RSC Advances

PAPER

View Article Online
View Journal | View Issue

Cite this: *RSC Adv.*, 2014, **4**, 33582

One-pot synthesis of new derivatives of pyran using *N*-halosulfonamide†

Ramin Ghorbani-Vaghei,* Zahra Salimi, Seyedeh Mina Malaekehpoor, Fatemeh Eslami and Samira Noori

Received 25th May 2014
Accepted 28th July 2014

DOI: 10.1039/c4ra04929b

www.rsc.org/advances

In this study *N*,*N*,*N*′,*N*′-tetrabromobenzene-1,3-disulfonamide was used as a reagent for the three-component one-pot synthesis of some novel 9-aryl-9*H*-2,4,5,7-tetramethyl-diuracilopyrans, which has not been published before, as well as 9-aryl-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-diones in excellent yields. This is obtained from the condensation of aromatic and heterocyclic aldehydes and *N*,*N*-dimethylbarbituric acid or cyclohexane-1,3-diones in ethanol at room temperature.

Introduction

An important challenge in organic synthesis is development of powerful methods for the synthesis of complex heterocyclic molecules from readily available reagents.[1] Multicomponent condensation reactions (MCRs) have recently been discovered to be a powerful method for the synthesis of organic compounds. High selectivity, high atom-economy, simplicity and relatively high speed are central issues in multicomponent reactions.[2–4]

In recent years, 4*H*-pyrans and their derivatives have attracted intense interest due to their useful biological and pharmacological properties, such as being anti-inflammatory,[5] antimicrobial,[6] anticonvulsant activities,[7] anticoagulant, spasmolytic, anticancer and anti-anaphylactic agents.[8] There are widely applied in photodynamic therapy,[9] and used as fluorescent dye materials[10] for visualization of biomolecules,[11,12] and in laser technology[13] (Fig. 1). Furthermore, substituted 4*H*-pyrans constitute a structural unit of a series of natural products.[14] Especially pyran diones, that belong to the naturally-occurring compounds, are used as reactive intermediates for the synthesis of various important compounds which have recently drawn great attention.

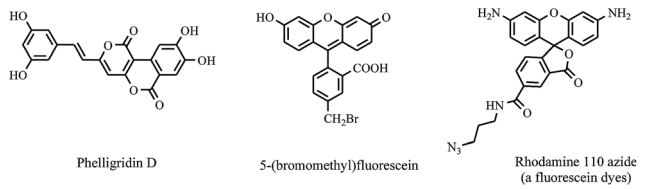


Fig. 1 Some examples of pyran derivatives with different properties.

Results and discussion

To pursue our interest in the application of *N*,*N*,*N*′,*N*′-tetrabromobenzene-1,3-disulfonamide [TBBDA],[15] (Fig. 2) in organic synthesis,[15–20] herein we introduce a facile, three-component one-pot synthesis of new 9-aryl-9*H*-2,4,5,7-tetramethyl-diuracilopyran (route A), which has not been published before, as well as 9-aryl-3,4,6,7-tetrahydro-2*H*-xanthene-1,8(5*H*,9*H*)-dione (route B). This is obtained from the condensation of various aromatic and heteroaromatic aldehydes and *N*,*N*-dimethylbarbituric acid or cyclohexane-1,3-dione in the presence of TBBDA as reagent in ethanol at room temperature (Scheme 1).

It is easy to prepare TBBDA and it is stable under atmospheric conditions for two months. Furthermore, TBBDA is a non-volatile, inexpensive, and safe reagent. After completion of the reaction, the sulphonamide was recovered, brominated and used for several times.

Initial efforts were focused on optimizing conditions for the formation of 9-(2-chlorophenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran using *N*,*N*-dimethylbarbituric acid and 2-chlorobenzaldehyde under various conditions (Table 1).

In this context, ethanol (EtOH) selected as best solvent for these reactions. Reactions in EtOH are generally considered environmentally safe, devoid of any carcinogenic effects, simple

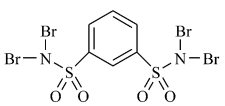
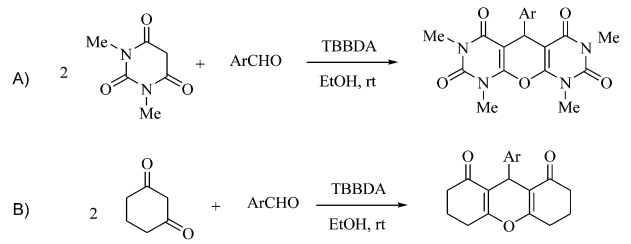


Fig. 2 The structure of TBBDA.

Department of Organic Chemistry, Faculty of Chemistry, Bu-Ali-Sina University, Hamedan, Iran. E-mail: rgvaghei@yahoo.com; Fax: +988118380709

† Electronic supplementary information (ESI) available. See DOI: 10.1039/c4ra04929b



Scheme 1 Synthesis of new derivatives of pyran using TBBDA.

Table 1 Optimization of reaction conditions for the synthesis of 9-(2-chlorophenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran[a]

Entry	Solvent	Amount of TBBDA (g)	Time (min)	Yield (%)
1	Ethanol	0	60	23
2	Ethanol	0.05	60	62
3	Ethanol	0.1	60	91
4	Ethanol	0.15	60	85
5	No solvent	0.1	60	41
6	Acetone	0.1	30	33
7	H_2O	0.1	30	42

[a] Experimental conditions: 2-chlorobenzaldehyde (1 mmol) and *N*,*N*-dimethylbarbituric acid (2 mmol).

to handle, cheaper to operate and especially important in industry.

We found that the reaction was rapid when using *N*,*N*,*N*′,*N*′-tetrabromobenzene-1,3-disulfonamide [TBBDA] (0.1 g, 60 min, entry 3). We then examined a wide variety of aromatic aldehyde and we observed that they successfully react with *N*,*N*-dimethylbarbituric acid or cyclohexane-1,3-dione. This clearly establishes the scope and generality of this method. As it is shown in Table 2, the electron withdrawing or donating groups on the phenyl rings did not have an influence on the reaction.

The probable mechanism of this reagent is that it releases Br^+ *in situ*, which can act as an electrophilic species.[15–20] Therefore, the mechanism shown in Scheme 2 may be suggested for the conversion of the various aldehyde, *N*,*N*-dimethylbarbituric acid, cyclohexane-1,3-dione to pyran derivatives.

Conclusions

In this study, we have developed a green one-pot synthesis of pyrans derivatives using [TBBDA] as new reagent. The conditions are mild and a wide range of functional groups can be tolerated. This method offers several advantages such as inexpensive reagent, short reaction times, easy synthetic procedure, good to high yields, simple work-up procedure and easy isolation.

Materials and equipment

All commercially available chemicals were obtained from Merck and Fluka and used without further purification unless otherwise stated. ^{1}H and ^{13}C-NMR spectra were recorded on Bruker Advance 400 FT NMR spectrometers (undertaken at University of Mazandaran, Iran). Infrared (IR) spectroscopy was performed on a Perkin Elmer GX FT-IR spectrometer. Mass spectra were recorded on a 5973 Network Mass Selective Detector Mass Spectrometer (undertaken at University of Tehran, Iran). Elemental analyses (C, H, N) were performed with a Elemental Combustion System 4010 (undertaken at University of Tehran, Iran).

Typical procedure for the preparation of 9-(2-chlorophenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 4)

A mixture of *N*,*N*-dimethylbarbituric acid (0.312 g, 2 mmol), 2-chlorobenzaldehyde (0.140 g, 1 mmol), ethanol (2 mL) and TBBDA (0.1 g, 0.18 mmol) was stirred at room temperature for 60 min. The progress of the reaction was monitored by TLC [acetone/*n*-hexane (3 : 10)]. After completion of the reaction, the reaction mixture was filtered and washed with ethanol. The crude product was recrystallized from hot ethanol to afford the pure product as a white powder (91%). After evaporation of the ethanol, cold methylene dichloride (2 mL) was added, and reagent was recovered by filtration.

9-(2-Chlorobenzo[h]quinoline)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 1); white powder 88%; m.p. 273–275 °C; elem. anal. found: C, 59.94; H, 3.35; N, 13.08 calc. for $C_{26}H_{20}ClN_5O_5$: C, 60.29; H, 3.89; N, 13.52%. IR (KBr, ν_{max}/cm^{-1}): 3450, 3053, 2956, 1724, 1650; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 2.44 (s, 3H, OMe), 3.14 (s, 3H, OMe), 3.27 (s, 3H, OMe), 3.47 (s, 3H, OMe), 5.45 (s, 1H, CH), 7.80–7.90 (m, 5H, ArH), 8.46 (s, 1H, ArH), 8.99–9.01 (q, 1H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 28.2, 28.2, 29.3, 30.3, 52.8, 85.6, 89.2, 124.4, 125.2, 125.6, 127.2, 128.2, 128.7, 129.2, 129.5, 129.9, 134.2, 141.5, 145.6, 148.4, 150.6, 151.4, 158.5, 163.2, 163.4, 165.8; MS *m*/*z*: 517 (M^+).

9-(2-Chloroquinolin-3-yl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 2); opalescent powder 85%; m.p. 265–267 °C; elem. anal. found: C, 56.43; H, 3.59; N, 14.78 calc. for $C_{22}H_{18}ClN_5O_5$: C, 56.48; H, 3.88; N, 14.97%. IR (KBr, ν_{max}/cm^{-1}): 3406, 3063, 2955, 1676, 1646; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 2.44 (s, 3H, OMe), 2.89 (s, 3H, OMe), 3.11 (s, 3H, OMe), 3.13 (s, 3H, OMe), 3.21 (s, 3H, OMe), 3.25 (s, 3H, OMe), 3.45 (s, 3H, OMe), 3.49 (s, 3H, OMe), 5.11 (s, 1H, CH), 5.39 (s, 1H, CH), 7.58–7.61 (t, *J* 7.2, 1H, ArH), 7.67–7.71 (t, *J* 7.6, 1H, ArH), 7.78–7.81 (t, *J* 7.6, 1H, ArH), 7.84–7.86 (d, *J* 7.6, 1H, ArH), 7.88–7.92 (t, *J* 7.2, 1H, ArH), 7.96–7.98 (d, *J* 8.4, 1H, ArH), 8.01–8.04 (t, *J* 7.6, 2H, ArH), 8.32 (s, 1H, ArH), 8.43 (s, 1H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 28.2, 28.2, 29.3, 29.6, 30.3, 35.1, 52.8, 55.6, 85.6, 86.1, 89.2, 126.3, 127.0, 127.1, 127.7, 128.0, 128.3, 128.5, 128.7, 131.5, 132.3, 139.2, 141.9, 147.0, 149.2, 150.6, 151.4, 158.5, 161.5, 163.1, 165.7; MS *m*/*z*: 467 (M^+).

9-(4-Methoxyphenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 3); white powder 85%; m.p. 246–248 °C; elem. anal. found: C, 51.91; H, 4.09; N, 12.4 calc. for $C_{20}H_{20}N_4O_6$: C, 53.25; H, 4.89; N, 13.59%. IR (KBr, ν_{max}/cm^{-1}): 3451, 2964, 1715, 1674; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 2.46 (s, 3H, OMe), 3.11 (s, 3H, OMe), 3.21 (s, 3H, OMe), 3.39 (s, 3H, OMe),

Table 2 Synthesis of new derivatives of pyran using TBBDA

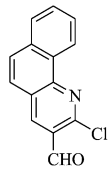
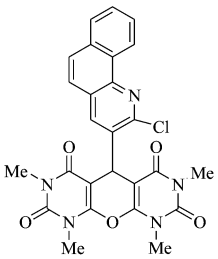
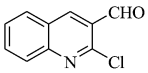
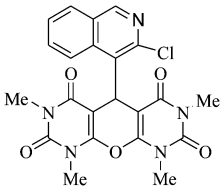
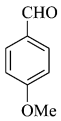
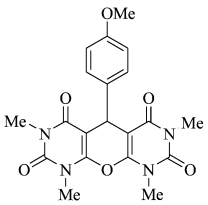
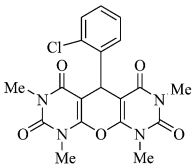
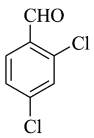
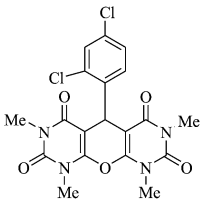
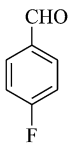
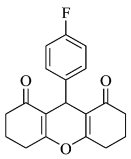
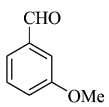
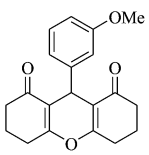
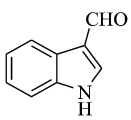
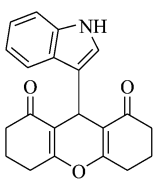
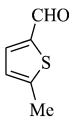
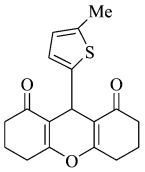
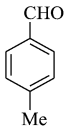
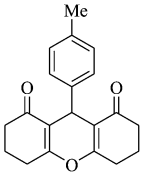
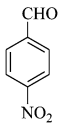
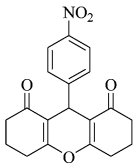
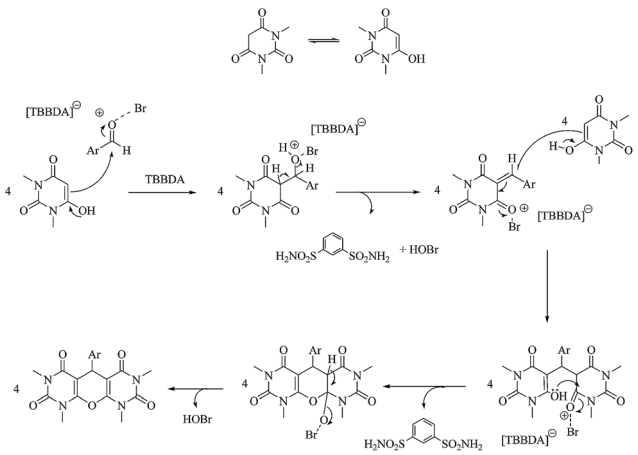
Entry	Aldehyde	Product	Time (min)	Yield[a] (%)	M.P. (°C)
1			60	88	273–275
2			30	85	265–267
3			100	85	246–248
4			60	91	199–201
5			25	82	258–259
6			120	61	266–268
7			120	66	199–201
8			180	63	268–269

Table 2 (*Contd.*)

Entry	Aldehyde	Product	Time (min)	Yield[a] (%)	M.P. (°C)
9			180	73	232–233
10			120	79	259–261
11			120	75	252–254

[a] Isolated yield.



Scheme 2 Suggested mechanism for synthesis of pyran derivatives.

3.73 (s, 3H, OMe), 5.05 (s, 1H, CH), 6.82–7.07 (s, 4H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 28.1, 28.2, 29.4, 30.1, 55.6, 56.0, 86.0, 90.6, 113.8, 126.7, 130.3, 150.571, 151.3, 158.6, 159.8, 162.6, 163.6, 166.0; MS *m*/*z*: 412 (M^+).

9-(2-Chlorophenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 4); white powder 91%; m.p. 199–201 °C; elem. anal. found: C, 52.97; H, 3.54; N, 12.70 calc. for $C_{19}H_{17}ClN_4O_5$: C, 53.75; H, 4.11; N, 13.44%. IR (KBr, ν_{max}/cm^{-1}): 3415, 3069, 2959, 1766, 1702, 1693, 1667; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 2.51 (s, 3H, OMe), 3.11 (s, 3H, OMe), 3.20 (s, 3H, OMe), 3.40 (s, 3H, OMe), 5.26 (s, 1H, CH), 7.23–7.37 (m, 3H, ArH), 7.46–7.48 (d, *J* 8, 1H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 28.1, 28.2, 29.2, 30.2, 52.8, 85.5, 89.3, 127.7, 129.4, 130.9, 131.9, 133.3, 150.5, 151.3, 158.4, 163.0, 163.3, 165.9; MS *m*/*z*: 415 (M^+-1).

9-(2,4-Dichlorophenyl)-9*H*-2,4,5,7-tetramethyl-diuracilopyran (Table 2, entry 5); white powder 82%; m.p. 258–259 °C; elem. anal. found: C, 48.82; H, 2.93; N, 12.22 calc. for $C_{19}H_{16}Cl_2N_4O_5$: C, 50.57; H, 3.57; N, 12.42 IR (KBr, ν_{max}/cm^{-1}): 3446, 3099, 2957, 1765, 1708, 1670; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 2.59 (s, 3H, OMe), 3.11 (s, 6H, 2 OMe), 3.40 (s, 3H, OMe), 5.23 (s, 1H, CH), 7.29–7.40 (m, 2H, ArH), 7.68–7.68 (d, *J* 2, 1H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 28.1, 28.2, 28.3, 28.4, 28.9, 29.2, 30.2, 52.2, 85.4, 89.1, 122.5, 127.1, 128.0, 128.7, 128.9, 128.9, 131.3, 132.1, 133.2, 133.3, 134.1, 134.3, 134.6, 135.9, 149.8, 150.5, 151.3, 158.4, 163.1, 163.2, 165.7, 166.3; MS *m*/*z*: 449 (M^+-1).

9-(4-Fluorophenyl)-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 6); white powder 61%; m.p. 266–268 °C; elem. anal. found: C, 72.75; H, 5.30; calc. for $C_{19}H_{17}FO_3$: C, 73.06; H, 5.49%. IR (KBr, ν_{max}/cm^{-1}): 2955, 1721, 1655; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.80–1.89 (m, 2H, CH_2), 1.91–1.98 (m, 2H, CH_2), 2.21–2.34 (m, 4H, $2CH_2$), 2.55–2.70 (m, 4H, $2CH_2$), 4.56 (s, 1H, CH), 7.00–7.04 (t, *J* 8.8, 2H, ArH), 7.19–7.22 (q, 2H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 20.3, 26.8, 30.7, 36.8, 114.9, 115.1, 115.7, 130.2, 130.3, 141.1, 141.1, 159.8, 162.2, 165.3, 196.8; MS *m*/*z*: 312 (M^+).

9-(3-Methoxyphenyl)-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 7); white powder 66%; m.p. 199–201 °C; elem. anal. found: C, 74.01; H, 6.07; calc. for $C_{20}H_{20}O_4$: C, 74.06; H, 6.21%. IR (KBr, ν_{max}/cm^{-1}): 3434, 2969, 2935, 2835, 1670, 1654; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.82–1.87 (m, 2H, CH_2), 1.92–1.98 (m, 2H, CH_2), 1.98–2.35 (m, 4H, $2CH_2$), 2.56–2.70 (m, 4H, $2CH_2$), 3.69 (s, 3H, OCH_3), 4.56 (s, 1H, CH), 6.68–6.71 (q, 2H, ArH), 6.73–6.75 (d, *J* 8, 1H, ArH), 7.10–7.14 (t, *J* 10,

1H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 20.3, 26.8, 31.1, 36.8, 55.2, 111.3, 114.8, 115.8, 120.5, 129.4, 146.4, 159.3, 165.3, 196.7; MS *m*/*z*: 324 (M^+).

9-(1*H*-Indole-3-yl)-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 8); opalescent powder 63%; m.p. 268–269 °C; elem. anal. found: C, 74.94; H, 5.49; N, 3.83; calc. for $C_{21}H_{19}NO_3$: C, 75.66; H, 5.74; N, 4.20%.IR (KBr, ν_{max}/cm^{-1}): 3415, 3058, 2946, 2895, 1676, 1656; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.79 (broad, 2H, CH_2), 1.92 (broad, 2H, CH_2), 2.24 (m, 4H, 2CH_2), 2.64–2.65 (m, 4H, 2CH_2), 4.87 (s, 1H, CH), 6.94–6.95 (t, *J* 7.2, 1H, ArH), 7.00 (m, 2H, ArH), 7.25–7.27 (d, *J* 8, 1H, ArH), 7.55–7.57 (d, *J* 8, 1H, ArH), 10.79 (s, 1H, NH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 20.4, 22.3, 26.9, 36.9, 111.8, 116.2, 118.5, 118.7, 119.3, 120.9, 124.2, 126.1, 136.6, 164.7, 196.8; MS *m*/*z*: 333 (M^+).

9-(5-Methylthiophen-2-yl)-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 9); pale yellow powder 73%; m.p. 232–233 °C; elem. anal. found: C, 68.44; H, 5.73; S, 9.11; calc. for $C_{18}H_{18}O_3S$: C, 68.76; H, 5.77; O, 15.27; S, 10.20%. IR (KBr, ν_{max}/cm^{-1}): 3313, 2957, 2936, 2892, 2818, 1671, 1618; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.85–1.93 (m, 2H, CH_2), 1.95–2.01 (m, 2H, CH_2), 2.29 (s, 3H, CH_3), 2.32–2.35 (m, 4H, 2CH_2), 2.55–2.68 (m, 4H, 2CH_2), 4.79 (s, 1H, CH), 6.47–6.50 (q, 2H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 15.3, 20.3, 25.8, 26.8, 36.8, 115.5, 124.3, 125.1, 137.7, 146.1, 165.5, 196.6; MS (*m*/*z*): 314 (M^+).

9-*p*-Tolyl-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 10); white powder 79%; m.p. 259–261 °C; elem. anal. found: C, 77.99; H, 6.63 calc. for $C_{20}H_{20}O_3$: C, 77.90; H, 6.54%. IR (KBr, ν_{max}/cm^{-1}): 3032, 2954, 2893, 1656, 1617; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.78–1.88 (m, 2H, CH_2), 1.92–1.97 (m, 2H, CH_2), 2.20 (s, 3H, CH_3), 2.22–2.33 (m, 4H, 2CH_2), 2.56–2.69 (m, 4H, 2CH_2), 4.54 (s, 1H, CH), 6.99–7.01 (d, *J* 8, 2H, Ph), 7.05–7.07 (d, *J* 8, 2H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 20.3, 21.0, 26.8, 30.8, 36.8, 116.1, 128.3, 128.9, 135.6, 142.1, 165.1, 196.7; MS (*m*/*z*): 308 (M^+).

9-(4-Nitrophenyl)-3,4,6,7-tetrahydro-2*H*-pyran-1,8(5*H*,9*H*)-dione (Table 2, entry 11); white powder 75%; m.p. 252–254 °C; elem. anal. found: C, 67.18; H, 4.91; N, 3.85; calc. for $C_{19}H_{17}NO_5$: C, 67.25; H, 5.05; N, 4.13%. IR (KBr, ν_{max}/cm^{-1}): 3071, 2949, 2874, 1660, 1617; ^{1}H-NMR (400 MHz, DMSO-d6) δ_H (ppm): 1.86–1.91 (m, 2H, CH_2), 1.93–1.99 (m, 2H, CH_2), 2.22–2.36 (m, 4H, 2CH_2), 2.58–2.71 (m, 4H, 2CH_2), 4.66 (s, 1H, CH), 7.47–7.49 (d, *J* 8.4, 2H, ArH), 8.07–8.09 (d, *J* 8.4, 2H, ArH); ^{13}C-NMR (100 MHz, DMSO-d6) δ_C (ppm): 20.2, 26.9, 32.0, 36.7, 114.8, 123.6, 129.9, 146.3, 152.4, 165.8; MS (*m*/*z*): 339 (M^+).

Acknowledgements

We would like to thank Bu-Ali Sina University, Center of Excellence in Development of Environmentally Friendly Methods for Chemical Synthesis (CEDEFMCS) for financial support of this study. Also, we would like to thank Zohreh Salimi for editing the manuscript.

Notes and references

1 P. Laszlo, in *Organic Reactions: Simplicity and Logic*, Wiley-VCH, New York, 1995.
2 C. O. Kappe, *Curr. Opin. Chem. Biol.*, 2002, **6**, 314.
3 A. Domling and I. Ugi, *Angew. Chem., Int. Ed.*, 2000, **39**, 3168.
4 J. Zhu and H. Bienayme, *Multicomponent Reactions*, Wiley-VCH, Weinheim, 2005.
5 J. P. Poupelin, G. Saint-Rut, O. Foussard-Blanpin, G. Narcisse, G. Uchida-Ernouf and R. Lacroix, *Eur. J. Med. Chem.*, 1978, **13**, 67–71.
6 S. C. Kuo, L. J. Huang and H. Nakamura, *J. Med. Chem.*, 1984, **27**, 539.
7 A. H. Bedair, N. A. El-Hady, M. S. A. El-Latif, A. H. Fakery and A. M. El-Agrody, *Farmaco*, 2000, **55**, 708.
8 L. Loy, G. Bonsignore, D. Secci and A. Calignano, *Eur. J. Med. Chem.*, 1993, **28**, 517.
9 S. M. Menchen, S. C. Benson, J. Y. L. Lam, W. Zhen, D. Sun, B. B. Rosenblum, S. H. Khan and M. Taing, U.S. Patent, US6583168, 2003, Chem. Abstr., 2003, 139, 54287f.
10 V. V. Rostovtsev, L. G. Green, V. V. Fokin and K. B. Sharpless, *Angew. Chem., Int. Ed.*, 2002, **41**, 2596.
11 O. Sirkeeioglu, N. Talinli and A. Akar, *J. Chem. Res.*, 1995, 502–506.
12 C. G. Knight and T. Stephens, *Biochem. J.*, 1989, **258**, 683–687.
13 M. Ahmad, T. A. King, D.-K. Ko, B. H. Cha and J. Lee, *J. Phys. D: Appl. Phys.*, 2002, **35**, 1473–1476.
14 S. Hatakeyama, N. Ochi, H. Numata and S. Takano, *J. Chem. Soc., Chem. Commun.*, 1988, 1202.
15 R. Ghorbani-Vaghei and H. Jalili, *Synthesis*, 2005, **7**, 1099.
16 R. Ghorbani-Vaghei, M. Amiri, R. Karimi-Nami and Z. Salimi, *RSC Adv*, 2013, **3**, 25924.
17 R. Ghorbani-Vaghei, H. Shahbazee and H. Veisi, *Tetrahedron Lett.*, 2012, **53**, 2325.
18 R. Ghorbani-Vaghei, R. Karimi-Nami, Z. Toghraei-Semiromi, M. Amiri, Z. Salimi and M. Ghavidel, *C. R. Chim.*, 2014, **17**, 324.
19 R. Ghorbani-Vaghei, R. Karimi-Nami, Z. Toghraei-Semiromi, M. Amiri and M. Ghavidel, *Tetrahedron*, 2011, **67**, 1930.
20 M. A. Zolfigol, R. Ghorbani-Vaghei, S. Mallakpour, G. Chehardoli, A. Ghorbani-Choghamani and A. Hosain Yazdi, *Synthesis*, 2006, **10**, 1631.

