | 4 – 0                        |
|       |          |        | 3a – 37           | 3a – 30                      |
| 11    | 3c+4     | 2 weeks| 5e – 58           | 5e – 46                      |
|       |          |        | 3e – 41           | 3e – 31                      |
| 12    | 3d+4     | 2 weeks| 5d – 42           | 5d – 45                      |
|       |          |        | 3d – 35           | 3d – 42                      |
| 13    | 3e+4     | 2 weeks| 5e – 38           | 5e – 41                      |
|       |          |        | 3e – 57           | 3e – 50                      |
| 14    | 3f+4     | 1 week | 5f – 50           | 5f – 41                      |
|       |          |        | 4 – 25            | 4 – 11                       |
|       |          |        | 3f – 24           | 3f – 20                      |
| 15    | 3g+4     | 2 weeks| 5f – 49           | 5f – 43                      |
|       |          |        | 4 – 23            | 4 – 12                       |
|       |          |        | 3f – 24           | 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\(_2\)CO\(_3\) 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 | Product – isolated yield (%) |
|-------|-------------------|-------------------|------------------------------|
|       |                   | GC-MS (%)         |                              |
| 1     | 5a                | 6a – 6            | 6a – 4                       |
|       |                   | 7a – 68           | 7a – 37                      |
|       |                   | Cy3PO – 18        |                               |
|       |                   | Impurities – 2    |                               |
| 2     | 5b                | 6b – 15           | 6b – 7                       |
|       |                   | 7b – 67           | 7b – 35                      |
|       |                   | Cy3PO – 16        |                               |
|       |                   | Impurities – 2    |                               |
| 3     | 5c                | 6c – 21           | 6c – 14                      |
|       |                   | 7c – 18           | 7c – 10                      |
|       |                   | Cy3PO – 50        |                               |
|       |                   | Impurities – 11   |                               |
| 4     | 5d                | 6d – 13           | 6d – 12                      |
|       |                   | 7d – 14           | 7d – 8                       |
|       |                   | Cy3PO – 78        |                               |
|       |                   | Impurities – 5    |                               |
| 5     | 5e                | 6e – 17           | 6e – 15                      |
|       |                   | 7e – 3            | 7e – 2                       |
|       |                   | Cy3PO – 74        |                               |
|       |                   | Impurities – 6    |                               |
| 6     | 5f                | 6f – 26           | 6f – 23                      |
|       |                   | 7f – 9            | 7f – 6                       |
|       |                   | Cy3PO – 64        |                               |
|       |                   | Impurities – 1    |                               |
| 7     | 5g                | 6g – 28           | 6g – 25                      |
|       |                   | 7g – 11           | 7g – 8                       |
|       |                   | Cy3PO – 59        |                               |
|       |                   | Impurities – 2    |                               |
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.\textsuperscript{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 $6a (-4.95 \text{ eV}) < 6b (-5.00 \text{ eV}) < 6c (-5.39 \text{ eV})$. 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$_4$Si and C$_6$F$_6$ 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$_2$O 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$_\alpha$ 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$_2$Cl$_2$), and a glassy carbon rod counter electrode were employed. The measurements were performed in anhydrous CH$_2$Cl$_2$ 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. The HOMO energy values were estimated from the onset potentials \( E_{\text{ox \text{onset}}} \) of the first oxidation event according to the following equations:

\[
E_{\text{HOMO}} (\text{eV}) = - \left[ E_{\text{ox \text{onset}}} - E_{1/2}(\text{Fc/Fc}^+) + 5.1 \right]
\]  

(1)

where \( E_{1/2}(\text{Fc/Fc}^+) \) 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), 1-benzothien-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\(_2\)Cl\(_2\) (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).** Yield (see Table 1, entry 1), white solid; mp 38-40 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)): \( \delta \) 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\(_8\)N\(_2\) (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; mp 118-120 °C. \(^1\)H NMR (500 MHz, CDCl\(_3\)): \( \delta \) 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\(_3\)): \( \delta \) 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-Trifluoromethyl)pyrimidine (3c).** Yield (see Table 1, entry 3), white solid; mp 110-112 °C. \(^1\)H NMR (500 MHz, CDCl\(_3\)): \( \delta \) 1.37 (s, 9H, CH\(_3\)), 7.52-7.56 (m, 4H, Ph), 8.95 (s, 2H, H-4 and H-6), 9.28 (s, 1H, H-2) ppm. \(^13\)C NMR (126 MHz, CDCl\(_3\)): \( \delta \) 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\(_7\)F\(_3\)N\(_2\) (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)arylpyrimidines (3a-g) (1.0 mmol) in CF\(_3\)COOH (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\(_3\)Fe(CN)\(_6\) (658 mg, 2.0 mmol, 2 equiv) in 10 mL water was added to

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residue. The resulting mixture was stirred for 24 h at room temperature, the precipitate or semisolid formed was filtered off, washed with H₂O, 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 S₂N₅-product (5a-g).

4-(3,5-Dibromothien-2-yl)-5-phenylpyrimidine (5a). Yield (see Table 1, entry 8), yellow semisolid; mp108-110 °C. ¹H NMR (500 MHz, DMSO-d₆): 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-2) ppm. ¹³C NMR (126 MHz, DMSO-d₆): δ 110.58, 115.40, 128.47, 128.74, 128.85, 133.12, 134.16, 134.72, 136.85, 154.93, 156.90, 158.65 ppm. GC tᵣ 25.74 min; MS m/z (rel intensity): 396 (M⁺, 100). Anal. Calcd for C₁₄H₈Br₂N₂S (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. ¹H NMR (500 MHz, CDCl₃): δ 1.34 (s, 9H, CH₃), 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-2) ppm. ¹³C NMR (126 MHz, CDCl₃): δ 31.22, 34.67, 110.94, 115.68, 132.00, 133.30, 134.54, 136.83, 151.87, 155.63, 156.74, 158.65 ppm. GC tᵣ 27.90 min; MS m/z (rel intensity): 452 (M⁺, 100). Anal. Calcd for C₁₈H₁₆Br₂N₂S (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. ¹H NMR (500 MHz, CDCl₃): 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-2) ppm. ¹³C NMR (126 MHz, CDCl₃): δ 111.16, 116.45, 123.83 (d, J₁C,F 272.4 Hz), 126.90, 130.74 (q, J₂C,F 109.3 Hz), 132.0, 133.28, 133.46, 136.15, 138.92, 155.93, 157.67, 158.49 ppm. ¹⁹F NMR (470.5 MHz, CDCl₃): 99.00 (s, CF₃) ppm. GC tᵣ 25.03 min; MS m/z (rel intensity): 464 (M⁺, 100). Anal. Calcd for C₁₅H₇Br₂F₃N₂S (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. ¹H NMR (500 MHz, CDCl₃): δ 6.97 (s, 1H, H-4'), 7.20 (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. ¹³C NMR (126 MHz, CDCl₃): 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 tᵣ 26.11 min; MS m/z (rel intensity): 402 (M⁺, 100). Anal. Calcd for C₁₂H₆Br₂N₂S (402.13): C 35.84, H 1.57, N, 6.04. 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. ¹H NMR (500 MHz, CDCl₃): δ 6.94 (s, 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-2), 9.17 (s, 1H, H-2) ppm. ¹³C NMR (126 MHz, CDCl₃): δ 111.18, 116.00, 127.90, 127.95, 128.42, 128.75, 133.15, 135.80, 135.97, 155.09, 156.71, 157.85 ppm. GC tᵣ 26.26 min; MS m/z (rel intensity): 402 (M⁺, 100). Anal. Calcd for C₁₂H₆Br₂N₂S (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 (5f). Yield (see Table 1, entry 14), yellow solid; mp241-243 °C. ¹H NMR (500 MHz, CDCl₃): 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. ¹³C NMR (126 MHz, CDCl₃): 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 tᵣ 26.26 min; MS m/z (rel intensity): 402 (M⁺, 100). Anal. Calcd for C₁₂H₆Br₂N₂S (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. 1H NMR (500 MHz, CDCl3): 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. 13C NMR (126 MHz, CDCl3): 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 tR 30.68 min; MS m/z (rel intensity): 452 (M+, 100). Anal. Calcd for C16H8Br2N2S2 (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. 1H NMR (500 MHz, CDCl3): 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, benzol[b]thienyl), 8.93 (s, 1H, H-6), 9.31 (s, 1H, H-2) ppm. 13C NMR (126 MHz, CDCl3): 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 tR 29.91 min; MS m/z (rel intensity): 452 (M+, 100). Anal. Calcd for C16H8Br2N2S2 (452.19): 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 %), PCy3 (56 mg, 0.2 mmol), and K2CO3 (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-g) and side product (7a-g). 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, CDCl3): 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. 13C NMR (126 MHz, CDCl3): 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 tR 26.09 min; MS m/z (rel intensity) 236 (M+, 100). Anal. Calcd for C14H8N2S (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. 1H NMR (500 MHz, CDCl3): 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. 13C NMR (126 MHz, CDCl3): 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 tR 28.63 min; MS m/z (rel intensity) 292 (M+, 100). Anal. Calcd for C18H16N2S (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; mp 248-250 °C. $^1$H NMR (500 MHz, CDCl$_3$): $\delta$ 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$_3$): $\delta$ 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$_3$): $\delta$ 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$_7$F$_3$N$_2$S (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; mp 224-226 °C. H NMR (500 MHz, DMSO-$d_6$): $\delta$ 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$_6$N$_2$S$_2$ (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; mp 238-240 °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$_6$N$_2$S$_2$ (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; mp 281-284 °C. H NMR (500 MHz, DMSO-$d_6$): $\delta$ 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$_8$N$_2$S$_2$ (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-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. $^{13}$C NMR (126 MHz, DMSO-$d_6$): 118.36, 122.62, 123.06, 127.83, 132.36, 132.54, 133.69, 133.71, 137.41, 145.90, 154.89, 156.16 ppm. GC $t_R$ 31.56 min; MS $m/z$ (rel intensity) 292 (M$^+$, 100). Anal. Calcd for C$_{16}$H$_8$N$_2$S$_2$ (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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