Amine-controlled reduction of 2-aminochromone-3-carbaldehyde with Zn and acetic acid

Pritam Biswas[a], Jaydip Ghosh[a], Tapas Sarkar[b] and Chandrakanta Bandyopadhyay[a]*

[a]*Department of Chemistry, R. K. Mission Vivekananda Centenary College, Rahara, Kolkata -700 118, West Bengal, India*
[b]*Chemistry Division, CSIR-Indian Institute of Chemical Biology, Jadavpur - 700 032, West Bengal, India*

On heating with zinc in acetic acid 2-(*N*-arylamino)chromone-3-carbaldehydes produce 2-(*N*-arylamino)-3-methylchromones, whereas 2-(*N*-alkylamino)chromone-3-carbaldehydes produce 4-hydroxy-3-methylcoumarin in moderate yields. Reduction of an aldehyde function to a methyl group has been achieved under very mild reaction conditions.

Keywords: 1-benzopyran, 2-aminochromone-3-carbaldehyde, Clemmensen reduction, zinc-acetic acid reduction, 2-aminochromone

The antiplatelet activity of 2-aminochromone class of compounds is well-known.[1-3] 2-(4-Morpholinyl)-8-phenylchromone inhibits NO production in cultured murine astrocytes[4] and also exhibits phosphoinositide-3-kinase inhibitory activity.[5] 5,4′-Diaminoflavone derivatives exhibit remarkable antiproliferative activity against human breast cancer cell MCF-7.[6] Recently, the chromone moiety has been incorporated into spiro compounds indicating its value in material science applications.[7,8] The ubiquity of the chromone moiety in the plant kingdom[9-12] and pharmaceutically important natural and synthetic compounds[13-16] warrants further studies in the field of chromone chemistry.

Reduction of chromone-3-carbaldehyde **A** has been studied under various conditions. Previously we have reported[17] reduction of **A** with (i) sodium naphthalenide, (ii) zinc in benzene in the presence of small amount of methanol or (iii) zinc in methanol to produce dichromonylcarbinol, dichromonylmethane and 1,4-disalicyloylbenzene. Reduction of **A** with Zn in acetic acid produced 3-hydroxymethylchromone **B** and a diastereomeric mixture of 1,2-di(4-oxo-4*H*-1-benzopyran-3-yl)ethane-1,2-diols, **C** and **C**′ (Scheme 1).[17,18] Compound **B** was also produced by the reduction of **A** using $NaBH_4$–$AlCl_3$,[19] isopropanol–alumina[20,21] or BH_3–THF[22] as reducing agent. Reduction of the aldehyde function of a 5,6-dihydroxychromone-6-carbaldehyde derivative to the corresponding 5,6-dihydroxy-6-methylchromone derivative by Zn–Hg/HCl[23] and H_2/Pd-C[24] has been reported. Reduction of 3-formylchromone to 3-methylchromone has been accomplished by $Fe(CO)_5$.HMPA in refluxing toluene.[25] These reduction processes require either harsh reaction conditions, long reaction times or costly reagents.

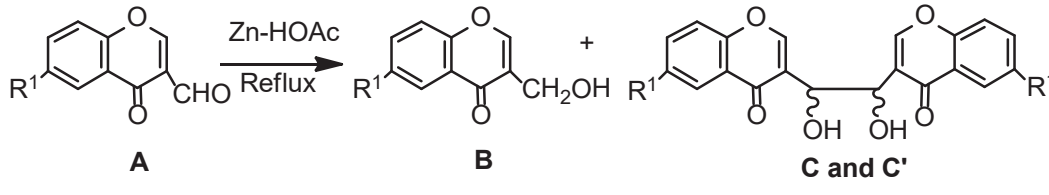
During the last few years we have been engaged in synthesising various polycyclic heterocycles using 2-aminochromone-3-carbaldehydes **1** as a building block.[26-28] We have reported the deformylation of **1**(R^2 = alkyl, R^3 = H) by heating with 70% aqueous H_2SO_4, where the C-2 amino group in the chromone ring initiates the reaction.[29] This observation prompted us to study the reduction of **1** where the C-2 amino group may participate in the reduction process. We report here a facile process for the reduction of **1** to 2-amino-3-methylchromone **2** by Zn in acetic acid.

Results and discussion

Compound **1a** was stirred with excess zinc powder (10 equiv.) in acetic acid at room temperature. The completion of the reaction was observed by TLC after 2 days (Table 1, entry 1). After work-up and chromatographic purification a white crystalline solid **2a** was isolated but in only 10% yield.

The structure of this crystalline solid was determined on the basis of IR, NMR, mass spectra and elemental analyses. The ^{1}H NMR spectrum of this solid showed the absence of an aldehyde proton, the presence of *N*-methyl and *N*-aryl moieties and a new singlet signal for three protons at δ 1.71. These reaction conditions for the conversion of the aldehyde group in **1a** to a methyl group in **2a** by Zn in acetic acid are mild and simple compared to the Clemmensen reduction method. This encouraged us to improve the yield of the reduction process. Fortunately, on heating **1a** with zinc powder (5 equiv.) in acetic acid under reflux the reaction was complete within 4 h only and the yield of the isolated product **2a** increased to 45% (Table 1, entry 2).

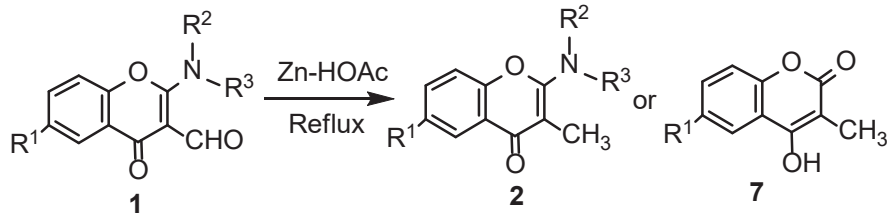
To check the scope of the reaction, different substituents on the amino function were considered. Amine **1b**, having an allyl group, produced **2b** in 52 % yield (entry 3). Compounds **1c** bearing a propargyl group and **1d** containing a 2-butynyl group in the amine function also followed this reduction process and produced **2c** and **2d** in 60% and 58% yields, respectively (entries 4 and 5). On heating **1e** (R^2 = *o*-bromobenzyl, R^3 = *p*-tolyl), having *N*-benzyl and aromatic *C*-halogen bonds, with Zn dust in acetic acid for 3 h produced **2e** in moderate yield (entry 6). Encouraged by these results obtained using a tertiary amine substrate (entries 2–6), we tested this reaction with secondary amino groups at the 2-position of chromone-3-carbaldehyde. 2-*N*-Arylaminochromone-3-carbaldehydes **1f** or **1g** also produced the corresponding 3-methyl derivative, but a slightly longer reaction time was required (entries 7 and 8). It was observed that C–Br and C–Cl bonds on the aromatic ring survived under the reaction conditions (entries 6 and 8). The reduction was then tested using 2-*N*-alkylaminochromones (**1**, R^2 = Alkyl, R^3 = H) in place of 2-*N*-arylaminochromones (**1**, R^2 = Aryl, R^3 = H). Thus, reaction of 2-*N*-ethylaminochromone-3-carbaldehyde (**1h**) with Zn in acetic acid under reflux for 4 h and



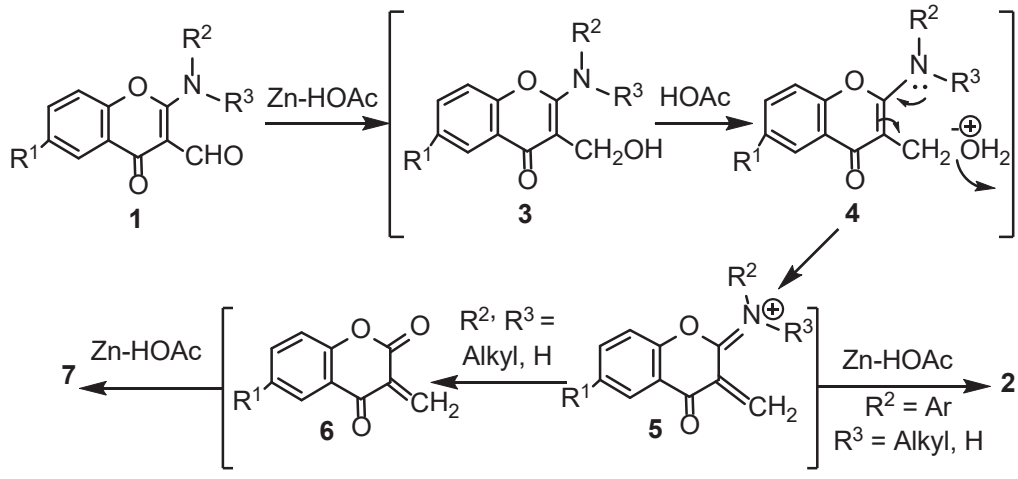
Scheme 1

* Correspondent. E-mail: kantachandra@rediffmail.com

Table 1 Reduction of 2-aminochromone-3-carbaldehydes by Zn/HOAc



Entry no.	Compound No.	R^1	R^2	R^3	Reaction conditions	Time	Product	Yield /%
1	**1a**	Me	Ph	Me	RT/ Stirring	2 days	**2a**	10
2	**1a**	Me	Ph	Me	Reflux	4 h	**2a**	45
3	**1b**	Me	*p*-tolyl	$CH_2CH{=}CH_2$	Reflux	4 h	**2b**	52
4	**1c**	H	*p*-tolyl	$CH_2C{\equiv}CH$	Reflux	4 h	**2c**	60
5	**1d**	Me	Ph	$CH_2C{\equiv}CMe$	Reflux	4 h	**2d**	58
6	**1e**	Me	*p*-tolyl	*o*-Bromobenzyl	Reflux	3 h	**2e**	62
7	**1f**	H	Ph	H	Reflux	5 h	**2f**	55
8	**1g**	H	*p*-ClC_6H_4	H	Reflux	5 h	**2g**	66
9	**1h**	Me	Et	H	Reflux	4 h	**7**	52
10	**1i**	Me	Me	H	Reflux	4 h	**7**	44
11	**1j**	Me	Et	Me	Reflux	4 h	**7**	47
12	**1k**	Me	H	H	Reflux	4 h	**7**	50



Scheme 2

subsequent work-up of the reaction mixture produced a white crystalline solid, the ^{1}H NMR spectrum of which showed two signals at δ 2.38 and 1.99 corresponding to two methyl groups at the C-6 and C-3 positions respectively. Surprisingly, the signals corresponding to the ethyl group were absent. This reaction was repeated using 2-*N*-methylaminochromone-3-carbaldehyde (**1i**) and the same coumarin derivative **7**[30,31] was obtained in moderate yield (entries 9 and 10). To examine the effect of an alkyl-substituted tertiary amino group at the 2-position of **1,** compound **1j** (R^2 = Et, R^3 = Me) was synthesised and subjected to reduction with Zn in HOAc, the reaction mixture produced **7** in moderate yield (entry 11). The presence of a primary amino group at the 2-position of chromone ring was also tested and **1k** was heated under reflux with Zn in acetic acid for 4 h, this reaction mixture also produced **7** in 50% yield (entry 12).

Considering all these observations and recalling previous work[17,18] on the reduction of **A** with zinc in acetic acid (Scheme 1), we envisaged the presence of an amino group in **1** to be responsible for the differing behaviour of the reduction of the aldehyde functions in **A** and **1**. The reduction reaction may be rationalised by considering the initial reduction of the formyl group at the 3-position of **1** by Zn-acetic acid to corresponding hydroxymethyl derivative **3** (Scheme 2). Elimination of water from the protonated species **4** forms the α,β–unsaturated iminium salt **5**, which on further reduction gives **2**. Whereas the imminium species **5**, generated from the *N*-alkyl amines **1h–j** or from unsubstituted aminochromone **1k**, undergoes ready hydrolysis to the α,β–unsaturated ketone **6**, which is further reduced to 4-hydroxy-3-methylcoumarin **7**. The greater reactivity of vinylogous amides **1h**–**k** than the vinylogous anilides **1a**–**g** may be responsible for altering the course of the reaction.[32,33]

In conclusion, we have reported an amino-controlled reduction of an aldehyde to a methyl group by Zn in acetic acid. 2(*N*-Arylamino)chromone-3-carbaldehydes produced the corresponding 2-amino-3-methylchromones, whereas 2-amino- or 2-(*N*-alkylamino)-chromone-3-carbaldehydes produced the corresponding 4-hydroxy-3-methylcoumarin. The reduction process is mild enough for alkene, alkyne, benzylic and aromatic *C*-halogen bonds to survive.

Experimental

The recorded melting points are uncorrected. IR spectra were recorded in KBr on a Shimadzu FTIR spectrophotometer, IR Affinity-1, ^{1}H and ^{13}C NMR spectra were obtained on Bruker 300 or 400 instruments (^{1}H at 300 MHz or 400 MHz and ^{13}C at 75 MHz, or 100 MHz respectively) for solutions in $CDCl_3$. Mass spectra were obtained on a Qtof micro YA 263 instrument and elemental analysis on a PerkinElmer 240c elemental analyser. Light petroleum refers to the fraction with b.p. 60–80 °C. 2-Aminochromone-3-carbaldehydes **1** were prepared following a literature procedure.[27] All other chemicals used were of commercial grade and were used as such.

*Reduction of 2-[(N-substituted or N-unsubstituted)amino]chromone-3-carbaldehydes (**1**) with Zn in acetic acid; general procedure*

The 2-aminochromone-3-carbaldehyde derivative **1** (0.25 mmol) was heated under reflux in acetic acid (5 mL) in the presence of an excess of Zn powder (1.25 mmol) for 4 h. The reaction mixture was filtered and the residue was washed with methanol. All the washings and filtrate were taken together and solvent was removed under reduced pressure. Ice-water (10 g) was added to the concentrate to produce a semi solid mass for **2a**–**e**, whereas for reactions with **1f**–**k**, a solid mass was obtained. The semi-solid or solid mass was dissolved in $CHCl_3$ (10 mL), the $CHCl_3$ solution was washed with water (2 × 10 mL), dried over Na_2SO_4 and purified by flash chromatography over silica gel (100-200 mesh) using 50% light petroleum in toluene for **2a**–**g** and 10% ethyl acetate in toluene for **7**. Compound **7** was further crystallised from methanol.

*3,6-Dimethyl-2-[(*N-*methyl*-N-*phenyl)amino]chromone* (**2a**): White crystalline solid; m.p. 90–92 °C; IR ν_{max}/cm^{-1}: 2984, 2916, 1608, 1560, 1390; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.99 (1H, d, *J* = 1.2 Hz, H-5), 7.42 (1H, dd, *J* = 8.4, 1.2 Hz, H-7), 7.33–7.30 (2H, m, ArH), 7.28 (1H, d, *J* = 8.4 Hz, H-8), 7.04–7.01 (1H, m, ArH), 6.97–6.95 (2H, m, ArH), 3.48 (3H, s, CH_3-*N*), 2.46 (3H, s, 6-CH_3), 1.71 (3H, s, 3-CH_3); MS: (+ve ion electrospray): *m/z* 280 (M + H$^+$), 302 (M + Na$^+$). Anal. calcd for $C_{18}H_{17}NO_2$: C, 77.40; H, 6.13; N, 5.01; found: C, 77.32; H, 6.09; N, 4.97%.

*2-[(*N-*Allyl*-N-p-*tolyl)amino]-3,6-dimethylchromone* (**2b**): White crystalline solid; m.p. 108–110 °C; IR ν_{max}/cm^{-1}: 2988, 2916, 1608, 1553, 1396; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.98 (1H, d, *J* = 1.6 Hz, H-5), 7.40 (1H, dd, *J* = 8.4, 1.6 Hz, H-7), 7.24 (1H, d, *J* = 8.4 Hz, H-8), 7.09 (2H, d, *J* = 8.4 Hz, H-3′ and H-5′), 6.90 (2H, d, *J* = 8.4 Hz, H-2′ and H-6′), 6.04–5.97 (1H, m, H-vinylic), 5.30–5.26 (1H, m, H-vinylic), 5.18 (1H, dd, *J* = 10.4, 1.6 Hz, H-vinylic), 4.49–4.48 (2H, m, CH_2), 2.45 (3H, s, 6-CH_3), 2.31 (3H, s, 4′-CH_3), 1.63 (3H, s, 3-CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 179.2, 158.7, 152.4, 142.2, 134.4, 134.1, 133.6, 133.1, 129.9, 125.2, 122.2, 121.1, 117.4, 116.6, 106.1, 53.9, 20.9, 20.8, 10.7; MS: (+ve ion electrospray): *m/z* 320 (M + H$^+$), 342 (M + Na$^+$). Anal. calcd for $C_{21}H_{21}NO_2$: C, 78.97; H, 6.63; N, 4.39; found: C, 78.91; H, 6.59; N, 4.41%.

*3-Methyl-2-[(*N-*propargyl*-N-p-*tolyl)amino]chromone* (**2c**): White crystalline solid; m.p. 108–110 °C; IR ν_{max}/cm^{-1}: 2965, 2918, 1610, 1562, 1514, 1398; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 8.21 (1H, dd, *J* = 8.1, 1.5 Hz, H-5), 7.65–7.59 (1H, m, H-7), 7.43–7.35 (2H, m, H-6 and H-8), 7.14 (2H, d, *J* = 8.4 Hz, H-3′ and H-5′), 7.00 (2H, d, *J* = 8.4 Hz, H-2′ and H-6′), 4.57 (2H, d, *J* = 2.4 Hz, CH_2), 2.33 (3H, s, 4′-CH_3), 2.29 (1H, t, *J* = 2.4 Hz, H-alkyne), 1.65 (3H, s, 3-CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 179.3, 158.2, 154.3, 141.4, 133.7, 132.7, 130.1, 125.9, 124.7, 122.5, 121.1, 117.1, 107.5, 79.3, 72.8, 40.9, 20.8, 10.4; MS: (+ve ion electrospray): *m/z* 304 (M + H$^+$), 326 (M + Na$^+$). Anal. calcd for $C_{20}H_{17}NO_2$: C, 79.19; H, 5.65; N, 4.62; found: C, 79.09; H, 5.58; N, 4.57%.

*2-[*N-*(2-Butynyl)*-N-*phenyl)amino]-3,6-dimethylchromone* (**2d**): White crystalline solid; m.p. 82–84 °C; IR ν_{max}/cm^{-1}: 2987, 2914, 1610, 1566, 1394; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 8.00 (1H, d, *J* = 2.0 Hz, H-5), 7.43 (1H, dd, *J* = 8.4, 2.0 Hz, H-7), 7.33–7.29 (3H, m, ArH), 7.06–7.04 (2H, m, ArH), 7.03 (1H, d, *J* = 8.4 Hz, H-8), 4.52 (2H, q, *J* = 2.0 Hz, CH_2), 2.46 (3H, s, 6-CH_3), 1.78 (3H, t, *J* = 2.0 Hz, CH_3), 1.71 (3H, s, 3-CH_3); MS: (+ve ion electrospray): *m/z* 318 (M + H$^+$), 340 (M + Na$^+$). Anal. calcd for $C_{21}H_{19}NO_2$: C, 79.47; H, 6.03; N, 4.41; found: C, 79.38; H, 5.98; N, 4.38%.

*2-[*N-*(*o-*Bromobenzyl)*-N-p-*tolyl)amino]-3,6-dimethylchromone* (**2e**): White crystalline solid; m.p. 120–122 °C; IR n_{max}/cm^{-1}: 3114, 2920, 1614, 1566, 1512, 1388; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.96 (1H, br s, H-5), 7.57 (1H, br d, *J* = 8.4 Hz, H-7), 7.43 (1H, br d, *J* = 7.6 Hz, H-3″), 7.37 (1H, dd, *J* = 7.6, 2.0 Hz, H-6″), 7.26–7.22 (1H, m, H-4″), 7.20 (1H, d, *J* = 8.4 Hz, H-8), 7.13–7.10 (1H, m, H-5″), 7.08 (2H, d, *J* = 8.0 Hz, H-3′ and H-5′), 6.89 (2H, d, *J* = 8.0 Hz, H-2′ and H-6′), 5.16 (2H, s, CH_2), 2.43 (3H, s, 6-CH_3), 2.30 (3H, s, 4′-CH_3), 1.71 (3H, s, 3-CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 179.3, 158.3, 152.4, 142.4, 136.9, 134.5, 133.8, 133.1, 132.9, 130.0, 128.8, 128.3, 127.7, 125.1, 122.4, 122.1, 120.4, 116.8, 107.1, 55.3, 20.9, 20.7, 10.8; MS: (+ve ion electrospray): *m/z* 448 (M + H$^+$), 450 (M + 2 + H$^+$), 470 (M + Na$^+$), 472 (M + 2 + Na$^+$). Anal. calcd for $C_{25}H_{22}BrNO_2$: C, 66.97; H, 4.95; N, 3.12; found: C, 66.93; H, 4.92; N, 3.09%.

*3-Methyl-2-(*N-*phenylamino)chromone* (**2f**): White crystalline solid; m.p. 194–196 °C; IR ν_{max}/cm^{-1}: 3235, 3080, 1631, 1599, 1541, 1417; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 8.20 (1H, dd, *J* = 7.8, 1.2 Hz, H-5), 7.56–7.51 (1H, m, H-7), 7.43–7.32 (5H, m, ArH), 7.29 (1H, br d, *J* = 8.4 Hz, H-8), 7.21–7.16 (1H, m, H-6), 6.69 (1H, br s, exchangeable, NH), 2.10 (3H, s, 3-CH_3); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 176.1, 157.3, 152.9, 137.4, 132.0, 129.4, 125.8, 124.8, 124.6, 122.7, 121.5, 116.6, 96.3, 8.1; MS: (+ve ion electrospray): *m/z* 252 (M + H$^+$), 274 (M + Na$^+$). Anal. calcd for $C_{16}H_{13}NO_2$: C, 76.48; H, 5.21; N, 5.57; found: C, 76.40; H, 5.16; N, 5.53%.

*2-(*N-p-*Chlorophenylamino)-3-methylchromone* (**2g**): White crystalline solid; m.p. >250 °C; IR: ν_{max}/cm^{-1} 3242, 3077, 1640, 1602, 1545, 1420; ^{1}H NMR (DMSO-d_6, 300 MHz): δ 9.21 (1H, br s, exchangeable, NH), 7.98 (1H, dd, *J* = 7.8, 1.2 Hz, H-5), 7.66–7.61 (1H, m, ArH), 7.45–7.37 (6H, m, ArH), 1.99 (3H, s, 3-CH_3); MS: (+ve ion electrospray): *m/z* 286 (M + H$^+$), 288 (M + 2 + H$^+$), 308 (M + Na$^+$), 310 (M + 2 + Na$^+$). Anal. calcd for $C_{16}H_{12}ClNO_2$: C, 67.26; H, 4.23; N, 4.90; found: C, 67.19; H, 4.18; N, 4.86%.

3,6-Dimethyl-4-hydroxycoumarin (**7**): White crystalline solid; m.p. 255–256 °C (lit.[30] 252–254 °C; lit.[31] 262–263 °C); IR ν_{max}/cm^{-1}: 3324, 3149, 2912, 2870, 1662, 1618, 1581, 1504; ^{1}H NMR (DMSO-d_6, 300 MHz): δ 11.17 (1H, br s, exchangeable, OH), 7.69 (1H, d, *J* = 1.2 Hz, H-5), 7.39 (1H, dd, *J* = 8.4, 1.2 Hz, H-7), 7.24 (1H, d, *J* = 8.4 Hz, H-8), 2.37 (3H, s, CH_3-6), 1.99 (3H, s, CH_3-3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 163.3, 159.9, 149.8, 133.0, 132.2, 122.6, 116.0, 115.8, 100.1, 20.5, 9.8; MS: (+ve ion electrospray): *m/z* 191 (M + H$^+$), 213 (M + Na$^+$).

We gratefully acknowledge CSIR, New Delhi [Project no. 02(0029)/11/EMR-II] for financial assistance; DST-FIST for instrumental help at RKMVC College; University of Kalyani and IICB, Jadavpur for spectral analysis and finally the college authority for providing other research facilities. J. G. thanks CSIR for Senior Research Fellowship.

Received 16 August 2015; accepted 15 November 2015
Paper 1503548 doi: 10.3184/174751915X14477880702453
Published online: 1 December 2015

References

1 M. Mazzei, A. Balbi, G. Roma, M. Di Braccio, G. Leoncini, E. Buzzi and M. Maresca, *Eur. J. Med. Chem.,* 1988, **23**, 237.
2 J. Morris, D. G. Wishka and Y. Fang, *J. Org. Chem.,*1992, **57**, 6502.
3 G. Roma, M. DiBraccio, A. Carrieri, G. Grossi, M. G. Signorello and A. Carotti, *Bioorg. Med. Chem.,* 2003, **11**, 123.
4 Y. D. Jung, M. S. Kim, K. S. Lee, I. C. Kang, A. S. Nah, D. U. Song, S. Y. Yang, J. K. Kim and B. W. Ahu, *Pharmacol. Res.,* 1999, **40**, 423.
5 Y. -H. Kuan, R. –H. Lin, H. –Y. Lin, L. –J. Huang, C. –R. Tsai, L. –T. Tsao, C. –N. Lin, L. –C. Chang and L. –P. Wang, *Biochem. Pharmacol.,* 2006, **71**, 1735.
6 T. Akama, Y. Shida, T. Sugaya, H. Ishida, K. Gomi and M. Kasai, *J. Med. Chem.,* 1996, **39**, 3461.
7 S. M. Lee, PCT WO2007/073022; *Chem. Abstr.,* 2007, **147**, 96337.

8 M. Vala, M. Weiter, G. Rajtrova, S. Nespurek, P. Toman and J. Sworakowski, *Nonlinear Optics, Quantum Optics* 2007, **37**, 53.
9 J. B. Harborne, T-J. Mabry and H. Mabry, *The flavonoids*. Academic Press, New York, 1975.
10 G. P. Ellis, *Heterocyclic compounds*, ed. A. Weissberger. Wiley-Interscience, New York, 1977, Vol. 31, pp. 903-1083.
11 A. Groweiss, J. H. Cardillena and R. M. Boyd, *J. Nat. Prod.,* 2000, **63**, 1537.
12 L. Liu, S. Liu, S. Niu, L. Guo, X. Chen and Y. Che, *J. Nat. Prod.,* 2009, **72**, 1482.
13 G. L. Korkina and L. B. Afanasev, *Advances in pharmacology*, ed. H. Sies. Academic Press, San Diego, 1997, Vol. 38, pp. 151-163.
14 D. E. Guinn, J. B. Summers, H. R. Heyman, R. G. Conway, D. A. Rhein, D. H. Albert, T. Magoc and G. W. Carter, *J. Med. Chem.,* 1992, **35**, 2055.
15 T. Dubufett, A. Newman-Taneredi, D. Cussac, V. Audinot, A. Loutz, M. J. Millan and G. Lavielle, *Bioorg. Med. Chem. Lett.,* 1999, **9**, 2059.
16 C. Quiney, D. Dauzonne, C. Kern, J. –D. Fourneron, J. -C. Izard, R. M. Mohammad, J. –P. Kolb and C. Billard, *Leukemia Res.,* 2004, **28**, 851.
17 C. Bandyopadhyay, K. R. Sur and H. K. Das, *J. Chem. Res. (S)*, 1999, 598; *J. Chem. Res. (M)*, 1999, 2561.
18 S. P. Dey, D. K. Dey, A. K. Mallik and L. Dahlenburg, *J. Chem. Res*., 2007, 89.
19 A. Nohara, T. Umetani and Y. Sanno, *Tetrahedron*, 1974, **30**, 3553.
20 G. H. Posner, A. W. Runquist and M. J. Chapdelaine, *J. Org. Chem.,* 1977, **42**, 1202.
21 G. –B. Liu, J. –L. Xu, M. Geng, R. Xu, R. –R. Hui, J. –W. Zhao, Q. Xu, H. –X. Xu and J. –X. Li, *Bioorg. Med. Chem.,* 2010, **18**, 2864.
22 C. K. Ghosh and S. Bhattacharyya, *Indian J. Chem*., 1997, **36B**, 267.
23 A. Schonberg, N. Badran and N. A. Starkowsky, *J. Am. Chem. Soc.,* 1953, **75**, 4992.
24 S. K. Mukherjee, S. Raychaudhuri and T. R. Seshadri, *Indian J. Chem.,* 1969, **7**, 1070.
25 A. A. Ambartsumyan, T. T. Vasil'eva, O. V. Chakhovskaya, N. E. Mysova, V. A. Tuskaev, V. N. Khrustalev and K. A. Kochetkov, *Russ. J. Org. Chem.,* 2012, **48**, 451.
26 G. Singh, M. P. S. Ishar, V. Gupta, M. Kalyan and S. S. Bhella, *Tetrahedron*, 2007, **63**, 4773.
27 S. Maiti, T. M. Lakshmykanth, S. K. Panja, R. Mukhopadhyay, A. Datta and C. Bandyopadhyay, *J. Heterocycl. Chem*., 2011, **48**, 763.
28 P. Biswas, J. Ghosh, S. Maiti and C. Bandyopadhyay, *Tetrahedron Lett*., 2014, **55**, 6882.
29 C. Bandyopadhyay, K. R. Sur, R. Patra and S. Banerjee, *J. Chem. Res. (S)*, 2003, 459; *J. Chem. Res. (M),* 2003, 0847.
30 P. D. Re and E. Sandri, *Chem. Ber*., 1960, **93**, 1085.
31 D. C. Dittmer, Q. Li and D. V. Avilov, *J. Org. Chem.,* 2005, **70**, 4682.
32 A. Alberola, A. Gonzalez-Ortega, M. L. Sadaba and M. C. Sanudo, *J. Chem. Soc., Perkin Trans., 1*, 1988, 4061.
33 T. Ghosh and C. Bandyopadhyay, *Tetrahedron Lett*., 2004, **45**, 6169.