$NiFe_2O_4$ nanoparticles: A green and reusable heterogeneous catalyst for the synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones

Roghaiieh Meghyasi, Javad Safaei-Ghomi* and Mahboubeh A. Sharif

Department of Chemistry, Qom Branch, Islamic Azad University, Iran

$NiFe_2O_4$ nanoparticles were used as an efficient catalyst for the preparation of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones by the multi-component condensation reaction of arylamines, acetylenedicarboxylates and isatins under reflux conditions in ethanol.

Keywords: spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-dione; isatin; $NiFe_2O_4$ nanoparticles; One-pot; robust catalyst

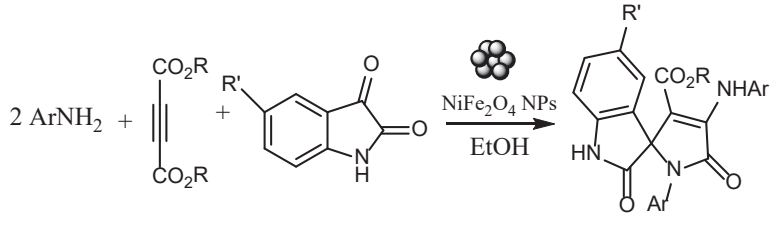
Introduction

Spirooxindoles represent an important class of compounds owing to their wide range of biological activities such as antiproliferative,[1] anticancer,[2] MDM2 inhibitors[3] and can also serve as synthetic intermediates for many kinds of pharmaceuticals or drug precursors.[4] Therefore, the development of simple methods for the synthesis of spirooxindoles is a major challenge and an interesting field in chemistry. Multicomponent reaction is one of the most common methods that have been utilised for the synthesis of a variety of biologically active compounds. Undoubtedly, the synthesis of spirooxindoles through multicomponent reactions (MCR) has been paid much attention due to experimental simplicity, excellent synthetic efficiency, inherent atom economy, and low environmental impact.[5,6] The synthesis of spirooxindoles has been reported in the presence of diverse catalysts including DBU,[7] piperidine,[8] ZnS nanoparticle,[9] $BF_3{\cdot}OEt_2$,[10] *p*-toluenesulfonic acid[11,12] and $NaHCO_3$.[13] However, some of the reported methods tolerate disadvantages including long reaction times, harsh reaction conditions and use of toxic and non-reusable catalyst. Consequently, to avoid these limitations, the searching of an efficient, easily available catalyst with high catalytic activity for the preparation of spirooxindoles is still favoured. Ideally, utilising environmental and green catalysts which can be simply recycled at the end of reactions has received important attention in recent years. To overcome the separation limitations of the nanocatalysts, magnetic materials have used as recoverable catalysts.[14,15]

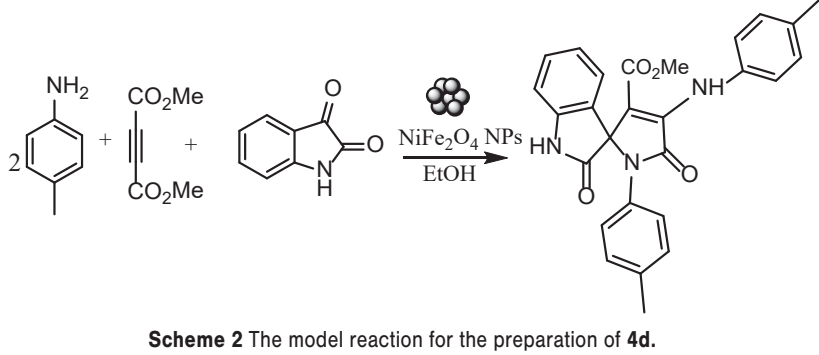
Herein we wish to report the synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones by the multi-component condensation reaction of arylamines, acetylenedicarboxylates and isatins in the presence of $NiFe_2O_4$ nanoparticles under reflux conditions in ethanol (Scheme 1).

Results and discussion

To optimise the reaction conditions, the condensation reaction of 4-methylaniline, dimethyl acetylenedicarboxylate and isatin was selected as a model study to examine the effects of the catalyst and solvent for the synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones (Scheme 2). A wide variety of catalysts including piperidine, $ZnCl_2$, $NiCl_2$, NiO, $FeCl_3$, Fe_3O_4 and $NiFe_2O_4$ NPs were employed to test their efficacy for the synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones. Then, we optimised the amount of $NiFe_2O_4$ NPs required; the optimum amount was found to be 0.3 mol%. Also, we examined the reaction in different solvents including water DMF, acetonitrile and ethanol. Ethanol was found to be the best solvent, in which the product was obtained in 93% yield (Table 1). Unfortunately, when the model reaction was carried out in water, the desired product was only obtained in 60% yield.



Scheme 1 Synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones using $NiFe_2O_4$ NPs.



Scheme 2 The model reaction for the preparation of **4d.**

* Correspondent. E-mail: safaei@kashanu.ac.ir

Table 1 Optimisation of reaction conditions using different catalysts[a]

Entry	Solvent (reflux)	Catalyst/mol%	Time/h	Yield/%[b]
1	EtOH	----------	14	trace
2	EtOH	piperidine (2)	10	28
3	EtOH	$ZnCl_2$ (3)	6	37
4	EtOH	$NiCl_2$ (4)	5	45
5	EtOH	NiO (3)	4	55
6	EtOH	$FeCl_3$ (4)	4	40
7	EtOH	Fe_3O_4 (3)	4	51
8	H_2O	$NiFe_2O_4$ NPs (0.3)	1.5	60
9	DMF	$NiFe_2O_4$ NPs (0.3)	1.5	74
10	CH_3CN	$NiFe_2O_4$ NPs (0.3)	1.5	81
11	EtOH	$NiFe_2O_4$ NPs (0.2)	1.5	91
12	**EtOH**	**$NiFe_2O_4$ NPs (0.3)**	**1.5**	**93**
13	EtOH	$NiFe_2O_4$ NPs (0.4)	1.5	93

[a]4-methylaniline (4 mmol), dimethyl acetylenedicarboxylate (2 mmol) and isatin (2 mmol).
[b]Isolated yield.

The above results obviously show the present catalytic procedure is extendable to a wide variety of substrates to construct a diversity-oriented library of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones (Table 2). An important feature of this method is that both electron-releasing and withdrawing groups give excellent yields.

The recoverability of the nano-$NiFe_2O_4$ catalyst was examined for the synthesis of product **4d** and it was found that product yields decreased to a small extent on each reuse (run 1, 93%; run 2, 93%; run 3, 92%; run 4, 92%; run 5, 91%). In the recycling procedure of $NiFe_2O_4$ NPs, after completion of the reaction, 10 mL ethanol was added and magnet was introduced into the mixture in the form of a magnetic stirrer bar and catalyst was separated magnetically.

In conclusion, we have developed a straightforward and efficient approach to synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones by the multi-component condensation reaction of arylamines, acetylenedicarboxylates and isatins in the presence of $NiFe_2O_4$ nanoparticles under reflux conditions in ethanol. The method offers several advantages including rapid assembly of heterocyclic molecules, cleaner reaction profiles, high yields, shorter reaction times, simple experimental, reusability of the catalyst and little catalyst loading.

Experimental

The products were isolated and characterised by physical and spectral data. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker Avance-400 MHz spectrometers in the presence of tetramethylsilane as internal standard. The IR spectra were recorded on FTIR Magna 550 apparatus using with KBr plates. Melting points were determined on Electro thermal 9200, and are not corrected. The elemental analyses (C, H, N) were obtained from a Carlo ERBA Model EA 1108 analyser. Powder X-ray diffraction (XRD) was carried out on a Philips diffractometer of X'pert Company with monochromatised Cu Kα radiation (λ = 1.5406 Å). Microscopic morphology of products was visualised by SEM (MIRA 3 TESCAN).

Preparation of $NiFe_2O_4$ nanoparticles

The $NiFe_2O_4$ nanoparticles were prepared according to the procedure reported in the literature.[16] 3 M solution of sodium hydroxide (as the precipitating agent) was slowly mixed with salt solutions of 0.4 M ferric chloride ($FeCl_3 \cdot 6H_2O$) and 0.2 M nickel chloride ($NiCl_2 \cdot 6H_2O$). The pH of the solution was constantly monitored as the NaOH solution was added dropwise. The reactants were constantly stirred using a magnetic stirrer until a pH level of >12 was achieved. A specified amount of oleic acid (2–3 drops for total reacting solution of 75 mL) was added to the solution as the surfactant. The liquid precipitate was then brought to a reaction temperature of 80 ºC and stirred for 40 min. The product was cooled to room temperature and then washed twice with distilled water and ethanol to remove unwanted impurities and the excess surfactant from the prepared sample. The sample was centrifuged for 15 min at 2000 rpm and then dried overnight at above 80 ºC. The acquired substance was then grinded into a fine powder and then annealed for 10 h at 600 ºC.

*Synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones* (**4a–h**)*; general procedure*

A solution of arylamine (4 mmol), and isatin (2.0 mmol), acetylenedicarboxylate (2.0 mmol) and $NiFe_2O_4$ NPs (0.3 mol%) as catalyst in 10 mL ethanol was refluxed for about 90 min. After completion of the reaction, 10 mL ethanol added and magnet was introduced into the mixture in the form of a magnetic stirrer bar and catalyst was separated magnetically. The precipitated solid was filtered and washed with ethanol to give the pure product.

Methyl 4'-(3-nitroanilino)-1'-(3-nitrophenyl)-2,5'-dioxo-1,1',2,5'-tetrahydrospiro[indole-3,2'-pyrrole]-3'-carboxylate (**4a**): Yellow solid; m.p. 236–238 °C, (lit.[11] 238–240 °C); IR ν_{max}/cm^{-1} (KBr): 3345, 3277, 3115, 2949, 1727, 1693, 1652, 1615, 1526, 1482, 1265; ^{1}H NMR (400 MHz, DMSO-d_6): δ 3.31 (3H, s, OCH_3), 6.84 (d, *J* = 7.8 Hz, 1H, ArH), 6.95 (t, *J* = 8 Hz, 1H, ArH), 7.12–7.15 (m, 2H, ArH), 7.29 (t, *J* = 8 Hz, 1 H, ArH), 7.42 (s, 1H, ArH), 7.50–7.53 (m, 3 H, ArH), 7.97–8.05 (m, 2H, ArH), 8.15 (s, 1, ArH), 9.20 (s, 1H, NH), 10.90 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 51.2, 70.9, 109.8, 110.5, 115.8, 117.9, 120.6, 122.5, 124.5, 124.8, 127.8, 129.2, 130.6, 130.7, 132.5, 136.0, 140.5, 141.0, 143.2, 147.6, 147.9, 161.7, 165.5, 173.5 ppm; Anal.

Table 2 Synthesis of spiro[indole-3,2'-pyrrole]-2,5'(1*H*,1'*H*)-diones (**4 a–h**)[a]

Entry	Ar	R	R'	Product	Time/min	Yield/%[b]	M.p./ °C Found	M.p./°C ref Reported
1	3-NO_2C_6H4	CH_3	H	**4a**	100	89	236–238	238–240 [11]
2	4-CH_3C_6H4	CH_3	NO_2	**4b**	90	95	276–278	–
3	4-$OCH_3C_6H_4$	CH_3	Cl	**4c**	90	94	256–258	254–256 [11]
4	4-$CH_3C_6H_4$	CH_3	H	**4d**	90	93	229–231	229–231 [11]
5	4-$CH_3C_6H_4$	Et	H	**4e**	93	92	228–230	–
6	4-$CH_3C_6H_4$	Et	Cl	**4f**	93	94	248–250	247–249 [11]
7	4-$CH_3C_6H_4$	CH_3	CH_3	**4g**	96	91	249–251	249–250 [11]
8	4-$CH_3C_6H_4$	CH_3	Cl	**4h**	90	94	256–258	258–260 [11]

[a]Arylamines, acetylenedicarboxylates and isatins with $NiFe_2O_4$ NPs (0.3 mol%).
[b]Isolated yield.

calcd for $C_{25}H_{17}N_5O_8$: C, 58.26; H, 3.32; N, 13.59; found: C, 58.32; H, 3.38; N, 13.68%.

Methyl 4'-(4-methylanilino)-1'-(4-methylphenyl)-5-nitro-2,5'-dioxo-1,1',2,5'-tetrahydrospiro [indole-3,2'-pyrrole]-3'-carboxylate (**4b**): Yellow solid; m.p. 276–278 °C; IR ν_{max}/cm^{-1} (KBr): 3325, 3257, 2947, 1722, 1691, 1650, 1612, 1523, 1480, 1350; ^{1}H NMR (400 MHz, DMSO-d_6): δ 2.24 (s, 3H, CH_3), 2.28 (s, 3H, CH_3), 3.28 (3H, s, OCH_3), 6.74 (d, *J* = 7.8 Hz, 1H, ArH), 6.95 (d, *J* = 8 Hz, 2H, ArH), 7.02–7.20 (m, 6H, ArH), 7.56 (d, *J* = 8 Hz, 1H, ArH), 7.96 (s, 1H, ArH), 9.21 (s, 1H, NH), 10.85 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 20.4, 20.5, 50.7, 70.6, 104.7, 111.4, 122.3, 124.6, 126.3, 126.9, 128.5, 129.5, 129.6, 129.7, 132.3, 133.2, 137.1, 137.5, 142.1, 142.3, 162.4, 165.2, 174.2 ppm; Anal. calcd for $C_{27}H_{22}N_4O_6$: C, 65.05; H, 4.45; N, 11.24; found: C, 65.15; H, 4.51; N, 11.32%.

Methyl 5-chloro-4'-(4-methoxyanilino)-1'-(4-methoxyphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydrospiro[indole-3,2'-pyrrole]-3'-carboxylate (**4c**): Yellow solid; m.p. 256–258 °C, (lit.[11] 254–256 °C); IR ν_{max}/cm^{-1} (KBr): 3331, 3250, 2953, 2835, 1730, 1624, 1510, 1475, 1360, 1302; ^{1}H NMR (400 MHz, DMSO-d_6): δ 3.26 (s, 3H, OCH_3), 3.67 (s, 3H, OCH_3), 3.74 (s, 3H, OCH_3), 6.74 (d, *J* = 7.8 Hz, 2H, ArH), 6.92–7.05 (m, 4H, ArH), 7.14 (m, 2H, ArH), 7.25 (d, *J* = 8 Hz, 2H, ArH), 7.56 (d, *J* = 7.6 Hz, 1H, ArH), 9.06 (s, 1H, NH), 10.83 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 50.7, 55.1, 55.2, 70.7, 103.2, 111.3, 113.1, 114.2, 124.3, 124.6, 126.2, 127.1, 128.3, 128.5, 129.7, 132.5, 142.2, 142.6, 156.2, 158.7, 162.3, 165.3, 174.2 ppm; Anal. calcd for $C_{27}H_{22}ClN_3O_6$: C, 62.37; H, 4.26; N, 8.08; found: C, 62.45; H, 4.34; N, 8.02%.

Methyl 4'-(4-methylanilino)-1'-(4-methylphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydrospiro[indole-3,2'-pyrrole]-3'-carboxylate (**4d**): Yellow solid; m.p. 229–231 °C (lit.[11] 229–231 °C); IR ν_{max}/cm^{-1} (KBr): 3294, 3192, 3091, 2943, 1712, 1674, 1623, 1512, 1474; ^{1}H NMR (400 MHz, DMSO-d_6): δ 2.21 (s, 3H, CH_3), 2.28 (s, 3H, CH_3), 3.22 (s, 3H, OCH_3), 6.86 (d, *J* = 7.8 Hz, 1H, ArH), 6.92 (d, *J* = 8 Hz, 2H, ArH), 7.05 (t, *J* = 7.8 Hz, 1H), 7.08–7.15 (m, 6 H, ArH), 7.18 (t, *J* = 8 Hz, 1H, ArH), 7.35 (d, *J* = 7.8 Hz, 1 H, ArH), 9.08 (s, 1H, NH), 10.75 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 20.4, 20.5, 50.6, 71.0, 105.7, 110.1, 122.0, 122.1, 124.3, 125.7, 127.0, 128.5, 129.5, 129.9, 132.3, 132.9, 137.3, 137.5, 141.7, 143.2, 162.2, 165.6, 174.1 ppm; Anal. calcd for $C_{27}H_{23}N_3O_4$: C, 71.51; H, 5.11; N, 9.27; found: C, 71.55; H, 5.02; N, 9.38%.

Ethyl 4'-(4-methylanilino)-1'-(4-methylphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydrospiro[indole-3,2'-pyrrole]-3'-carboxylate (**4e**): Yellow solid; m.p. 228–230 °C; IR ν_{max}/cm^{-1} (KBr): 3335, 3283, 3032, 2914, 1700, 1544, 1512, 1473, 1442, 1376, 1346, 1293, 1252; ^{1}H NMR (400 MHz, DMSO-d_6): δ 0.97 (t, *J* = 7.2 Hz, 3H, CH_3); 2.19 (s, 3 H, CH_3), 2.24 (s, 3 H, CH_3), 3.92–4.02 (m, 2H, OCH_2), 6.71 (d, *J* = 8 Hz, 1 H, ArH), 6.84 (d, *J* = 8.4 Hz, 2H, ArH), 7.06–7.10 (m, 6H, ArH), 7.17–7.50 (m, 3H), 9.08 (s, 1H, NH), 10.80 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 13.1, 20.4, 20.5, 59.7, 70.9, 105.2, 111.3, 121.9, 124.8, 126.2, 126.7, 128.2, 128.4, 129.6, 129.7, 132.4, 132.7, 137.1, 137.6, 142.1, 142.2, 161.7, 165.4, 174.1 ppm; Anal. calcd for $C_{28}H_{25}N_3O_4$: C, 71.93; H, 5.39; N, 8.99; found: C, 71.99; H, 5.48; N, 8.85%.

Ethyl 5-chloro-4'-(4-methylanilino)-1'-(4-methylphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydrospiro [indole-3,2'-pyrrole]-3'-carboxylate (**4f**): Yellow solid; m.p. 248–250 ºC; (lit.[11] 247–249 ºC); IR ν_{max}/cm^{-1} (KBr): 3332, 3281, 3032, 2913, 1703, 1542, 1517, 1477, 1441, 1376, 1346, 1293, 1252, 854, 812, 774; ^{1}H NMR (400 MHz, DMSO-d_6): δ 0.66 (t, *J* = 7.2 Hz, 3H, CH_3); 2.21 (s, 3H, CH_3), 2.25 (s, 3H, CH_3), 3.65–3.75 (m, 2H, OCH_2), 6.75 (d, *J* = 8 Hz, 1 H, ArH), 6.95 (d, *J* = 8 Hz, 2H, ArH), 7.05–7.16 (m, 6H), 7.25 (m, 2H) 9.15 (s, 1H, NH), 10.88 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 13.0, 20.4, 20.5, 59.5, 70.9, 105.1, 111.4, 121.9, 124.7, 126.1, 126.9, 128.1, 128.4, 129.6, 129.8, 132.3, 132.8, 137.0, 137.6, 142.1, 142.3, 161.8, 165.5, 174.2 ppm; Anal. calcd for $C_{28}H_{24}ClN_3O_4$: C, 67.00; H, 4.82; N, 8.37; found: C, 67.09; H, 4.73; N, 8.24%.

Methyl 5-methyl-4'-(4-methylanilino)-1'-(4-methylphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydro spiro[indole-3,2'-pyrrole]-3'-carboxylate (**4g**): Yellow solid, m.p. 249–251 ºC; (lit.[11] 249–250 ºC); IR ν_{max}/cm^{-1} (KBr): 3361, 3273, 3023, 2950, 2912, 1672, 1632, 1545, 1515, 1495, 1432, 1391, 1350, 1290, 1252, 1233, 1197, 1108; ^{1}H NMR (400 MHz, DMSO-d_6): δ 2.21–2.24 (6H, 2 CH_3), 2.28 (s, 3H, CH_3), 3.28 (s, 3H, OCH_3), 6.64 (d, *J* = 7.6 Hz, 1H, ArH), 6.87 (d, *J* = 7.6 Hz, 2H, ArH), 6.98 (d, *J* = 7.8 Hz, 1H, ArH), 7.03 (d, *J* = 7.8 Hz, 2H, ArH), 7.11–7.07 (m, 4H, ArH), 7.14 (s, 1H, ArH), 9.06 (s, 1H, NH), 10.64 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 20.4, 20.5, 20.7, 50.7, 71.0, 105.9, 109.8, 122.2, 124.7, 125.6, 126.8, 128.4, 129.5, 130.3, 131.1, 132.4, 132.9, 137.2, 137.4, 140.4, 141.6, 162.3, 165.5, 174.1 ppm; Anal. calcd for $C_{28}H_{25}N_3O_4$: C, 71.93; H, 5.39; N, 8.99; found: C, 72.04; H, 5.48; N, 8.90%.

Methyl 5-chloro-4'-(4-methylanilino)-1'-(4-methylphenyl)-2,5'-dioxo-1,1',2,5'-tetrahydro spiro[indole-3,2'-pyrrole]-3'-carboxylate (**4h**): Yellow solid; m.p. 256–258 ºC; (lit.[11] 258–260 ºC); IR ν_{max}/cm^{-1} (KBr): 3343, 3274, 3032, 2950, 2918, 1703, 1544, 1512, 1475, 1440, 1354, 1292, 1254, 1195; ^{1}H NMR (400 MHz, DMSO-d_6): δ 2.24 (s, 3H, CH_3), 2.29 (s, 3H, CH_3), 3.26 (s, 3H, OCH_3), 6.76 (d, *J* = 7.8 Hz, 1H, ArH), 6.93 (d, *J* = 8 Hz, 2H, ArH), 7.08–7.15 (m, 6H, ArH), 7.25 (m, 2H, ArH), 9.11 (s, 1H, NH), 10.87 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): δ 20.4, 20.5, 50.7, 70.8, 104.8, 111.4, 122.4, 124.7, 126.9, 128.0, 128.4, 129.6, 129.7, 129.8, 132.2, 133.1, 137.0, 137.6, 142.1, 142.2, 162.3, 165.3, 174.1 ppm; Anal. calcd for $C_{27}H_{22}ClN_3O_4$: C, 66.46; H, 4.54; N, 8.61; found: C, 66.35; H, 4.50; N, 8.50%.

The authors acknowledge a reviewer who provided helpful insights. The authors gratefully acknowledge the financial support of this work by the Research Affairs Office of the Qom Branch, Islamic Azad University, I. R. Iran. Also authors are grateful to Dr. Hossein Shahbazi-Alavi for their help.

Electronic Supplementary Information

The spectral data are available through:
stl.publisher.ingentaconnect.com/content/stl/jcr/supp-data

Received 26 February 2016; accepted 16 April 2016
Paper 1603945 doi: 10.3184/174751916X14640003438169
Published online: 13 June 2016

References

1 B. Yu, X.J. Shi, P.P. Qi, D.Q. Yu and H.M. Liu, *J. Steroid Biochem. Mol. Biol*., 2014, **141**, 121.
2 B. Yu, Z. Yu, P.P. Qi, D.Q. Yu and H.M. Liu, *Eur. J. Med. Chem*., 2015, **95**, 35.
3 Y. Zhao, L. Liu, W. Sun, J. Lu, D. McEachern, X. Li, S. Yu, D. Bernard, P. Ochsenbein, V. Ferey, J.C. Carry, J.R. Deschamps, D. Sun and S. Wang, *J. Am. Chem. Soc*., 2013, **135**, 7223.
4 M.M.M. Santos, *Tetrahedron,* 2014, **52**, 9735.
5 J. Safaei-Ghomi, M.R. Saberi-Moghadam, H. Shahbazi-Alavi and M. Asgari-Kheirabadi, *J. Chem. Res*., 2014, **38**, 583.
6 J. Safaei-Ghomi, M. Navvab and H. Shahbazi-Alavi, *Ultrason. Sonochem*., 2016, **31**, 102.
7 P. Saluja, K. Aggarwal and J.M. Khurana, *Synth. Commun*., 2013, **43**, 3239.
8 S. Ahadi, Z. Yasaei and A. Bazgir, *J. Heterocyclic Chem*., 2010, **47**, 1090.
9 A. Dandia, V. Parewa, A.K. Jain and K.S. Rathore, *Green Chem*., **13**, 2011, 2135.
10 H. Gao, J. Sun and C.G. Yan, *J. Org. Chem*., 2014, **79**, 4131.
11 Y. Han, Q. Wu, J. Sun and C.G. Yan, *Tetrahedron,* 2012, **68**, 8539.
12 K. Jadidi, R. Ghahremanzadeh and A. Bazgir, *Tetrahedron,* 2009, **65**, 2005.
13 T. Shen, Y. Zhou, F. Che, J. Yu, Y. Lin and Q. Song, *J. Chem. Res*., 2015, **39**, 115.
14 J. Safaei-Ghomi, H. Shahbazi-Alavi and E. Heidari-Baghbahadorani, *J. Chem. Res*., 2015, **39**, 410.
15 L.M. Rossi, N.J.S. Costa, F.P. Silva and R. Wojcieszak, *Green Chem*., 2014, **16**, 2906.
16 K. Maaz, S. Karim, A. Mumtaz, S.K. Hasanain, J. Liu and J.L. Duan, *J. Magn. Mater*., 2009, **321**, 1838.