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A Novel Synthesis of Heterocyclic Analogues of Thioflavanones from Haloheteroaromatic Carboxylic Acids

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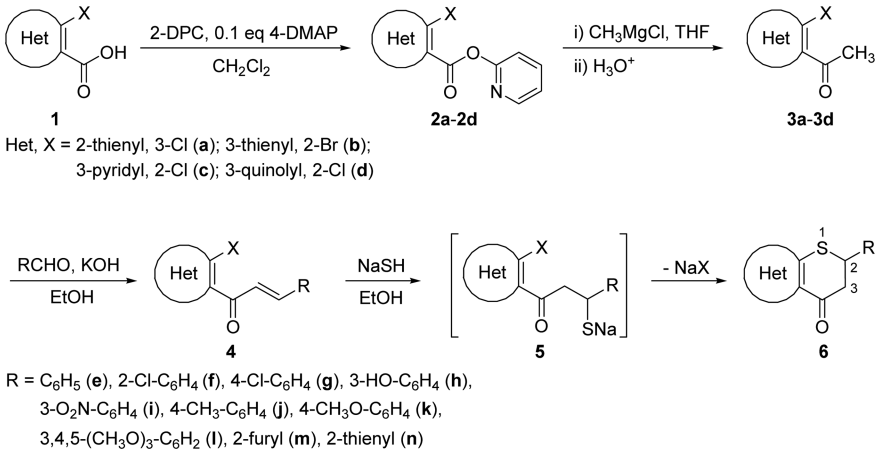
Thioflavanones (2-phenylthiochroman-4-ones), the thio analogues of flavanones, are an interesting class of heterocycles[1] because their biological activities sometimes can be improved. We recently investigated the anticancer effects of thioflavanone in MCF-7 human breast cancer cell lines and found that it inhibited cellular proliferation by inducing apoptosis with weak cytotoxicity.[2] The 3-cinnamylidene derivatives of thioflavanones showed antiproliferative effects[3] on mouse lymphoma cells, and the 3-chloromethylene derivatives of thiochroman-4-ones showed antifungal activities.[4]

Thiochroman-4-ones have been generally synthesized by the Friedel-Crafts acylation of 3-arylmercaptopropanoic acids, which are prepared by adding thiophenols to α,β-unsaturated esters or substituting 3-bromo (mesyl) esters with thiophenols and subsequent hydrolysis, with H_2SO_4[5] or polyphosphoric acid[6] in moderate yields. The cyclization of 3-arylthiopropanoic acids proceeded by a catalytic amount of Lewis acid, such as $Bi(NTf_2)_3$ or $Yb(OTf)_3$, at 200 °C.[7] The direct cyclocondensation of thiophenols and 3-methyl-2-butenoic acid with methanesulfonic acid resulted in thiochroman-4-ones, with the corresponding disulfides and enol thioethers obtained as minor products.[8]

Another thioflavanone synthesis involved intramolecular cyclization of 2'-mercaptochalcones, which are prepared by the base catalyzed condensation of 2'-benzylthioacetophenones and benzaldehydes followed by subsequent debenzylation, with *p*-toluenesulfonic acid[9] or phosphomolybdic acid supported on silica (PMA-SiO_2).[10] The cyclization of *S*-benzyl protected α-sulfinyl chalcones followed by debenzylation with formic acid proceeds smoothly to give 3-sulfinylthioflavanones. These compounds undergo sulfinyl group elimination to form thioflavones in refluxing benzene.[11] The treatment of benzoxathiolane chalcones with NaOH in refluxing *aq* EtOH also provided thioflavanones by the intramolecular 1,4-addition of thiol groups generated from benzoxathiolane ring opening.[12]

Despite potential in bioisoterism of thioflavanones, only a few synthetic methods are reported[13] for heterocyclic analogues. As an extension of our research on thioflavonoids,[14] we describe the novel synthesis of heterocyclic analogues of thioflavanones from haloheteroaromatic carboxylic acids as potential drug candidates.

Initial attempts to prepare 1-(haloheteroaryl)ethanones (**3**) directly by treating haloheteroaromatic acids (**1**) with 2 equiv of methyllithium were fruitless. Therefore, **3** were synthesized *via* 2-pyridyl haloheteroaroates (**2**), which were readily prepared from **1** using di-2-pyridyl carbonate (2-DPC) according to previously developed method[14b] (**2a**: 83%, **2b**: 90%, **2c**: 87%, **2d**: 87%, Scheme 1). The synthesis of **3** was successfully accomplished by nucleophilic acyl substitution of **2** with methylmagnesium chloride. The addition of methylmagnesium chloride to a solution of **2** in THF at 0 °C led to the formation of precipitates, which were hydrolyzed with saturated NH_4Cl solution to give **3** (**3a**:



Scheme 1

92%, **3b**: 87%, **3c**: 91%, **3d**: 78%).

Haloheteroaryl chalcones (**4**) were synthesized by condensation between **3** and (hetero)arylaldehydes using KOH. The treatment of a solution of **3** and (hetero)arylaldehydes in EtOH with 0.5 N KOH afforded corresponding β-hydroxyketones which then underwent dehydration to give **4**. After completing the reaction, the resulting yellow solution containing white precipitates was quenched with 0.5 N HCl and separated by aqueous workup. Purification of the residue by silica gel column chromatography or recrystallization afforded **4** in 68-89% yields.

The cyclization of **4** was carried out by one-pot sequence of a 1,4-addition of sodium hydrosulfide followed by intramolecular substitution of halides. The addition of **4** to a suspended solution of sodium hydrosulfide in EtOH at room temperature prompted 1,4-addition of hydrosulfide anion to result in sodium thiolate adducts (**5**). These intermediates underwent intramolecular nucleophilic aromatic substitution at reflux for 1.5-4 h to give the heterocyclic analogues of thioflavanones (**6**) by eliminating sodium halides. After completing the reaction, the resulting light yellow solution containing precipitates was treated with H_2O and separated by aqueous workup. The residue was purified by silica gel column chromatography or recrystallization in 10% EtOAc/*n*-hexane to give **6** in 87-93% yields. The characteristic ^{1}H NMR absorptions of **6** appeared as a doublet of doublets for the C_2 proton signals from δ 4.74 to 5.35 and two doublet of doublets for two C_3 protons signals from δ 3.07 to 3.43.

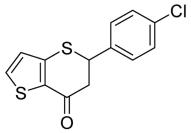
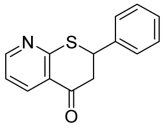
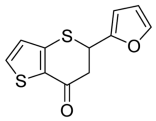
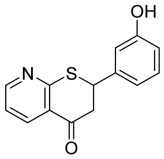
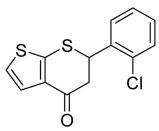
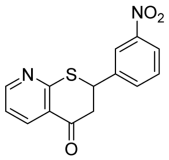
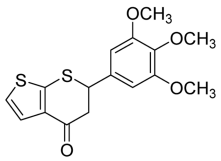
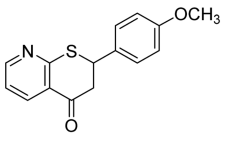
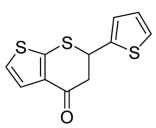
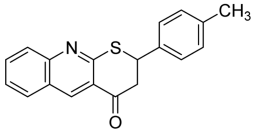
As shown in Table 1, various heterocyclic thioflavanone analogues were synthesized with overall high yields (50-62%) from readily available starting material **1**. The reaction proceeded equally well with 2-bromothiophene (**6bf**, **6bl**, **6bn**) and 3-chlorothiophene groups (**6ag**, **6am**), regardless of the position of the 2-bromo or 3-chloro group in thiophenecarboxylic acids. The reaction also proceeded well for the electron-withdrawing substituents, such as chloro (**6ag**, **6bf**) and nitro groups (**6ci**), and electron-donating substituents, such as methoxy (**6bl**, **6ck**) and methyl groups (**6dj**), of 2-substituted phenyl rings. Without protection of hydroxyl group, **4ch** was also cyclized to afford **6ch**. Furthermore, the present method was applicable for synthesizing **6** containing a heteroaromatic ring, such as 2-furyl (**6am**) or 2-thienyl (**6bn**), in place of phenyl group.

In conclusion, the present method provides (i) novel synthesis of heterocyclic thioflavanone analogues **6** from starting material **1**, (ii) a rapid and versatile reaction, and (iii) overall high yields.

Experimental Section

General Procedure for Synthesizing 1-(2-Chloropyridin-3-yl)ethanone (3c). Methylmagnesium chloride (0.5 M in THF, 8.0 mL, 4.0 mmol) was added to a solution of 2-pyridyl 2-chloropyridine-3-carboxylate (**2c**, 939 mg, 4.0

Table 1. Preparation of haloheteroaryl chalcones **4** and heterocyclic thioflavanone analogues **6** from haloheteroaromatic acids **1**

Entry	Product	Isolated yields, %[a]		Entry	Product	Isolated yields, %[a]	
		4	**6**			**4**	**6**
ag		83	87 (55)	**ce**		76	90 (54)
am		87	89 (59)	**ch**		68	93 (50)
bf		80	92 (58)	**ci**		89	87 (61)
bl		81	88 (56)	**ck**		82	91 (59)
bn		86	92 (62)	**dj**		83	91 (51)

[a]The numbers in parentheses indicate the overall yields of four steps from haloheteroaromatic acids **1**.

mmol) in THF (12 mL) at 0 °C under argon atmosphere. After stirring for 0.5 h, the mixture was quenched with saturated NH_4Cl solution (5 mL) and THF was evaporated *in vacuo*. The mixture was poured into saturated NH_4Cl solution (30 mL) and extracted with dichloromethane (3 × 20 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo.* The residue was purified by vacuum distillation using a Kugelrohr apparatus to give **3c** (566 mg, 91%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.50 (dd, J_1 = 4.8 Hz, J_2 = 1.9 Hz, 1H), 7.92 (dd, J_1 = 7.6 Hz, J_2 = 1.9 Hz, 1H), 7.36 (dd, J_1 = 7.6 Hz, J_2 = 4.8 Hz, 1H), 2.71 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 198.9, 151.5, 147.8, 138.5, 135.3, 122.6, 30.5; FT-IR (film) 1702 (C=O) cm^{-1}; Ms *m/z* (%) 157 (M^++2, 8), 155 (M^+, 25), 142 (34), 140 (100), 114 (16), 112 (45).

General Procedure for Synthesizing 1-(2-Chloropyridin-3-yl)-3-(4-methoxyphenyl)-2-propen-1-one (4ck). A 0.5 N KOH solution (0.5 N in CH_3OH, 6.0 mL, 3.0 mmol) was added to a mixture of **3c** (467 mg, 3.0 mmol) and 4-methoxybenzaldehyde (408 mg, 3.0 mmol) in EtOH (15 mL) at 0 °C. The mixture was stirred for 0.5 h between 0 °C and room temperature. The resulting yellow solution containing white precipitate was quenched with 0.5 N HCl solution (6 mL). After evaporating the solvent, the mixture was poured into saturated NH_4Cl solution (30 mL), extracted with dichloromethane (3 × 20 mL), and washed with brine (30 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo.* The residue was recrystallized twice in 5% EtOAc/*n*-hexane to give **4ck** (673 mg, 82%). mp 114-115 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.52 (dd, J_1 = 4.8 Hz, J_2 = 2.0 Hz, 1H), 7.82 (dd, J_1 = 7.5 Hz, J_2 = 2.0 Hz, 1H), 7.54 (d, J = 8.8 Hz, 2H), 7.45 (d, J = 16.0 Hz, 1H), 7.37 (dd, J_1 = 7.5 Hz, J_2 = 4.8 Hz, 1H), 7.03 (d, J = 16.0 Hz, 1H), 6.93 (d, J = 8.8 Hz, 2H), 3.86 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.0, 162.3, 150.9, 147.7, 147.1, 138.3, 135.7, 130.7, 126.8, 123.3, 122.5, 114.6, 55.5; FT-IR (KBr) 1655 (C=O) cm^{-1}; Ms *m/z* (%) 275 (M^++2, 34), 273 (M^+, 100), 242 (38), 161 (74).

General Procedure for Synthesizing 2,3-Dihydro-2-(4-methoxyphenyl)-4*H*-thiopyrano[2,3-*b*]pyridin-4-one (6ck). A solution of **4ck** (547 mg, 2.0 mmol) in EtOH (15 mL) was added to a suspended solution of sodium hydrosulfide hydrate (~60%, 224 mg, 2.4 mmol) in EtOH (10 mL) at room temperature. The solution was stirred for 0.5 h at room temperature to give tan solution and then refluxed for 3 h more. After evaporating EtOH, the mixture was poured into saturated NH_4Cl solution (30 mL) and extracted with dichloromethane (3 × 20 mL). The combined organic phases were dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo.* The residue was recrystallized twice in 10% EtOAc/*n*-hexane to give **6ck** (494 mg, 91%) as a pale yellow solid. mp 103-104 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.57 (dd, J_1 = 4.7 Hz, J_2 = 1.9 Hz, 1H), 8.33 (dd, J_1 = 7.9 Hz, J_2 = 1.9 Hz, 1H), 7.36 (d, J = 8.7 Hz, 2H), 7.16 (dd, J_1 = 7.9 Hz, J_2 = 4.7 Hz, 1H), 6.92 (d, J = 8.7 Hz, 2H), 4.74 (dd, J_1 = 12.8 Hz, J_2 = 3.2 Hz, 1H), 3.82 (s, 3H), 3.32 (dd, J_1 = 16.3 Hz, J_2 = 12.8 Hz, 1H), 3.19 (dd, J_1 = 16.3 Hz, J_2 = 3.2 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.2, 164.2, 159.7, 153.9, 136.6, 129.7, 128.7, 126.9, 120.2, 114.4, 55.4, 46.0, 43.5; FT-IR (KBr) 1683 (C=O) cm^{-1}; Ms *m/z* (%) 271 (M^+, 73), 134 (46), 121 (100), 91 (21).

5,6-Dihydro-5-(4-chlorophenyl)-7*H*-thieno[3,2-*b*]thiopyran-4-one (6ag): mp 125-126 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.70 (d, J = 5.1 Hz, 1H), 7.35-7.39 (m, 4H), 6.95 (d, J = 5.1 Hz, 1H), 4.81 (dd, J_1 = 13.1 Hz, J_2 = 3.2 Hz, 1H), 3.23 (dd, J_1 = 16.6 Hz, J_2 = 13.1 Hz, 1H), 3.07 (dd, J_1 = 16.6 Hz, J_2 = 3.2 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 187.5, 144.9, 136.5, 135.1, 134.5, 131.7, 129.2, 128.9, 126.8, 47.6, 45.5; FT-IR (KBr) 1652 (C=O) cm^{-1}; Ms *m/z* (%) 282 (M^++2, 43), 280 (M^+, 100), 169 (72), 142 (98).

5,6-Dihydro-5-(2-furyl)-7*H*-thieno[3,2-*b*]thiopyran-4-one (6am): Viscous liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.67 (d, J = 5.1 Hz, 1H), 7.38-7.41 (m, 1H), 6.93 (d, J = 5.2 Hz, 1H), 6.33 (dd, J_1 = 3.3 Hz, J_2 = 1.9 Hz, 1H), 6.29 (d, J = 3.3 Hz, 1H), 4.88 (dd, J_1 = 9.4 Hz, J_2 = 4.3 Hz, 1H), 3.27 (dd, J_1 = 16.8 Hz, J_2 = 9.4 Hz, 1H), 3.18 (dd, J_1 = 16.8 Hz, J_2 = 4.3 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 187.2, 151.0, 143.6, 142.8, 134.9, 131.3, 127.1, 110.6, 108.0, 42.8, 40.7; FT-IR (film) 1651 (C=O) cm^{-1}; Ms *m/z* (%) 236 (M^+, 100), 142 (80), 114 (16), 81 (37).

5,6-Dihydro-6-(2-chlorophenyl)-4*H*-thieno[2,3-*b*]thiopyran-4-one (6bf): Viscous liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.52-7.56 (m, 1H), 7.51 (d, J = 5.4 Hz, 1H), 7.42-7.45 (m, 1H), 7.28-7.33 (m, 2H), 7.07 (d, J = 5.4 Hz, 1H), 5.35 (dd, J_1 = 12.0 Hz, J_2 = 3.4 Hz, 1H), 3.22 (dd, J_1 = 16.8 Hz, J_2 = 12.0 Hz, 1H), 3.06 (dd, J_1 = 16.8 Hz, J_2 = 3.4 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 188.7, 150.6, 135.3, 134.9, 133.6, 130.3, 129.8, 128.2, 127.5, 126.1, 122.5, 45.7, 44.5; FT-IR (film) 1666 (C=O) cm^{-1}; Ms *m/z* (%) 282 (M^++2, 31), 280 (M^+, 74), 169 (34), 142 (100), 114 (26).

5,6-Dihydro-6-(3,4,5-trimethoxyphenyl)-4*H*-thieno[2,3-*b*]thiopyran-4-one (6bl): mp 155-156 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.49 (d, J = 5.4 Hz, 1H), 7.07 (d, J = 5.4 Hz, 1H), 6.65 (s, 2H), 4.81 (dd, J_1 = 13.3 Hz, J_2 = 3.0 Hz, 1H), 3.87 (s, 6H), 3.86 (s, 3H), 3.23 (dd, J_1 = 16.7 Hz, J_2 = 13.3 Hz, 1H), 3.07 (dd, J_1 = 16.7 Hz, J_2 = 3.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 188.9, 153.5, 150.9, 138.2, 135.1, 133.1, 126.1, 122.5, 104.5, 60.9, 56.2, 50.2, 45.8; FT-IR (KBr) 1663 (C=O) cm^{-1}; Ms *m/z* (%) 336 (M^+, 75), 194 (55), 181 (100), 179 (57), 151 (12).

5,6-Dihydro-6-(2-thienyl)-4*H*-thieno[2,3-*b*]thiopyran-4-one (6bn): Viscous liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.49 (d, J = 5.4 Hz, 1H), 7.29 (dd, J_1 = 5.1 Hz, J_2 = 1.2 Hz, 1H), 7.08-7.11 (m, 1H), 7.06 (d, J = 5.4 Hz, 1H), 6.98 (dd, J_1 = 5.1 Hz, J_2 = 3.6 Hz, 1H), 5.12 (dd, J_1 = 9.3 Hz, J_2 = 5.7 Hz, 1H), 3.20-3.26 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 188.3, 150.0, 141.0, 135.2, 127.1, 126.3, 126.1, 125.8, 122.6, 46.4, 44.7; FT-IR (film) 1663 (C=O) cm^{-1}; Ms *m/z* (%) 254 (M^++2, 12), 252 (M^+, 80), 142 (100), 114 (20).

2,3-Dihydro-2-phenyl-4*H*-thiopyrano[2,3-*b*]pyridin-4-one (6ce): Viscous liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.57 (dd, J_1 = 4.7 Hz, J_2 = 1.9 Hz, 1H), 8.34 (dd, J_1 = 7.9 Hz, J_2 = 1.9 Hz, 1H), 7.35-7.46 (m, 5H), 7.16 (dd, J_1 = 7.9 Hz, J_2 = 4.7 Hz, 1H), 4.78 (dd, J_1 = 12.7 Hz, J_2 = 3.3 Hz, 1H), 3.35

(dd, J_1 = 16.3 Hz, J_2 = 12.7 Hz, 1H), 3.22 (dd, J_1 = 16.3 Hz, J_2 = 3.3 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.0, 164.1, 153.9, 137.8, 136.6, 129.1, 128.7, 127.5, 126.9, 120.3, 45.8, 44.1; FT-IR (film) 1682 (C=O) cm^{-1}; Ms *m/z* (%) 241 (M^+, 100), 164 (21), 137 (26), 104 (32).

2,3-Dihydro-2-(3-hydroxyphenyl)-4*H*-thiopyrano[2,3-*b*]pyridin-4-one (6ch): mp 182-183 ºC; ^{1}H NMR (300 MHz, $CDCl_3$/DMSO-d_6 = 3/1) δ 9.29 (s, 1H), 8.55 (dd, J_1 = 4.7 Hz, J_2 = 1.8 Hz, 1H), 8.29 (dd, J_1 = 7.9 Hz, J_2 = 1.8 Hz, 1H), 7.15-7.23 (m, 2H), 6.85-6.91 (m, 2H), 6.79 (dd, J_1 = 8.1 Hz, J_2 = 1.2 Hz, 1H), 4.77 (dd, J_1 = 12.5 Hz, J_2 = 3.1 Hz, 1H), 3.31 (dd, J_1 = 16.3 Hz, J_2 = 12.5 Hz, 1H), 3.15 (dd, J_1 = 16.3 Hz, J_2 = 3.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$/DMSO-d_6 = 3/1) δ 198.4, 168.5, 162.7, 158.5, 144.1, 141.1, 134.8, 131.6, 125.2, 122.9, 120.5, 119.3, 50.4, 48.4; FT-IR (KBr) 3420 (OH), 1653 (C=O) cm^{-1}; Ms *m/z* (%) 257 (M^+, 100), 164 (22), 138 (26), 120 (49).

2,3-Dihydro-2-(3-nitrophenyl)-4*H*-thiopyrano[2,3-*b*]pyridin-4-one (6ci): mp 154-155 ºC; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.60 (dd, J_1 = 4.7 Hz, J_2 = 1.9 Hz, 1H), 8.34-8.38 (m, 2H), 8.24 (d, J = 8.1 Hz, 1H), 7.80 (d, J = 7.8 Hz, 1H), 7.61 (t, J = 8.0 Hz, 1H), 7.21 (dd, J_1 = 7.9 Hz, J_2 = 4.7 Hz, 1H), 4.88 (dd, J_1 = 11.9 Hz, J_2 = 3.5 Hz, 1H), 3.39 (dd, J_1 = 16.2 Hz, J_2 = 11.9 Hz, 1H), 3.28 (dd, J_1 = 16.2 Hz, J_2 = 3.6 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.9, 162.9, 154.2, 148.6, 140.0, 136.7, 133.6, 130.3, 126.9, 123.7, 122.7, 120.7, 45.2, 43.2; FT-IR (KBr) 1682 (C=O) cm^{-1}; Ms *m/z* (%) 286 (M^+, 100), 164 (18), 137 (93), 109 (35).

2,3-Dihydro-2-(4-methylphenyl)-4*H*-thiopyrano[2,3-*b*]quinolin-4-one (6dj): mp 134-135 ºC; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.86 (s, 1H), 7.94 (d, J = 8.5 Hz, 1H), 7.87 (d, J = 8.1 Hz, 1H), 7.75-7.80 (m, 1H), 7.47-7.52 (m, 1H), 7.35 (d, J = 7.8 Hz, 2H), 7.20 (d, J = 7.7 Hz, 2H), 4.82 (dd, J_1 = 12.0 Hz, J_2 = 2.9 Hz, 1H), 3.43 (dd, J_1 = 16.3 Hz, J_2 = 12.0 Hz, 1H), 3.31 (dd, J_1 = 16.3 Hz, J_2 = 3.0 Hz, 1H), 2.36 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.4, 161.6, 150.0, 138.5 (overlapped), 135.0, 133.1, 129.9, 129.8, 128.0, 127.4, 126.5, 125.5, 125.2, 46.7, 43.5, 21.2; FT-IR (KBr) 1686 (C=O) cm^{-1}; Ms *m/z* (%) 305 (M^+, 100), 213 (24), 118 (31), 105 (35).

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References

1. (a) Schneller, S. W. *Adv. Heterocycl. Chem.* **1975**, *18*, 59. (b) Rimbault, C. G. *U. S. Patent* 1989, 4,885,298.
2. Choi, E. J.; Lee, J. I.; Kim, G.-H. *Int. J. Mol. Med.* **2012**, *29*, 252.
3. Engi, H.; Gyemant, N.; Lorand, T.; Levai, A.; Ocsovszki, I.; Molnar, J. *In Vivo* **2006**, *20*, 119.
4. Zhang, X.; Ma, Z.; Yang, G.; Zheng, Y. *Modern Appl. Sci.* **2011**, *5*, 217.
5. (a) Robillard, B.; Slaby, H. M.; Lindsay, D. A.; Ingold, K. U. *J. Org. Chem.* **1986**, *51*, 1700. (b) Dike, S. Y.; Ner, D. H.; Kumar, A. *Synlett* **1991**, 443.
6. Aramaki, Y.; Seto, M.; Okawa, T.; Oda, T.; Kanzaki, N.; Shiraishi, M. *Chem. Pharm. Bull.* **2004**, *52*, 254.
7. Cui, D.-M.; Kawamura, M.; Shimada, S.; Hayashi, T.; Tanaka, M. *Tetrahedron Lett.* **2003**, *44*, 4007.
8. Clayton, S. E.; Gabbutt, C. D.; Hepworth, J. D.; Heron, B. M. *Tetrahedron* **1993**, *49*, 939.
9. Konieczny, M. T.; Horowska, B.; Kunikowski, A.; Konopa, J.; Wierzba, K.; Yamada, Y.; Asao, T. *J. Org. Chem.* **1999**, *64*, 359.
10. Sakirolla, R.; Yaeghoobi, M.; Rahman, N. A. *Monatsh. Chem.* **2012**, *143*, 797.
11. (a) Kataoka, T.; Watanabe, S.; Mori, E.; Kadomoto, R.; Tanimura, S.; Kohno, M. *Bioorg. Med. Chem.* **2004**, *12*, 2397. (b) Cordonnier, G.; Rolando, C.; Barbry, D. *9th Int. Electronic Conference on Synth. Org. Chem.* **2005**, 1-30 Nov, C022.
12. Konieczny, W.; Konieczny, M. *Synthesis* **2009**, 1811.
13. (a) Ponticello, G. S.; Freedman, M. B.; Habecker, C. N.; Holloway, M. K.; Amato, J. S.; Conn, R. S.; Baldwin, J. J. *J. Org. Chem.* **1988**, *53*, 9. (b) Bates, D. K.; Li, K. *J. Org. Chem.* **2002**, *67*, 8662.
14. (a) Lee, J. I. *Bull. Korean Chem. Soc.* **2008**, *29*, 1263. (b) Lee, J. I. *Bull. Korean Chem. Soc.* **2012**, *33*, 1375.