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Synthesis, characterization and bioactivity of novel 5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one derivatives

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Abstract: A series of novel 6-(*sec*-butyl)-3-methyl-1-(substitutedphenyl)-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)ones **5a–h** were synthesized using L-isoleucine methyl ester hydrochloride as the starting material. Their structures were characterized by ^{1}H NMR, FT-IR, EI-MS and elemental analysis. Compound **5f** was further analyzed by single-crystal X-ray diffraction. The bioassay results indicate that most of the compounds exhibit inhibitory activity against four plant pathogenic fungi *Fusarium graminearum*, *Botrytis cinerea*, *Rhizoctonia cerealis* and *Colletotrichum capsici*.

Keywords: biological activity; crystal structure; pyrrolo[3,4-*c*]pyrazol-4-(1*H*)one; synthesis.

Introduction

Some pyrrolopyrazole ketones containing a biheterocyclic ring system are bioactive [1–4]. The substituted 4,6-dihydropyrrolo[4,3-*c*]pyrazol-4-ones are useful herbicides, fungicides, insecticides or intermediate products in synthetic organic chemistry [5]. The hexahydropyrrolo[3,4-*c*]pyrazol-6-one derivatives can be effectively applied to plants or soils for plant disease control [6]. Another series of compounds, 4,5-dihydropyrrolo[3,4-*c*]pyrazol-6-(2*H*) ones, display activity as melanin concentrating hormone receptor-1 antagonists [7].

Tenuazonic acid [5-*sec*-butyl-3-(1-hydroxyethylidene) pyrrolidine-2,4-dione, TeA, **3** in Scheme 1] is a naturally occurring tetramic acid with a broad spectrum of bioactivity [8–11]. It has been used as a lead compound to design and synthesize new bioactivitive derivatives [12–14]. In this work, the total synthesis of TeA is described for the first step. And then this compound was used to synthesize a series of substituted 4,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)ones **5a–h**. Their structures were characterized by ^{1}H NMR, FT-IR, EI-MS and elemental analysis. A single crystal X-ray diffraction analysis was conducted for the selected compound **5f**. The fungicidal activity of the synthesized compounds were also evaluated.

Results and discussion

Tenuazonic acid **3** was prepared by intramolecular Lacey-Dieckmann condensation [15, 16] of the β-keto amide **2** which, in turn, was obtained from L-isoleucine methyl ester hydrochloride **1** as the starting material according to the reported method [17, 18].

The treatment of TeA (**3**) with hydrazine gave compound **4a** which underwent cyclization to diastereomers **5a** under acidic conditions (Scheme 1). In a similar way, the treatment of **3** with phenylhydrazine and its substituted analogs furnished the corresponding compounds **4b–h** that underwent cyclization to diastereomeric products **5a–h** upon treatment with acid. The yields of **5a–h** ranged from 53% to 78%.

The structures of the final products **5a–h** were confirmed by spectroscopic techniques and elemental analysis. Compound **5f** was additionaly characterized by single crystal X-ray analysis (Table 1). The crystal structure is shown in Figure 1, and selected bond lengths and bond angles are listed in Table 2. The crystallographic analysis reveals the presence of the *S*,*S*-isomer (molecule *A*) and *R*,*S*-isomer (molecule *B*) in the asymmetric unit. They are connected by intermolecular hydrogen bonds N1-H1A···O1a and N1a-H1aA···O1 to form a stable dimer. This result confirms tautomerism in compounds **5a–h**. The bond length of C11-N3 (1.422(4) Å) is shorter than the normal length of C-N single bond (1.49 Å), suggesting the presence of an electron density delocalization between two aromatic rings of benzene and pyrazole to form a large conjugated system. There is a $\pi\cdots\pi$ stacking interaction between the parallel benzene rings (Figure 2). The

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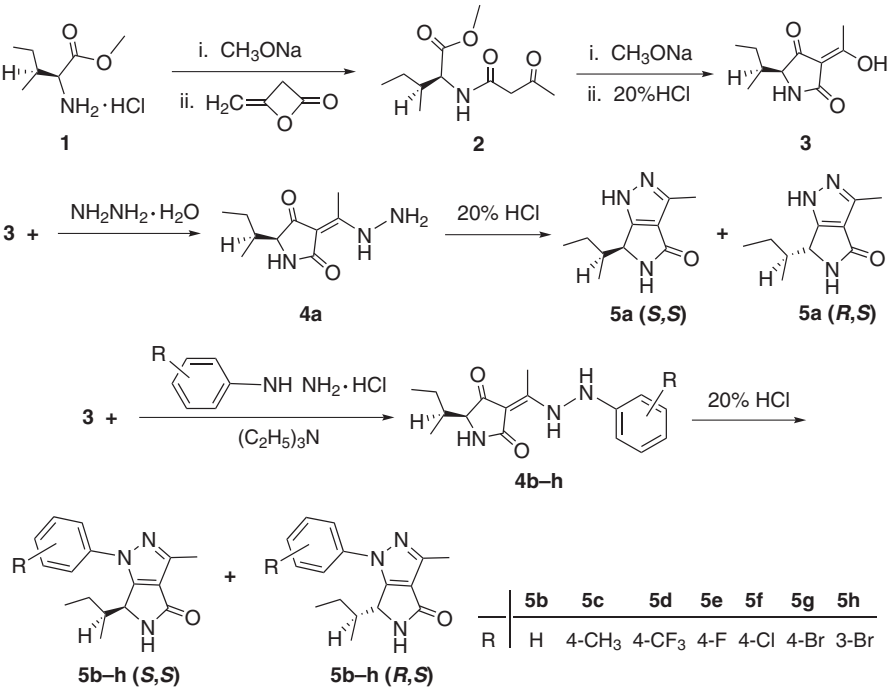

Scheme 1 Synthetic route to title compounds **5a–h**.

Table 1 Crystallographic data for compound **5f**.

Empirical formula	$C_{16}H_{18}ClN_3O$
Formula weight	303.79
Crystal system	Triclinic
Space group	$P\bar{1}$
a (Å)	6.333(3)
b (Å)	9.280(5)
c (Å)	13.707(7)
α (°)	94.522(6)
β (°)	97.138(6)
γ (°)	93.299(6)
Volume (Å^3)	795.0(7)
Z	2
Calculated density (g · cm^{-3})	1.269
Absorption coefficient (mm^{-1})	0.243
F(000)	320
Crystal size (mm^3)	0.30×0.26×0.20
θ range for data collection (°)	2.21–26.24
Index ranges	$-7 \le h \le 7$, $-11 \le k \le 11$, $-17 \le l \le 16$
Reflections collected/unique	6313/3146 [*R*(int)=0.0453]
Completeness to θ	0.983 (θ =26.24°)
Data/restraints/parameters	3146/4/223
Goodness-of-fit on F^2	0.998
Final *R* indices [$I>2\sigma(I)$]	R_1=0.0707, wR_2=0.1648
R indices (all data)	R_1=0.0792, wR_2=0.1696
Largest diff. Peak and hole (e · Å^{-3})	0.280 and -0.339

centroid to centroid distance is 4.0625 Å, and vertical distance is 3.6035 Å. The angle between the centroid to centroid line and benzene plane is 27.541°. The intermolecular hydrogen bonds and $\pi\cdots\pi$ stacking interactions make the crystal packings form a 3-D supramolecular structure.

Biological evaluation

The products **5** were evaluated for the antifungal activities *in vitro* against *Fusarium graminearum*, *Botrytis cinerea*, *Rhizoctonia cerealis* and *Colletotrichum capsici* using a mycelia growth inhibition technique at the concentration of 100 μg/mL [19, 20]. The results are summarized in Table 3. The data indicate that almost all compounds exhibit certain inhibitory activities against four tested plant pathogenic fungi. Compounds **5d** and **5f–h** show inhibitory rates of 57.1–82.5% against *F. graminearum*. Compounds **5c–d** and **5f–h** display inhibitory rates of 58.2–81.8% against *B. cinerea*. Compounds **5d** and **5f–g** demonstrate inhibitory rates of 71.2–85.7% against *R. cerealis*. And compounds **5d** and **5f–h** give inhibitory rates of 61.0–70.6% against *C. capsici*. It can be seen that the compounds containing substituted phenyl moiety present better bioactivity.

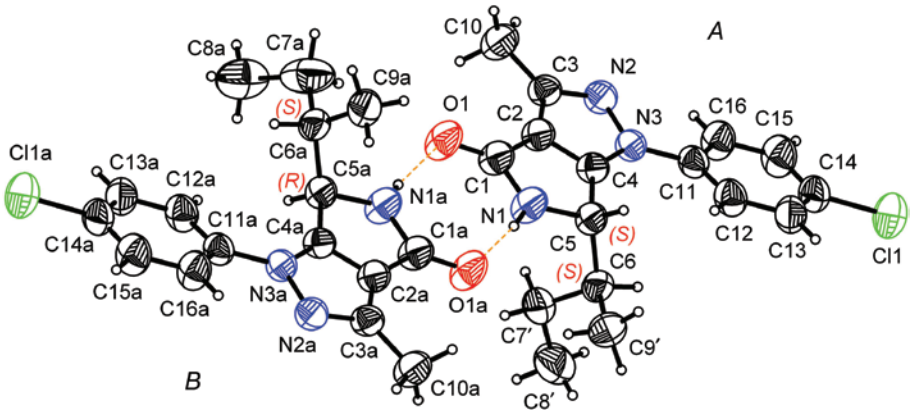

Figure 1 Molecular structure of compound **5f** with thermal ellipsoids drawn at the 50% probability level.
Dashed lines show intramolecular hydrogen bonds.

Table 2 Selected bond lengths (Å) and bond angles (°) of compound **5f**.

O1-C1	1.227(4)	N2-N3	1.390(4)
N1-C5	1.464(4)	N2-C3	1.324(4)
N1-C1	1.358(4)	N3-C4	1.352(4)
C1-C2	1.472(4)	N3-C11	1.422(4)
C2-C3	1.414(4)	Cl1-C14	1.745(3)
C1-N1-C5	116.0(2)	N2-C3-C2	109.5(3)
N1-C1-C2	104.9(2)	N3-N2-C3	106.5(2)
O1-C1-C2	129.3(3)	N2-N3-C4	109.7(2)
O1-C1-N1	125.9(3)	N3-C4-C2	107.8(2)
C1-C2-C3	144.9(3)	N3-C4-C5	140.1(3)
C1-C2-C4	108.5(3)	C2-C4-C5	112.1(2)
C3-C2-C4	106.5(2)	N1-C5-C4	98.5(2)

Experimental

Melting points were determined on a WRS-1B digital melting-point apparatus and are uncorrected. ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded on a Bruker-400 spectrometer in DMSO-d_6 solution for compound **5a** and $CDCl_3$ solution for compounds **5b–h** at room temperature. FT-IR spectra (4000–400 cm^{-1}) were recorded on a Bruker Tensor 27 FT-IR spectrometer in KBr disks. Mass spectra (electron impact) were recorded on a GC/MS-QP2010 spectrometer using a direct injection technique. Elemental analyses were performed on a Vario EL III elemental analyzer. The progress of the reactions was routinely monitored by thin layer chromatography (TLC) on silica gel GF254 and the products were visualized with an ultraviolet lamp (254 and 365 nm). All reagents and starting materials were obtained from commercial suppliers and were used without further purification.

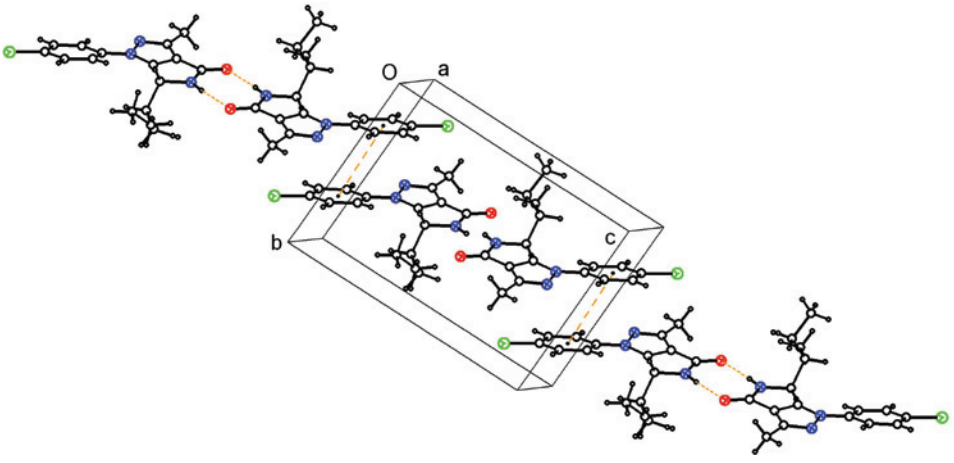

Figure 2 Packing diagram of compound **5f**.
Dashed lines show intermolecular hydrogenbonds and $\pi\cdots\pi$ interaction.

Table 3 Antifungal activities of compounds **5a–h** against four plant pathogenic fungi (100 μg/mL, inhibition rate percent).

Compounds	*F. graminearum*	*B. cinerea*	*R. cerealis*	*C. capsici*
5a	20.2±3.5	2.70±1.3	0	6.10±2.0
5b	34.1±3.5	45.3±1.3	2.9±4.3	38.2±2.6
5c	41.5±2.1	58.2±2.0	25.7±1.4	41.2±0.8
5d	75.4±1.3	80.8±1.9	71.2±2.7	62.5±2.3
5e	41.9±2.8	49.3±1.3	4.8±2.2	36.8±1.3
5f	64.0±2.8	72.4±0.8	76.2±0.8	64.0±1.5
5g	82.5±0.8	81.8±2.0	85.7±1.4	61.0±0.8
5h	57.1±1.4	68.9±0.8	43.3±2.2	70.6±3.0
TeA	10.9±1.7	18.3±2.8	13.7±3.1	14.6±3.0

The values are expressed as means±SD of the replicates; n=3 for all groups. TeA, tenuazonic acid.

General procedure for the preparation compounds 5a–h

The β-keto amide **2** was prepared according to the reported method [17, 18]. The mixture of **2** (0.2 mol) and sodium methoxide solution (0.2 mol of Na metal and 60 mL of methanol) in benzene (60 mL) was heated under reflux for 4 h. After concentration under reduced pressure, 100 mL water was added to the residue. The aqueous layer was extracted with ethyl acetate to remove the impurities and acidified to pH 2–3 with 20% hydrochloric acid, which furnished an orange oil. This product was purified by crystallization from ethanol below 0°C to give a buff powder of TeA (**3**). Then compound **3** (10 mmol) and equimolar quantity of hydrazine hydrate were dissolved in absolute ethanol (20 mL), and the solution was heated under reflux with stirring. When TLC analysis (ethyl acetate/light petroleum/acetic acid, V/V, 10:10:1) showed that **3** had been consumed, the reaction was stopped by cooling. The mixture was extracted with ethyl acetate, dried, and concentrated under reduced pressure. The oily residue was crystallized from petroleum/ethyl acetate (V/V, 1:1) below 0°C to provide compound **4a**. Compounds **4b–h** were synthesized from phenylhydrazine in the presence of trimethylamine (1.2 equiv) at room temperature by using a similar method.

Finally, an ethanol solution (15 mL) of **4** (5 mmol) was treated with 20% hydrochloric acid (1 mmol). The mixture was stirred and heated to reflux until TLC (ethyl acetate/light petroleum, V/V, 1:1) indicated the absence of **4**. After cooling, the precipitate was filtrated and washed with a small amount of water and absolute ethanol to give the desired compound **5a**–**h**.

(*RS*)-6-((*S*)-*sec*-Butyl)-3-methyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5a) Yellowish powder; yield 70%; mp 192.2–193.7°C; ^{1}H NMR: δ 12.57 (s, 1H, NH), 7.90 (s, 1H, NH), 4.31 (d, *J* = 2.2 Hz, 1H, C*H*NH), 4.29 (d, *J* = 2.6 Hz, 1H, C*H*NH), 2.31 (s, 3H, CH_3), 1.69–1.59 (m, 1H, CH_3CH), 1.57–0.94 (m, 2H, CH_3CH_2), 0.91–0.74 (m, 6H, $CH_3CH_2(CH_3)CH$); ^{13}C NMR: δ 166.5, 163.0, 135.9, 115.6, 57.3, 38.0, 25.2, 14.6, 12.4, 11.2; IR: 3200, 3088, 2970, 2878, 1701, 1605, 1151, 760 cm^{-1}; MS(EI): *m/z* 193 (M$^+$, 9), 164 (2), 136 (100), 109 (10), 57 (2). Anal. Calcd for $C_{10}H_{15}N_3O$ (193.25): C, 62.15; H, 7.82; N, 21.74. Found: C, 62.23; H, 7.71; N, 21.85.

(*RS*)-6-((*S*)-*sec*-Butyl)-3-methyl-1-phenyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5b) White powder; yield 75%; mp 155.3–156.7°C; ^{1}H NMR: δ 7.60–7.30 (m, 5H, PhH), 6.44 (s, 1H, NH), 6.30 (s, 1H, NH), 4.94 (d, *J* = 2.7 Hz, 1H, C*H*NH), 4.83 (d, *J* = 2.9 Hz, 1H, C*H*NH), 2.49 (s, 3H, $PyCH_3$), 1.95–1.83 (m, 1H, CH_3CH), 1.52–1.25 (m, 1H, CH_3CH_2 (1H)), 1.01–0.49 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.6, 155.8, 145.0, 139.1, 129.6, 127.6, 121.1, 120.8, 57.9, 35.7, 27.5, 22.7, 17.1, 12.4, 12.3, 11.8; IR: 3202, 3075, 2966, 2876, 1685, 1598, 1545, 1517, 1142, 763, 674 cm^{-1}; MS(EI): *m/z* 269 (M$^+$, 17), 212 (100), 184 (3), 116 (5), 77 (19), 57 (5). Anal. Calcd for $C_{16}H_{19}N_3O$ (269.34): C, 71.35; H, 7.11; N, 15.60. Found: C, 71.52; H, 7.02; N, 15.37.

(*RS*)-6-((*S*)-*sec*-Butyl)-3-methyl-1-(4-methylphenyl)-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5c) Colorless crystals; yield 55%; mp 170.5–171.0°C; ^{1}H NMR: δ 7.40 (t, *J* = 7.9 Hz, 2H, PhH), 7.30 (d, *J* = 7.7 Hz, 2H, PhH), 6.23 (s, 1H, NH), 6.10 (s, 1H, NH), 4.91 (d, *J* = 1.8 Hz, 1H, C*H*NH), 4.80 (d, *J* = 2.5 Hz, 1H, C*H*NH), 2.47 (s, 3H, $PyCH_3$), 2.41 (s, 3H, $PhCH_3$), 1.93–1.81 (m, 1H, CH_3CH), 1.50–1.26 (m, 1H, CH_3CH_2 (1H)), 0.99–0.49 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.7, 155.7, 144.7, 137.6, 136.7, 130.1, 121.1, 120.5, 57.8, 35.5, 27.4, 22.7, 21.1, 17.1, 12.4, 12.3, 11.8; IR: 3191, 3081, 2966, 2875, 1693, 1547, 1523, 1456, 1397, 1142, 807, 745 cm^{-1}; MS(EI): *m/z* 283 (M$^+$, 25), 246 (2), 226 (100), 130 (3), 91 (13), 77 (2). Anal. Calcd for $C_{17}H_{21}N_3O$ (283.37): C, 72.06; H, 7.47; N, 14.83. Found: C, 72.11; H, 7.39; N, 14.92.

(*RS*)-6-((*S*)-*sec*-Butyl)-3-methyl-1-(4-(trifluoromethyl)phenyl)-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5d) Yellow powder; yield 70%; mp 159.3–160.7°C; ^{1}H NMR: δ 7.76 (d, *J* = 8.7 Hz, 2H, PhH), 7.68 (d, *J* = 8.5 Hz, 2H, PhH), 6.10 (s, 1H, NH), 6.00 (s, 1H, NH), 4.99 (d, *J* = 2.6 Hz, 1H, C*H*NH), 4.88 (d, *J* = 2.8 Hz, 1H, C*H*NH), 2.49 (s, 3H, $PyCH_3$), 1.99–1.89 (m, 1H, CH_3CH), 1.54–1.31 (m, 1H, CH_3CH_2 (1H)), 1.06–0.50 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.2, 156.0, 145.9, 141.6, 129.3, 126.9, 123.7, 121.8, 120.6, 58.1, 35.6, 27.6, 22.4, 17.4, 12.4, 12.3, 11.8; IR: 3197, 3081, 2964, 2876, 1693, 1615, 1505, 1321, 1112, 1067, 842, 682 cm^{-1}; MS(EI) *m/z*: 337 (M$^+$, 15), 299 (16), 280 (100), 145 (24), 86 (18), 57 (12). Anal. Calcd for $C_{17}H_{18}F_3N_3O$ (337.34): C, 60.53; H, 5.38; N, 12.46. Found: C, 60.67; H, 5.52; N, 12.34.

(*RS*)-6-((*S*)-*sec*-Butyl)-1-(4-fluorophenyl)-3-methyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5e) Khaki powder; yield 78%; mp 125.4–127.5°C; ^{1}H NMR: δ 7.51 (dt, *J* = 9.3, 4.8 Hz, 2H, PhH), 7.68 (t, *J* = 8.4 Hz, 2H, PhH), 6.33 (s, 1H, NH), 6.21 (s, 1H, NH), 4.90 (d, *J* = 2.1 Hz, 1H, C*H*NH), 4.80 (d, *J* = 2.2 Hz, 1H, C*H*NH), 2.47 (s, 3H, $PyCH_3$), 1.89–1.77 (m, 1H, CH_3CH), 1.52–1.25 (m, 1H, CH_3CH_2 (1H)), 1.00–0.50 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.5, 161.6, 155.9, 145.1, 135.3, 123.2, 120.8, 116.6, 57.8, 35.7, 27.4, 22.8, 17.0, 12.4, 12.3, 11.9; IR: 3175, 3080, 2967, 2875, 1697, 1515, 1225, 1145, 1009, 831, 672 cm^{-1}; MS (EI): *m/z* 287 (M$^+$, 14), 230(100), 134(6), 95(13), 70(5), 57(3). Anal. Calcd for $C_{16}H_{18}FN_3O$ (287.33): C, 66.88; H, 6.31; N, 14.62. Found: C, 66.73; H, 6.18; N, 14.49.

(*RS*)-6-((*S*)-*sec*-Butyl)-1-(4-chlorophenyl)-3-methyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5f) Yellow crystals; yield 53%; mp 170.0–171.3°C; ^{1}H NMR: δ 7.50–7.44 (m, 4H, PhH), 6.25 (s, 1H, NH), 6.12 (s, 1H, NH), 4.92 (d, *J* = 2.0 Hz, 1H, C*H*NH), 4.81 (d, *J* = 2.2 Hz, 1H, C*H*NH), 2.47 (s, 3H, $PyCH_3$), 1.94–1.82 (m, 1H, CH_3CH), 1.52–1.28 (m, 1H, CH_3CH_2 (1H)), 1.02–0.49 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.4, 155.8, 145.3, 137.6, 133.1, 129.8, 122.2, 121.2, 57.9, 35.6, 27.5, 22.6, 17.2, 12.4, 12.3, 11.9; IR: 3193, 3087, 2967, 2875, 1701, 1598, 1508, 1312, 1145, 1094, 1011, 810, 668 cm^{-1}; MS(EI) *m/z*: 303 (M$^+$, 24), 274 (2), 246 (100), 111 (10), 75 (6), 57 (4). Anal. Calcd for $C_{16}H_{18}ClN_3O$ (303.78): C, 63.26; H, 5.97; N, 13.83. Found: C, 63.29; H, 5.88; N, 13.72.

(*RS*)-1-(4-Bromophenyl)-6-((*S*)-*sec*-butyl)-3-methyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5g) Yellowish powder; yield 72%; mp 165.3–166.0°C; ^{1}H NMR: δ 7.61 (d, *J* = 8.6 Hz, 2H, PhH),

7.43 (dd, *J* = 8.8, 4.1 Hz, 2H, PhH), 6.32 (s, 1H, NH), 6.18 (s, 1H, NH), 4.92 (d, *J* = 2.5 Hz, 1H, C*H*NH), 4.81 (d, *J* = 2.7 Hz, 1H, C*H*NH), 2.47 (s, 3H, $PyCH_3$), 1.94–1.83 (m, 1H, CH_3CH), 1.52–1.29 (m, 1H, CH_3CH_2 (1H)), 1.03–0.49 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.4, 155.7, 145.4, 138.0, 132.8, 122.4, 121.2, 120.9, 57.9, 35.5, 27.5, 22.6, 17.2, 12.4, 12.3, 11.9; IR: 3186, 3081, 2965, 2874, 1694, 1592, 1504, 1311, 1143, 1072, 807, 664 cm^{-1}; MS (EI): *m/z* 349 ([M^++H], 16), 347 ([M^+-H], 17), 292 (100), 183 (18), 155 (12), 76 (15), 57 (14). Anal. Calcd for $C_{16}H_{18}BrN_3O$ (348.24): C, 55.18; H, 5.21; N, 12.07. Found: C, 55.32; H, 5.13; N, 12.31.

(*RS*)-1-(3-Bromophenyl)-6-((*S*)-*sec*-butyl)-3-methyl-5,6-dihydropyrrolo[3,4-*c*]pyrazol-4-(1*H*)one (5h) Khaki powder; yield 56%; mp 132.8–134.4°C; ^1H NMR: δ 7.77 (s, 1H, ArH), 7.50–7.43 (m, 2H, PhH), 7.35 (t, *J* = 7.8 Hz, 1H, PhH), 6.46 (s, 1H, NH), 6.34 (s, 1H, NH), 4.98 (d, *J* = 1.9 Hz, 1H, C*H*NH), 4.86 (d, *J* = 2.1 Hz, 1H, C*H*NH), 2.47 (s, 3H, $PyCH_3$), 1.99–1.87 (m, 1H, CH_3CH), 1.55–1.26 (m, 1H, CH_3CH_2 (1H)), 1.02–0.51 (m, 7H, $CH_3CH_2(CH_3)CH+CH_3CH_2$ (1H)); ^{13}C NMR: δ 166.3, 156.0, 145.5, 140.0, 130.9, 130.5, 124.2, 123.3, 121.6, 119.1, 57.9, 35.7, 27.6, 22.8, 17.2, 12.5, 12.4, 11.9; IR: 3186, 3078, 2960, 2872, 1701, 1591, 1498, 1311, 1143, 764, 714, 689 cm^{-1}; MS (EI): *m/z* 349 ([M^++H], 19), 347 ([M^+-H], 19), 292 (100), 211 (11), 183 (19), 155 (10), 70 (14). Anal. Calcd for $C_{16}H_{18}BrN_3O$ (348.24): C, 55.18; H, 5.21; N, 12.07. Found: C, 55.42; H, 5.08; N, 12.26.

Single-crystal X-ray diffraction analysis of compound 5f

The yellow single crystal of compound **5f** grown from ethanol at room temperature, was selected for lattice parameter determination. The intensity data were recorded on a Bruker Smart APEX II CCD diffractometer equipped with graphite monochromatized Mo K_α radiation (λ=0.71073 Å) at 296(2) K. The intensities were corrected for Lorentz and polarization effects, and all data were corrected using the SADABS program [21]. The crystal structure was solved by direct methods using the SHELXS-97 program [22, 23]. All non-hydrogen atoms were refined by full-matrix least-squares technique on F^2 with anisotropic thermal parameters. The hydrogen atoms were positioned geometrically and refined using a riding model. Details on crystal data are summarized in Table 1.

The crystallographic data of compound **5f** have been deposited as supplementary publication No. CCDC 890343. Copy of this information can be obtained free of charge from the Cambridge Crystallographic Data Centre via fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk or http://www.ccdc.cam.ac.uk.

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