Alexander Schmidt, Matthias Baune, Alexander Hepp, Jutta Kösters and Jens Müller*

Gold(III)-mediated cyclization of 2-hydrazinylquinolines

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Abstract: The Au(III)-mediated oxidative cyclization of a series of 2-hydrazinylquinolines is reported. This intramolecular reaction represents a reliable way towards obtaining various 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium cations. The molecular structures of three of the starting compounds (2-(1-methyl-2-(pyridin-2-ylmethylene)hydrazinyl)quinoline, 2-(1-methyl-2-(thiophen-2-ylmethylene) hydrazinyl)quinoline, 2-((2-methyl-2-(quinolin-2-yl)hydrazono)methyl)aniline) as well as of one cyclized system (3-methyl-1-(pyridin-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I)) were determined by means of single-crystal X-ray diffraction.

Keywords: cyclization; gold; hydrazone; triazoloquinolinium.

Dedicated to: Professor Wolfgang Jeitschko on the occasion of his 80th birthday.

1 Introduction

The oxidative cyclization is a common procedure for the synthesis of annulated derivatives of triazoles. This family of compounds is intensely investigated because of their potential application as fungicides or bactericides [1]. The synthesis of 1,2,4-triazolo[4,3-*b*]pyridazine derivatives via oxidative cyclization of pyridazine-substituted hydrazones was recently reported, using nitrobenzene as oxidant [2]. Similarly, hydrazones can also be used as starting materials for the synthesis of 1,2,4-triazolo[4,3-*a*] pyridine and its derivatives [3–6]. Moreover, heterocycles such as triazoloquinolines and triazolopyrazines can also be synthesized [6]. Finally, the oxidative cyclization reaction can be applied for the synthesis of 1,2,3-benzotriazoles, 1,2,3-benzotriazolium salts, and their derivatives, as was first shown more than 60 years ago for 1,2,3-triazolo[1,5-*a*] quinolin-10-ium and 1,2,3-triazolo[1,5-*a*]pyridine-8-ium salts [7]. Besides such classical organic syntheses, hydrazones with electron-rich aromatic substituents can be cyclized electrochemically by anodic oxidation, as evidenced by the synthesis of 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium and 1,2,4-triazolo[4,3-*a*]pyridinium salts [8]. The presence of other heteroatoms such as sulfur does not prohibit the oxidative cyclization, as was shown for example in the synthesis of 1,2,4-triazolo[3,4-*b*]-1,3,4-thiadiazole derivatives [9].

In this paper, we describe the intramolecular cyclization of 2-hydrazinylquinolines to 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium compounds mediated by $[AuCl_4]^-$. In general, Au(I) is well-known for its application in catalysis, but several transformations mediated by Au(III) have been reported, too [10]. The cyclization of 2-(1-methyl-2-(pyridin-2-ylmethylene)hydrazinyl)quinolone (**2**) to 3-methyl-1-(pyridin-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (**6**) was confirmed by means of single-crystal X-ray diffraction analysis, by ^{1}H NMR spectroscopy and by mass spectrometry. We furthermore show by using ^{1}H NMR spectroscopy and mass spectrometry that the cyclization also takes place with other 2-hydrazinylquinolines. Towards this end, three additional related 2-hydrazinylquinolines were synthesized and characterized and were subsequently subjected to an oxidative cyclization.

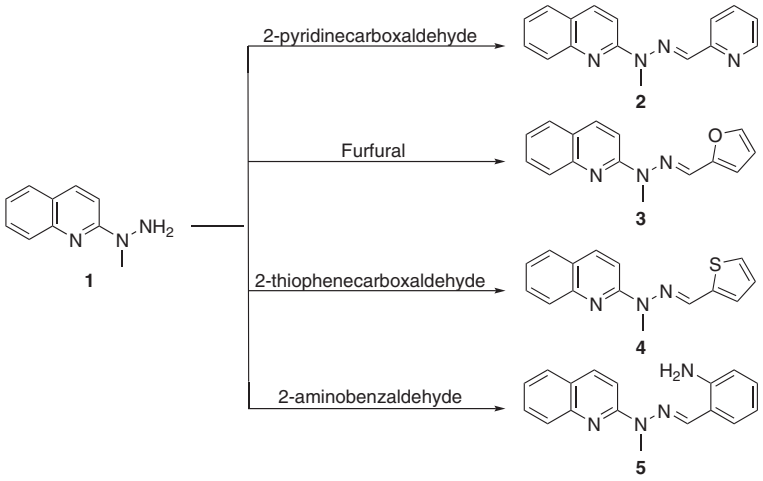
2 Results and discussion

2.1 Synthesis and general characterization of hydrazones 2–5

The hydrazones **2**–**5** were synthesized in a condensation reaction from 2-(1-methylhydrazinyl)quinoline (**1**) and the respective aldehyde in ethanol under closely related conditions (Scheme 1).

The ^{1}H NMR spectra of the resulting hydrazones (in $CDCl_3$) show the characteristic signals of the methyl group

***Corresponding author: Jens Müller,** Institut für Anorganische und Analytische Chemie, Westfälische Wilhelms-Universität Münster, Corrensstraße 28–30, 48149 Münster, Germany,
Phone: +49 251 83 36006, E-mail: mueller.j@uni-muenster.de
Alexander Schmidt, Matthias Baune, Alexander Hepp and Jutta Kösters: Institut für Anorganische und Analytische Chemie, Westfälische Wilhelms-Universität Münster, Corrensstraße 28–30, 48149 Münster, Germany



Scheme 1: Synthesis of hydrazones **2**–**5** (ethanol, reflux, 2–6 h).

(δ = 3.85 (**2**), 3.79 (**3**), 3.80 (**4**), 3.78 ppm (**5**)) and the Schiff base proton (δ = 7.83 (**2**), 7.60 (**3**), 7.87 (**4**), 8.10 ppm (**5**)). The high-resolution mass spectra and the elemental analyses nicely match the calculated ones.

2.2 Structural description of hydrazones 2–5

2.2.1 2-(1-Methyl-2-(pyridin-2-ylmethylene)hydrazinyl) quinoline (2)

The single-crystal X-ray diffraction analysis of compound **2** revealed that the molecule crystallizes in the monoclinic space group $P2_1/n$ with $Z = 4$. As shown in Fig. 1, the molecule is planar, which is not unexpected due to its delocalized π electron system. The nitrogen atom of the quinoline moiety is oriented towards the methyl substituent of the hydrazone, forming a weak C–H···N hydrogen bond (2.740(1) Å, 108°). All bond lengths and angles are in good agreement with typical values for related organic molecules [11].

2.2.2 2-(1-Methyl-2-(thiophen-2-ylmethylene) hydrazinyl)quinoline (4)

For compound **4**, the X-ray diffraction data revealed that the molecule crystallizes in the monoclinic space group *Pc* with $Z = 2$. The molecule is again planar due to the delocalized π electron system (Fig. 2). As in **2**, the quinoline nitrogen atom is oriented towards the methyl group because of a hydrogen bonding interaction (2.733(3) Å, 108°) and all interatomic distances and angles agree with the typical values of related organic molecules [11].

2.2.3 2-((2-Methyl-2-(quinolin-2-yl)hydrazono)methyl) aniline (5)

The hydrazone **5** crystallizes in the monoclinic space group $P2_1/c$ with $Z = 4$. The quinoline nitrogen atom is oriented towards the methyl group, forming a weak hydrogen bond (2.769(2) Å, 106°, Fig. 3). Two additional hydrogen bonds

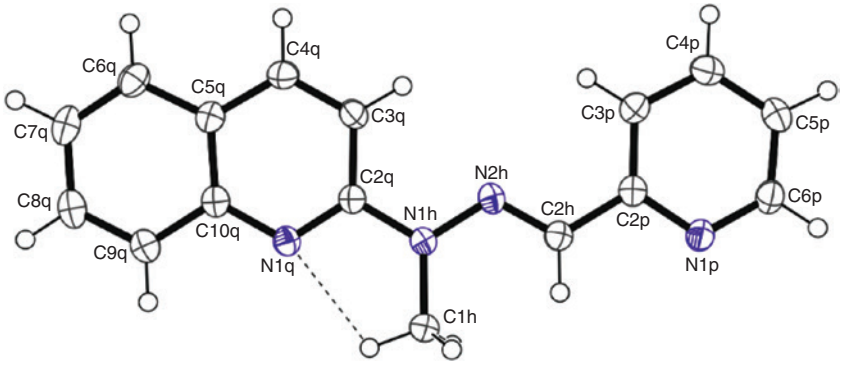


Fig. 1: Molecular structure of **2** in the crystal with the weak intramolecular hydrogen bond. Displacement ellipsoids are drawn at the 50% probability level, H atoms as spheres with arbitrary radii.

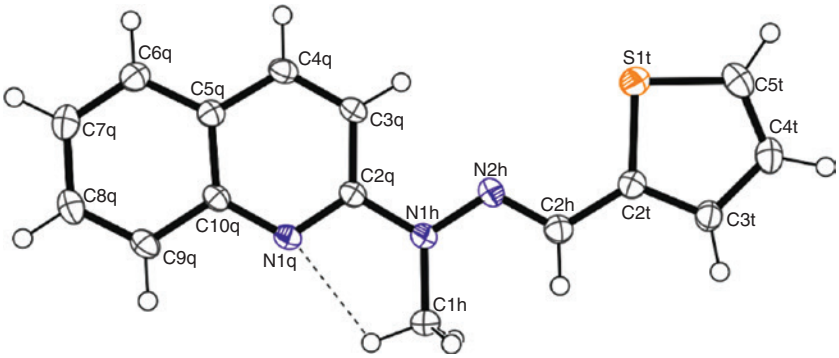


Fig. 2: Molecular structure of **4** in the crystal with the intramolecular hydrogen bond. Displacement ellipsoids are drawn at the 50% probability level, H atoms as spheres with arbitrary radii.

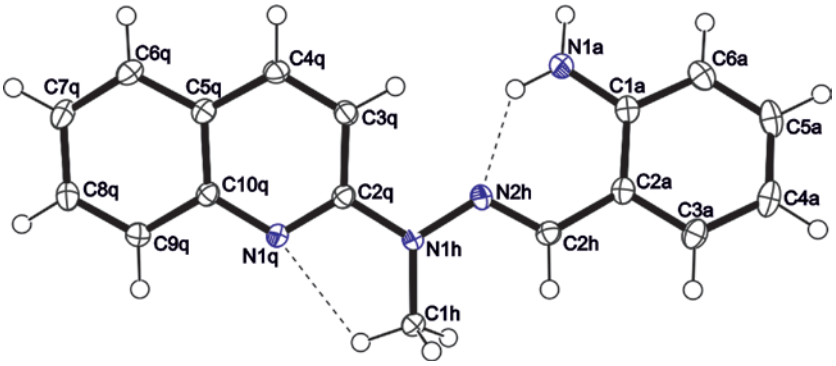
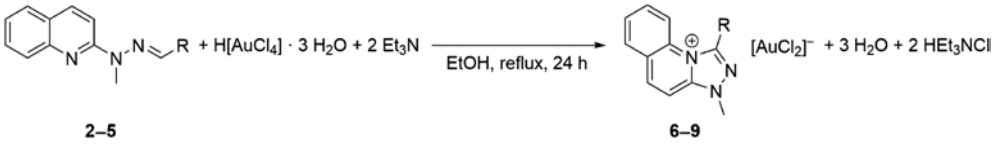


Fig. 3: Molecular structure of compound **5** in the crystal with intramolecular hydrogen bonds. Displacement ellipsoids are drawn at the 50% probability level, H atoms as spheres with arbitrary radii.



Scheme 2: Au(III)-mediated cyclization of various hydrazones (R = pyridin-2-yl (**2**, **6**), furan-2-yl (**3**, **7**), thiophen-2-yl (**4**, **8**) or 2-aminophenyl (**5**, **9**)).

are found in compound **5**, namely N1a–H···N1q (3.078(2) Å, 168(1)°, intermolecular) and N1a–H···N2h (2.696(2) Å, 133(2)°, intramolecular). In contrast to **2** and **4**, compound **5** is not planar. It rather comprises two planar moieties that are oriented at an angle of 21.87(6)° with respect to each other. Again, all bond lengths and angles agree well with the typical values for related organic molecules [11].

2.3 Cyclization of compound 2

Reaction of compound **2** with $H[AuCl_4]$ yields 3-methyl-1-(pyridin-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (**6**) in an unprecedented gold(III)-mediated cyclization reaction. The conversion of **2** with chloroauric acid and triethylamine in refluxing ethanol results in a pale yellow solid and involves a reduction of Au(III) to Au(I) (Scheme 2). The formation of product **6** includes a C–H activation of the Schiff base, finally resulting in the oxidative cyclization of the molecule.

The ^{1}H NMR spectrum of **6** (CD_3CN) shows a downfield shift of all signals compared to the spectrum of the starting compound **2** (CD_3CN). For example, the characteristic resonance of the methyl group shifts by 0.53 ppm from δ = 3.82 to δ = 4.35 ppm. Moreover, the signal of the Schiff base proton of **2** (δ = 7.86 ppm) no longer exists in the spectrum

of compound **6**. The high-resolution mass spectrum and the elemental analysis data match the calculated values for the cyclized product. As expected, the hydrazone **2** is not converted to **6** under Au(III)-free reaction conditions.

2.4 Structural description of compound 6

The single-crystal X-ray diffraction analysis of compound **6** shows that the salt crystallizes in the monoclinic space group $P2_1/n$ with $Z = 4$. Figure 4 shows that the cation consists of two planar aromatic systems, which are rotated with respect to each other at an angle of 45.42(7)°. The interatomic distances and angles are in the expected ranges [11]. The counterion $[AuCl_2]^-$ is linear (angle: 179.29(3)°) and exhibits two (within standard deviations) identical Au–Cl distances of 2.2552(6) Å and 2.2560(6) Å. There are no aurophilic interactions between neighboring gold(I) ions.

2.5 Screening of hydrazones 3–5

After having established the Au(III)-mediated cyclization of compound **2**, the scope of this reaction was tested by investigating other 2-hydrazinylquinolines under the same reaction conditions. The resulting 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium compounds were not isolated. Instead, the successful conversion of the respective starting compounds was confirmed by ^{1}H NMR spectroscopy (CD_3CN) and high-resolution mass spectrometry. For the screening, 2-(2-(furan-2-ylmethylene)-1-methylhydrazinyl)quinoline (**3**), 2-(1-methyl-2-(thiophen-2-ylmethylene)hydrazinyl)quinoline (**4**) and 2-((2-methyl-2-(quinolin-2-yl)hydrazono)methyl)aniline (**5**) were used (Scheme 2). All compounds contain one methyl group, enabling a ^{1}H NMR-spectroscopic verification of the successful cyclization. The disappearance of the resonance due to the Schiff base hydrogen atom serves as an additional indicator. Moreover, the existence of the signal of the respective 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium cation in the mass spectrum was used to evaluate the success of the cyclization.

In the ^{1}H NMR spectra of the cyclization product of compound **3**, i.e. 1-(furan-2-yl)-3-methyl-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (**7**), the resonance of the methyl group is shifted towards lower field from 3.74 to 4.36 ppm ($\Delta\delta$ = 0.62 ppm). In the case of 3-methyl-1-(thiophen-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (**8**), representing the cyclization product of compound **4**, this downfield shift amounts to 0.58 ppm (from 3.75 to 4.33 ppm). Moreover, the product resulting from the cyclization of compound **5**, i.e. 1-(2-aminophenyl)-3-methyl-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (**9**), features a downfield shift of the methyl resonance of 0.53 ppm (from 3.81 to 4.34 ppm). In all three cases, the signal due to the Schiff base hydrogen atom (**3**: δ = 7.73 ppm, **4**: δ = 8.05 ppm, **5**: δ = 8.06 ppm) is lost after the conversion.

The high-resolution mass spectra of **7**, **8** and **9** show signals at m/z = 250.0980 (**7**: calcd. 250.0975), 266.0755 (**8**: calcd. 266.0746) and 275.1290 (**9**: calcd. 275.1291), respectively, thereby confirming the successful cyclization. Hence, the Au(III)-mediated cyclization of **2** to **6** is not a single case but represents a general procedure for the synthesis of 1,2,4-triazolo[4,3-*a*]quinolin-10-ium compounds.

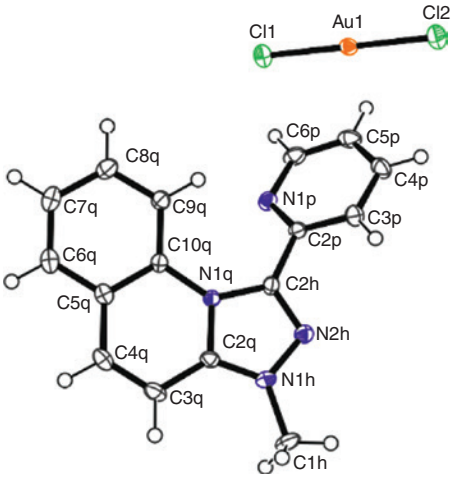


Fig. 4: Molecular structure of compound **6** in the crystal. Displacement ellipsoids are drawn at the 50% probability level, H atoms as spheres with arbitrary radii.

3 Conclusions

We have reported an unprecedented Au(III)-mediated cyclization reaction of 2-hydrazinylquinolines. The cyclization involves a C–H activation of the Schiff base and an oxidation of the quinoline. As a result, a series of 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium cations are formed. For one of the heterocycles, the structure could be confirmed by single-crystal X-ray diffraction analysis. The hydrazones required as starting compounds are easily accessible from 2-(1-methylhydrazinyl)quinoline (**1**) and an aldehyde. Hence, this Au(III)-mediated cyclisation represents an easy access to a variety of 3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium cations.

4 Experimental section

All starting materials were commercially available and used as received without any further purification. The synthesis of compound **1** is described in the literature [12, 13]. The NMR-spectroscopic analyses were performed at 300 K on Bruker Avance (I) 400 and Bruker Avance (III) 400 instruments. For the interpretation of the NMR spectra, the software MestReNova V8.1.4 was used. In assignment of the NMR signals, the same atom numbering scheme was applied as in the description of the molecular structures. ESI-MS spectra were measured on an LTQ Orbitrap XL (Thermo Scientific, Bremen, Germany), and ESI-TOF MS spectra were obtained on the oa-TOF mass spectrometer MicrOTOF (Bruker Daltonik GmbH, Bremen, Germany). The elemental analyses were performed on a Vario EL III CHNS analyzer.

4.1 Synthesis of 2-(1-methyl-2-(pyridin-2-ylmethylene)hydrazinyl)quinoline (2)

Compound **1** (2.12 g, 12.2 mmol) was dissolved in ethanol (50 mL) and 2-pyridinecarboxaldehyde (1.31 g, 1.16 mL, 12.2 mmol) was added. After refluxing for 2 h and cooling, the solid was filtered off. Recrystallization from toluene gave an orange solid (50%, 1.60 g, 6.10 mmol). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.58 (d, $^3J_{H,H}$ = 4 Hz, 1H, H6p), 8.06 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3p), 8.05 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3q), 8.02 (d, $^3J_{H,H}$ = 8 Hz, 1H, H4q), 7.84 (d, $^3J_{H,H}$ = 8 Hz, 1H, H9q), 7.83 (s, 1H, H2h), 7.72 (m, 1H, H4p), 7.69 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6q), 7.60 (m, 1H, H8q), 7.33 (m, 1H, H7q), 7.19 (m, 1H, H5p), 3.85 (s, 3H, H1h) ppm. – ^{13}C NMR (101 MHz, $CDCl_3$): δ = 156.0 (C2q), 155.2 (C2p), 149.2 (C6p), 146.9 (C10q), 137.4 (C4q), 136.3 (C4p), 135.4 (C2h), 129.6 (C8q), 127.4 (C9q), 127.4 (C6q), 124.8 (C5q), 123.7 (C7q), 122.6 (C5p), 119.4 (C3p), 111.4 (C3q), 29.6 (C1h) ppm. – HRMS ((+)-ESI; $CHCl_3/CH_3OH$): *m/z* = 263.1289 (calcd. 263.1297 for $[C_{16}H_{15}N_4]^+$). – Analysis for $C_{16}H_{14}N_4$ (%): calcd. C 73.3, H 5.4, N 21.4; found: C 73.4, H 5.3, N 21.4.

4.2 Synthesis of 2-(2-(furan-2-ylmethylene)-1-methylhydrazinyl)quinoline (3)

Compound **1** (429 mg, 2.48 mmol) was dissolved in ethanol (5 mL) and furfural (238 mg, 205 µL, 2.50 mmol) was added. After refluxing for 3 h and cooling, the volume was halved by evaporation and the solid was filtered off. The product was obtained as a yellow solid in 73% yield (457 mg, 1.82 mmol). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.02 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3q), 8.00 (d, $^3J_{H,H}$ = 8 Hz, 1H, H4q), 7.82 (d, $^3J_{H,H}$ = 8 Hz, 1H, H9q), 7.68 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6q), 7.60 (s, 1H, H2h), 7.59 (m, 1H, H8q), 7.50 (m, 1H, H5f), 7.31 (m, 1H, H7q), 6.64 (m, 1H, H3f), 6.49 (m, 1H, H4f), 3.79 (s, 3H, H1h) ppm. – ^{13}C NMR (101 MHz, $CDCl_3$): δ = 156.2 (C2q), 151.7 (C2f), 146.9 (C10q), 142.8 (C5f), 137.4 (C4q), 129.4 (C8q), 127.4 (C6q), 127.2 (C9q), 125.1 (C2h), 124.6 (C5q), 123.4 (C7q), 111.6 (C4f), 111.5 (C3q), 109.0 (C3f), 29.2 (C1h) ppm. – HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 252.1126 (calcd. 252.1137 for $[C_{15}H_{14}N_3O]^+$). – Analysis for $C_{15}H_{13}N_3O$ (%): calcd. C 71.7, H 5.2, N 16.7; found: C 71.5, H 5.1, N 16.9.

4.3 Synthesis of 2-(1-methyl-2-(thiophen-2-ylmethylene)hydrazinyl)quinoline (4)

Compound **1** (500 mg, 2.89 mmol) was dissolved in ethanol (5 mL) and 2-thiophenecarboxaldehyde (324 mg, 270 µL, 2.89 mmol) was added. After refluxing for 2 h and cooling, the solid was filtered off. Drying *in vacuo* gave a yellow solid (70%, 544 mg, 2.03 mmol). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 (m, 2H, H3q, H4q), 7.87 (s, 1H, H2h), 7.82 (d, $^3J_{H,H}$ = 8 Hz, 1H, H9q), 7.68 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6q), 7.59 (t, $^3J_{H,H}$ = 8 Hz, 1H, H8q), 7.32 (t, $^3J_{H,H}$ = 8 Hz, 1H, H7q), 7.28 (d, $^3J_{H,H}$ = 4 Hz, 1H, H5t), 7.19 (d, $^3J_{H,H}$ = 4 Hz, 1H, H3t), 7.05 (t, $^3J_{H,H}$ = 4 Hz, 1H, H4t), 3.80 (s, 3H, H1h) ppm. – ^{13}C NMR (101 MHz, $CDCl_3$): δ = 156.0 (C2q), 146.9 (C10q), 141.9 (C2t), 137.4 (C4q), 129.4 (C8q), 129.4 (C2h), 127.4 (C6q), 127.4 (C4t), 127.2 (C9q), 126.7 (C3t), 125.6 (C5t), 124.6 (C5q), 123.3 (C7q), 111.5 (C3q), 29.4 (C1h) ppm. HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 268.0906 (calcd. 268.0908 for $[C_{15}H_{14}N_3S]^+$). – Analysis for $C_{15}H_{13}N_3S$ (%): calcd. C 67.4, H 4.9, N 15.7; found: C 67.2, H 4.8, N 15.7.

4.4 Synthesis of 2-((2-methyl-2-(quinolin-2-yl)hydrazono)methyl)aniline (5)

2-Aminobenzaldehyde (385 mg, 3.18 mmol) was dissolved in ethanol (5 mL) at –78°C. Compound **1** (661 mg, 3.82 mmol) was dissolved in ethanol (5 mL) and the solution added at –78°C. The reaction mixture was stirred, warmed slowly to room temperature and refluxed for 6 h. The suspension was filtered and the pale yellow solid was dried *in vacuo*. The product was obtained in 55% yield (483 mg, 1.75 mmol). – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.20 (d, $^3J_{H,H}$ = 8 Hz, 1H, H4q), 8.10 (s, 1H, H2h), 7.79 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6q), 7.73 (d, $^3J_{H,H}$ = 8 Hz, 1H, H9q), 7.68 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3q), 7.62 (t, $^3J_{H,H}$ = 8 Hz, 1H, H8q), 7.42 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3a), 7.32 (t, $^3J_{H,H}$ = 8 Hz, 1H, H7q), 7.08 (t, $^3J_{H,H}$ = 8 Hz, 1H, H5a), 6.80 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6a), 6.63 (t,

$^3J_{H,H}$ = 8 Hz, 1H, H4a), 6.43 (s, 2H, H1a), 3.78 (s, 3H, H1h) ppm. – ^{13}C NMR (101 MHz, $CDCl_3$): δ = 155.5 (C2q), 146.5 (C10q), 146.4 (C1a), 140.1 (C2h), 137.8 (C4q), 130.8 (C3a), 129.7 (C8q), 129.1 (C5a), 127.5 (C6q), 126.5 (C9q), 123.8 (C5q), 123.0 (C7q), 117.0 (C2a), 115.6 (C4a), 115.4 (C6a), 110.2 (C3q), 29.1 (C1h) ppm. – HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 277.1450 (calcd. 277.1453 for $[C_{17}H_{17}N_4]^+$). – Analysis for $C_{17}H_{16}N_4$ (%): calcd. C 73.9, H 5.8, N 20.3; found: C 73.9, H 5.8, N 20.3.

4.5 Synthesis of 3-methyl-1-(pyridin-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*]quinolin-10-ium dichloridoaurate(I) (6)

The hydrazone **2** (77 mg, 0.29 mmol) was suspended in ethanol (15 mL) and triethylamine (30 mg, 40 µL, 0.30 mmol) was added. A solution of $H[AuCl_4] \cdot 3H_2O$ (100 mg, 0.254 mmol) in ethanol (7.5 mL) was added and refluxed for 24 h. The pale yellow precipitate was filtered off, washed with ethanol (3 × 0.5 mL) and dried. The filtrate was left at room temperature for slow evaporation. After a few days, pale yellow crystals were obtained. The product was obtained in an overall yield of 52% (70 mg, 0.13 mmol). – ^{1}H NMR (400 MHz, CD_3CN): δ = 8.91 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6p), 8.55 (d, $^3J_{H,H}$ = 8 Hz, 1H, H4q), 8.22 (d, $^3J_{H,H}$ = 8 Hz, 1H, H6q), 8.19 (t, $^3J_{H,H}$ = 8 Hz, 1H, H4p), 7.99 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3p), 7.96 (d, $^3J_{H,H}$ = 8 Hz, 1H, H3q), 7.83 (t, $^3J_{H,H}$ = 8 Hz, 1H, H7q), 7.81 (t, $^3J_{H,H}$ = 8 Hz, 1H, H5p), 7.75 (t, $^3J_{H,H}$ = 8 Hz, 1H, H8q), 7.67 (d, $^3J_{H,H}$ = 8 Hz, 1H, H9q), 4.35 (s, 3H, H1h) ppm. – ^{13}C NMR (101 MHz, CD_3CN): δ = 151.9 (C6p), 148.0 (C2h), 145.8 (C2p), 145.5 (C2q), 141.2 (C4q), 139.7 (C4p), 133.6 (C8q), 131.8 (C6q), 131.5 (C10q), 130.2 (C7q), 128.3 (C5p), 127.9 (C3p), 125.6 (C5q), 119.3 (C9q), 108.5 (C3q), 38.3 (C1h) ppm. – ^{15}N NMR (41 MHz, CD_3CN): δ = 299.6 (N2h), 190.6 (N1h), 183.1 (N1q) ppm. – HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 261.1134 (calcd. 261.1140 for $[C_{16}H_{13}N_4]^+$). – Analysis for $C_{16}H_{13}AuCl_2N_4$ (%): calcd. C 36.3, H 2.5, N 10.6; found: C 36.2, H 2.5, N 10.6.

4.6 Screening of hydrazones 7–9

The respective hydrazone (**3**–**5**) (0.30 mmol) was suspended in ethanol (15 mL), and triethylamine (30 mg, 40 µL, 0.30 mmol) was added. A solution of $H[AuCl_4] \cdot$

Table 1: Crystallographic data and data collection and refinement details for compound **2** and **4**–**6**.

	2	**4**	**5**	**6**
Empirical formula	$C_{16}H_{14}N_4$	$C_{15}H_{13}N_3S$	$C_{17}H_{16}N_4$	$C_{16}H_{13}AuCl_2N_4$
Formula weight	262.31	267.34	276.34	529.17
Crystal system	monoclinic	monoclinic	monoclinic	monoclinic
Space group	$P2_1/n$	Pc	$P2_1/c$	$P2_1/n$
a, Å	4.8772(2)	14.9394(8)	10.9227(5)	7.7088(2)
b, Å	21.835(1)	3.9787(2)	8.8828(4)	14.4171(4)
c, Å	12.1652(6)	11.2090(6)	14.1507(6)	14.9632(4)
β, deg	93.257(1)	107.882(2)	94.641(1)	102.116(1)
V, Å^3	1293.4(1)	634.07(6)	1368.5(2)	1625.94(8)
Z	4	2	4	4
ρ_{calcd}, g cm^{-3}	1.35	1.40	1.34	2.16
μ(MoK_α), mm^{-1}	0.1	0.2	0.1	9.4
Crystal size, mm^3	0.13 × 0.17 × 0.18	0.15 × 0.23 × 0.34	0.06 × 0.24 × 0.26	0.08 × 0.19 × 0.42
Temperature (K)	153(2)	153(2)	100(2)	152(2)
θ range, deg	3.26–28.69	2.87–30.05	2.71–28.36	3.12–30.03
hkl range	−5:6, −29:28, −15:16	−21:20, −5:5, −15:15	−14:14, −11:11, −18:18	−10:10, −20:20, −21:21
Total/unique data/R_{int}	9559/3308/0.023	6163/3213/0.018	18626/3401/0.037	27588/4737/0.046
Observed data [$I > 2\sigma(I)$]	2633	3110	2524	4479
N_{ref}/N_{par}	3308/182	3213/173	3401/197	4737/209
R_1/wR_2 [$I > 2\sigma(I)$][a]	0.0454/0.1208	0.0308/0.0787	0.0437/0.1104	0.0195/0.0494
R_1/wR_2 (all data)[a]	0.0575/0.1296	0.0321/0.0795	0.0660/0.1212	0.0210/0.0501
x(Flack)	–	−0.03(3)	–	–
S	1.048	1.104	1.046	1.056
Min./max. residual density, e Å^{-3}	0.29/−0.20	0.23/−0.28	0.33/−0.22	1.5/−1.3

[a] $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$; $wR_2 = [\Sigma w(F_o^2 - F_c^2)^2/\Sigma w(F_o^2)^2]^{1/2}$.

$3H_2O$ (100 mg, 0.254 mmol) in ethanol (7.5 mL) was added and the reaction mixture was refluxed for 24 h. The pale yellow precipitation was filtered off, washed with ethanol (3 × 0.5 mL) and dried. The solid was analyzed by ^{1}H NMR spectroscopy and high-resolution mass spectrometry.

4.6.1 1-(Furan-2-yl)-3-methyl-3*H*-1,2,4-triazolo[4,3-*a*] quinolin-10-ium dichloridoaurate(I) (7)

^{1}H NMR (400 MHz, CD_3CN): δ = 8.60 (d, $^3J_{H,H}$ = 10 Hz, 1H), 8.26 (d, $^3J_{H,H}$ = 8 Hz, 1H), 8.08 – 8.04 (m, 2H), 7.91 – 7.85 (m, 2H), 7.44 (d, $^3J_{H,H}$ = 8 Hz, 1H), 7.31 (d, $^3J_{H,H}$ = 4 Hz, 1H), 6.92 – 6.90 (m, 1H), 4.36 (s, 3H) ppm. – HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 250.0980 ($[C_{15}H_{12}N_3O]^+$, calcd. 250.0975).

4.6.2 3-Methyl-1-(thiophen-2-yl)-3*H*-1,2,4-triazolo[4,3-*a*] quinolin-10-ium dichloridoaurate(I) (8)

^{1}H NMR (400 MHz, CD_3CN): δ = 8.54 (d, $^3J_{H,H}$ = 10 Hz, 1H), 8.23 (d, $^3J_{H,H}$ = 8 Hz, 1H), 8.05 (d, $^3J_{H,H}$ = 6 Hz, 1H), 7.95 (d, $^3J_{H,H}$ = 10 Hz, 1H), 7.85 – 7.76 (m, 2H), 7.73 (d, $^3J_{H,H}$ = 4 Hz, 1H), 6.67 (d, $^3J_{H,H}$ = 8 Hz, 1H), 7.45 – 7.44 (m, 1H), 4.33 (s, 3H) ppm. – HRMS ((+)-ESI-TOF; CH_3OH): *m/z* = 266.0755 ($[C_{15}H_{12}N_3S]^+$, calcd. 266.0752).

4.6.3 1-(2-Aminophenyl)-3-methyl-3*H*-1,2,4-triazolo[4,3-*a*] quinolin-10-ium dichloridoaurate(I) (9)

^{1}H NMR (400 MHz, CD_3CN): δ = 8.51 (d, $^3J_{H,H}$ = 8 Hz, 1H), 8.20 (d, $^3J_{H,H}$ = 8 Hz, 1H), 7.96 (d, $^3J_{H,H}$ = 10 Hz, 1H), 7.82 – 7.78 (m, 2H), 7.75 (d, $^3J_{H,H}$ = 4 Hz, 1H), 7.54 (t, $^3J_{H,H}$ = 6 Hz, 1H), 7.35 (d, $^3J_{H,H}$ = 8 Hz, 1H), 6.99 (d, $^3J_{H,H}$ = 6 Hz, 1H), 6.93 (t, $^3J_{H,H}$ = 8 Hz, 1H), 4.34 (s, 3H) ppm. – HRMS ((+)-ESI; CH_3OH): *m/z* = 275.1290 (calcd. 275.1291 for $[C_{17}H_{15}N_4]^+$).

4.7 Crystal structure determinations

Single-crystal X-ray diffraction data were collected with graphite-monochromated MoK_α radiation (λ = 0.71073 Å) on a Bruker Quazar diffractometer (**2** and **6**) and a Bruker D8 Venture diffractometer (**4** and **5**). The structures were solved by Direct Methods and refined by full-matrix least-squares on F^2 by using the SHELXTL and SHELXL-97 programs [14]. Relevant crystallographic data are listed in Table 1.

CCDC 1446274 (**2**), 1446275 (**4**), 1446276 (**5**) and 1446277 (**6**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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