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Chemoselective Synthesis of Tetraketones in Water Catalyzed by Nanostructured Diphosphate $Na_2CaP_2O_7$

Behrooz Maleki,[1] Massomeh Raei,[1] Heshmatollah Alinezhad,[2] Reza Tayebee,[1] and Alireza Sedrpoushan[3]

[1]Department of Chemistry, Hakim Sabzevari University, Sabzevar, 96179-76487, Iran
[2]Faculty of Chemistry, University of Mazandaran, P.O. Box 47416-95447, Babolsar, Iran
[3]Institute of Industrial Chemistry, Iranian Research Organization for Science and Technology, Tehran, Iran

Green chemistry has now attained the status of a major scientific discipline[1] and studies in this area have led to the development of cleaner and more benign chemical processes, with many new technologies being developed each year. Much effort has been devoted to the use of non-traditional solvents for chemical synthesis. In addition to solvent-free media,[2–3] these unconventional media include water,[4] supercritical CO_2,[5] perfluorinated solvents[6] and ionic liquids.[7–9] The use of water as a medium for organic reactions is one of the latest challenges for modern organic chemists. It will be a major step forward to carry out organic reactions in water for environmental and economic reasons. Furthermore, because of its high polarity, high surface tension, high specific heat capacity and network of hydrogen bonds, water plays a significant role in many reactions.[10–13]

Another aspect of green chemistry is the development of reusable and heterogeneous catalysts under environmentally friendly conditions. From the viewpoint of green chemistry, good recovery and reusability of the catalyst are highly preferable. These concepts are at the center of chemical activity, and research on high selectivity is the driving force for the conception of all new catalytic processes. At present, it is well known that a heterogeneous catalyst must have three characteristics: high activity, selectivity and stability. Nanotechnologies constitute an invaluable tool in catalysis. Considerable progress has been made, but many challenges that deal with the control of the localization of active sites still exist.[14–17]

Arylmethylene *bis*-(3-hydroxy-2-cyclohexene-1-one) derivatives (tetraketones) are important substrates used as precursors in the syntheses of xanthenes and acridinediones for laser dye technology.[18] These compounds have also shown potent activity as antioxidants, lipoxygenase inhibitors,[19] and a new clinical class of tyrosinase inhibitors against important dermatological disorders including hyper-pigmentation and skin melanoma.[20]

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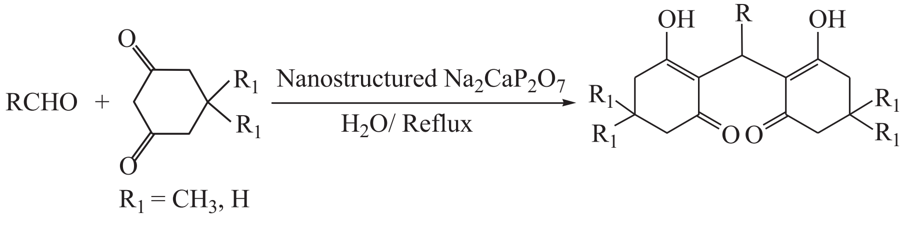
Address correspondence to Behrooz Maleki, Department of Chemistry, Hakim Sabzevari University, Sabzevar, 96179-76487, Iran. E-mail: malekibehrooz@gmail.com

Tetraketones are synthesized through Knoevenagel condensations and Michael additions of aldehydes with cyclohexane-1,3-diones, dimedones or other 1,3-cyclic diketones. They were first reported by Merling in 1894 in the preparation of cyclohexane-1,3-dione from resorcinol.[21] Vorlander and Kalkow reported a practical synthesis of tetraketones as early as 1899.[22]

Several reports of the attempts to carry out an efficient synthesis of tetraketones have appeared in the literature. The most commonly exploited method is condensation of aromatic aldehydes (1 mmol) with 1,3-cyclohexanediones (2 mmol) under a variety of conditions. This reaction has been carried out using a number of catalysts, such as sodium dodecylsulfate (SDS),[23] $HClO_4$–SiO_2 or PPA–SiO_2,[24] molecular iodine,[25] *L*-histidine in an ionic liquid,[26] $SmCl_3$,[27] polyvinylpyrrolidone(PVP)-stabilized nickel nanoparticles,[28] KF/Al_2O_3,[29] catalyst-free,[30–31] triethylbenzylammonium chloride (TEBA),[32–33] $FeCl_3.6H_2O$/TMSCl/[bmim][BF_4],[34] In(OTf)$_3$,[35] Yb(OTf)$_3$-SiO_2,[36] cetyltrimethylammonium bromide (CTMAB),[37] nanoparticles of Pd,[38] choline chloride/urea (2:1),[39] silica/HBF_4,[40] ultrasonic conditions,[41] water,[42] and hexafluoro-2-propanol.[43] Many of these catalysts have such disadvantages as the use of hazardous organic solvents, pollution discharge, high reaction temperatures, low yields, long reaction times, the utilization of expensive reagents of toxic metals and harsh reaction conditions, tedious workup conditions, the need to use high catalyst loading, a need for a large excess of the reagents and catalysts. There is still interest in developing green, economical, and mild methods to produce the desirable tetraketones in high yields and short reaction times. Also, desirable catalysts are waste-free, easily prepared, and efficiently re-used.

In continuation of our efforts toward the development of greener methodologies,[44–54] we now report that the reaction of aldehydes with 1,3-cyclohexanediones proceeds at reflux in H_2O using nanostructured diphosphate $Na_2CaP_2O_7$ (DIPH) as a basic heterogeneous catalyst in excellent yields and without the formation of by-products (*Scheme 1*).



Scheme 1 Synthesis of arylmethylene *bis*-(3-hydroxy-2-cyclohexene-1-ones) "tetraketones."

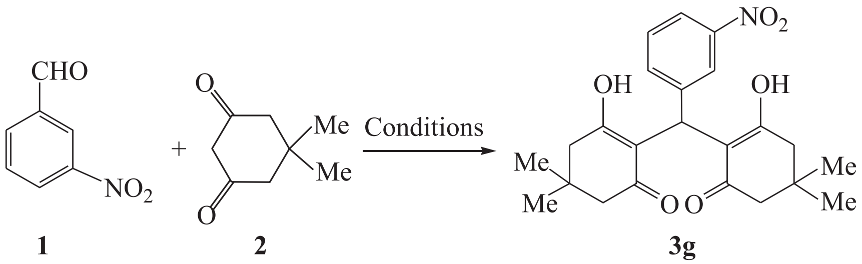
The synthesis of the nanostructured diphosphate $Na_2CaP_2O_7$ (DIPH) in powder state has been carried out from Na_2CO_3, $CaCO_3$ and $NH_4H_2PO_4$ in proportions 1:1:2, respectively in a well-documented procedure.[55–58]

To achieve optimum reaction conditions in a model reaction, a mixture of 3-nitrobenzaldehyde (1 mmol) and dimedone (2 mmol), was stirred in water (3 mL) in the presence of different amounts of $Na_2CaP_2O_7$ under various temperature conditions (*Table 1, Entries 1–6*). As it can be seen in *Table 1*, 20 mol% of $Na_2CaP_2O_7$ was sufficient to catalyze the reaction under reflux conditions. The expected tetraketone was obtained in 95% yield within 5 min (*Table 1, Entry 2*). We also tested this amount of catalyst (20 mol% of $Na_2CaP_2O_7$) in the presence of different solvents (5 mL). As shown as *Table 1*, water is a more suitable medium.

The scope and the generality of the present method were then further demonstrated by the reaction of different aldehydes with dimedone or 1,3-cyclohexandione (*Table 2*). In all cases good yields and selectivity were obtained. As shown in *Table 2*, aromatic

Table 1

Optimization of reaction conditions for synthesis of **3 g**



Entry	Catalyst (mol%)	Conditions	Time (min)	Yield (%)
1	$Na_2CaP_2O_7$ (20)	Water/rt	140	82
2	$Na_2CaP_2O_7$ (20)	Water/Reflux	5	95
3	$Na_2CaP_2O_7$ (20)	Water/90^{0}C	60	85
4	$Na_2CaP_2O_7$ (20)	Water/80^{0}C	90	85
5	$Na_2CaP_2O_7$ (15)	Water/Reflux	10	85
6	$Na_2CaP_2O_7$ (25)	Water/Reflux	5	88
7	$Na_2CaP_2O_7$ (20)	Ethanol/Reflux	20	90
8	$Na_2CaP_2O_7$ (20)	Methanol/Reflux	20	86
9	–[a]	Water/Reflux	180	72

[a] This reaction was carried out in the absence of any catalyst.

aldehydes with electron withdrawing and electron-donating groups as well as heteroaromatic and aliphatic aldehydes were employed. The nature of the substituents on the aromatic ring showed no obvious effect on this conversion; all products were obtained in high yields in relatively short reaction times.

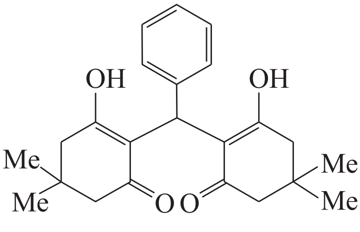
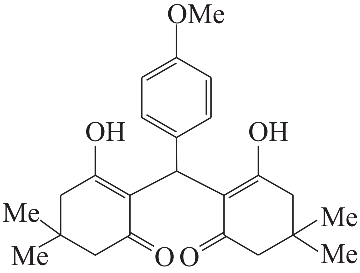
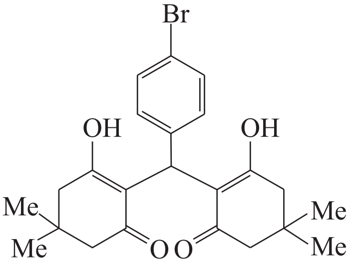
Synthetically, chemoselectivity in chemistry is regarded as one of the most important aspects of organic reactions. In all cases, the desired products (**3 a-r**) were obtained in high yields as the major products. For example, none of the corresponding xanthene was formed on heating 2,2′-[(3-nitrophenyl)-methylene] *bis*-(3-hydroxy-5,5-dimethyl-2-cyclohexen-1-one) (**3 g**, 1 mmol) in the presence of nanostructured diphosphate $Na_2CaP_2O_7$ (20 mol%) in refluxing water (1 ml); only starting material was recovered.

The scope of the methodology was studied in the preparation of **7 a** and **8 a** by using 1,3-cyclopentanedione (**5**) or 1,3-indanedione (**6**) as one of the components (*Scheme 2*).

In order to illustrate the efficacy of our procedure, results for the preparation of 2,2′-arylmethylene *bis*-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives reported previous-ly are compared with our data (*Table 3*). Our process using nanostructured diphosphate $Na_2CaP_2O_7$ offers several advantages such as excellent yields, a simple procedure, short reaction times, facile work-up and recyclability.

We believe that the surface of $Na_2CaP_2O_7$ presents multiple catalytic active sites. The basic sites (oxygens of P_2O_7 group and CaO_6 octahedra) may abstract the proton from the dimedone or 1,3-cyclohexandione. The acidic sites (phosphorus of the P_2O_7 group, Na^+ and Ca^{2+} cations) probably induce the polarization of the C=O bond and facilitate domino Knoevenagel condensation/Michael addition reaction leading to the tetraketones.

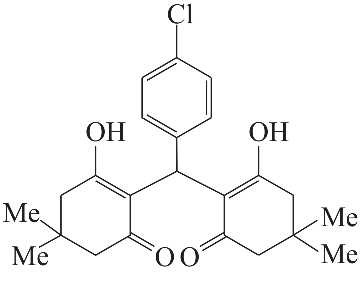
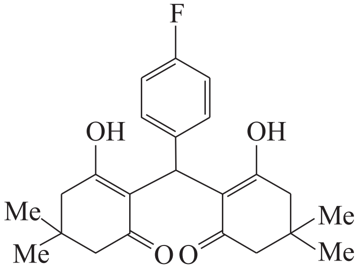
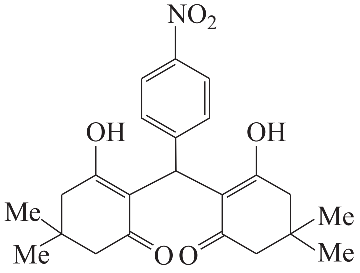
Table 2
Synthesis of tetraketone derivatives

				Mp (^{0}C)	
Entry	Products (3 a-r)	Yield (%)	Time (min)	Found	Lit.
1	 **3a**	93	10	188–190	186–188[27]
2	 **3b**	92	10	144–146	146–148[27]
3	 **3c**	93	10	157–159	158–159[28]

(*Continued on next page*)

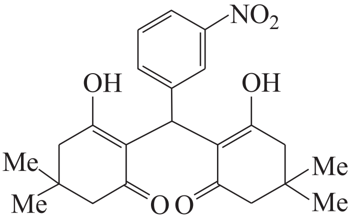
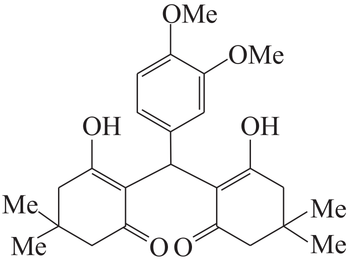
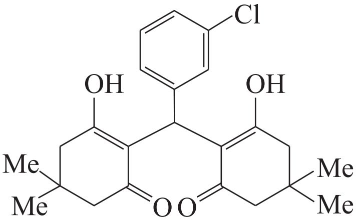
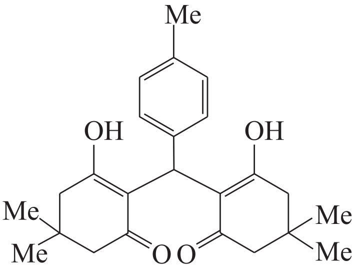
Table 2

Synthesis of tetraketone derivatives *(Continued)*

				Mp (^{0}C)	
Entry	Products (3 a-r)	Yield (%)	Time (min)	Found	Lit.
4	 **3d**	90	10	143–145	142–144[27]
5	 **3e**	90	10	166–168	167–168[28]
6	 **3f**	94	5	190–192	194–196[21]

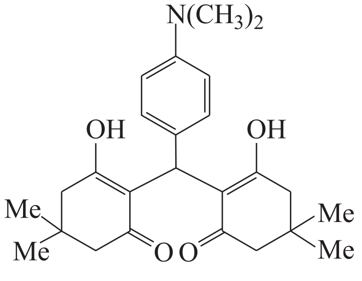
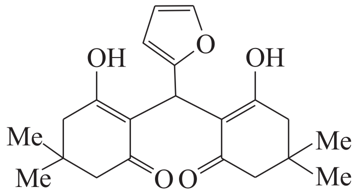
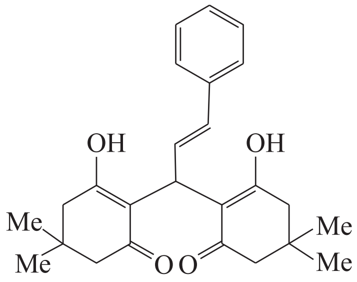
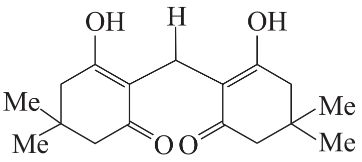
(*Continued on next page*)

Table 2
Synthesis of tetraketone derivatives *(Continued)*

				Mp (^{0}C)	
Entry	Products (3 a-r)	Yield (%)	Time (min)	Found	Lit.
7	 **3g**	95	5	201–203	201–203[27]
8	 **3h**	90	10	175–177	178–180[27]
9	 **3i**	91	15	184–186	185–187[24]
10	 **3j**	86	20	140–142	139–141[27]

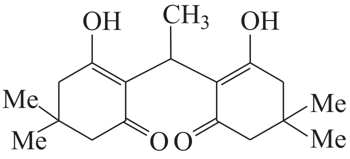
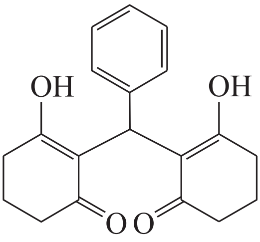
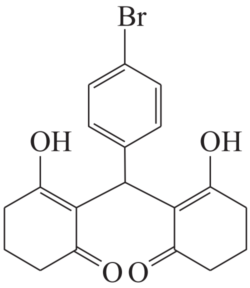
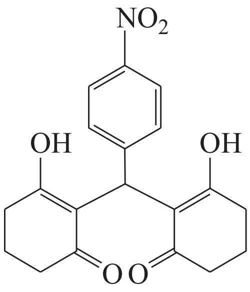
(*Continued on next page*)

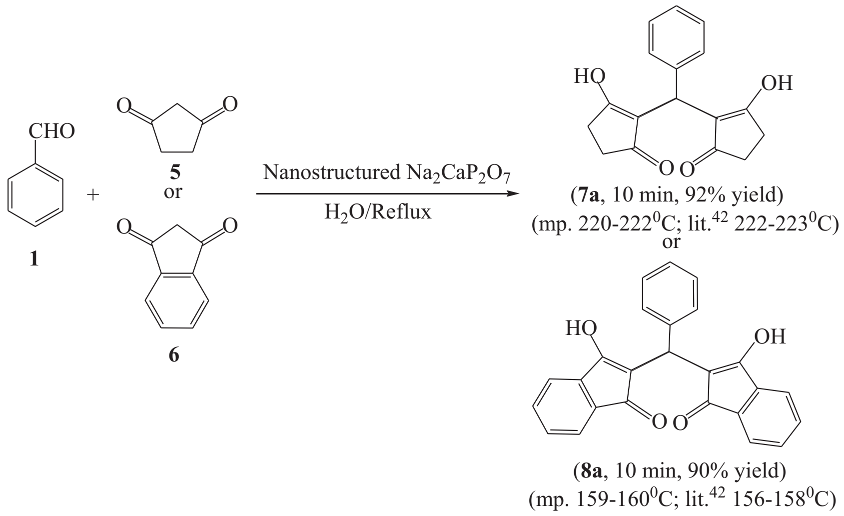
Table 2
Synthesis of tetraketone derivatives *(Continued)*

				Mp (^{0}C)	
Entry	Products (3 a-r)	Yield (%)	Time (min)	Found	Lit.
11	 **3k**	87	20	193–195	195–196[28]
12	 **3l**	90	10	140–142	139–141[27]
13	 **3m**	86	25	203–205	204[27]
14	 **3n**	84	40	191–193	192–193[30]

(*Continued on next page*)

Table 2
Synthesis of tetraketone derivatives *(Continued)*

				Mp (^{0}C)	
Entry	Products (3 a-r)	Yield (%)	Time (min)	Found	Lit.
15	 **3o**	81	50	182–183	182–184[30]
16	 **3p**	92	10	206–208	207–208[30]
17	 **3q**	91	10	238–240	240–241[31]
18	 **3r**	92	5	193–195	194–196[28]



Scheme 2. Reaction of benzaldehyde with 1,3-cyclopentadione or 1,3-indandione.

The reusability of the catalyst was also investigated. The same model reaction mentioned above was again studied under the optimized conditions. After the completion of the reaction, acetone was added to the reaction mixture to dissolve the product. Then the catalyst was removed by filtration and washed with acetone and calcined at 500°C for 1 h before re-use. It was re-used directly in the model reaction to give **3 g** in yields of 95%, 92%, 89% for three consecutive runs at 5 min.

Table 3
Comparison of the efficiency of various catalysts in the synthesis of tetraketone derivatives

Entry	Tetraketones	Conditions	Time (min)	Yield (%)
1	**3 a**	$HClO_4$–SiO_2/acetonitrile/reflux [24]	360	54
		$SmCl_3$/water/rt [27]	30	91
		KF/Al_2O_3/solvent-free/rt [29]	840	86
		Catalyst-free/solvent-free/rt [30]	2880	86
		p-Dodecylbenzenesulfonic acid/water/us/25-30^{0}C [42]	60	89
		HFIP/ reflux [43]	180	90
		Present work	10	93
2	**3 g**	$SmCl_3$/water/rt [27]	30	91
		PVP-Ni NPs/ ethylene glycol/rt [28]	10	90
		KF/Al_2O_3/solvent-free/rt [29]	840	91
		Catalyst-free/water/rt [31]	2880	88
		Pd(0) NPs/water/rt [38]	25	88
		p-Dodecylbenzenesulfonic acid/water/us/25-30^{0}C [42]	60	94
		HFIP/ reflux [43]	140	95
		Present work	5	95

In conclusion, novel synthetic nanostructured diphosphate ($Na_2CaP_2O_7$) in the presence of water is an excellent catalyst for the synthesis of tetraketone derivatives *via* the condensation of aldehydes and 1,3-cyclic dicarbonyl compounds. The current method offers many advantages. These include high efficiency, high yields, short reaction times, freedom from waste, operational simplicity, facile separation and re-use of the catalyst from the reaction medium.

Experimental Section

All reagents were obtained from commercial sources and were used without purification. IR spectra were recorded as KBr pellets on a Shimadzu 435-U-04 spectrophotometer. ^1H and ^{13}C NMR spectra were determined on a Bruker DRX-300 Avance spectrometer in DMSO-d_6 or $CDCl_3$. Melting points were determined using an Electrothermal 9200 apparatus and are uncorrected. Scanning electron microscopy (SEM) images were obtained with a Philips CM_{10}. The synthesis of catalyst has been previously described.[55-58]

General Procedure for the Synthesis of Arylmethylene bis-(3-Hydroxy-2-cyclohexene-1-one)

The catalyst, $Na_2CaP_2O_7$ (20 mol%), was added to a mixture of the aldehyde (1 mmol), dimedone or 1,3-cyclohexandione (2 mmol), and 3 ml of water in a 5 ml flask fitted with a reflux condenser. The resulting mixture was heated to reflux for the appropriate time (*see Table 2*) with stirring. After the completion of the reaction as determined by TLC (silica gel; hexane-ethyl acetate, 4:1), acetone (2 ml) was added and the mixture stirred for 2 min. The catalyst was removed by filtration and washed with acetone and calcined at 500 °C for 1 h before re-use. After concentration of the filtrate, the residue was purified by recrystallization (8 ml, EtOH 96%) to afford the pure arylmethylene *bis*-(3-hydroxy-2-cyclohexene-1-one) derivatives. The products were identified by their melting points, ^1H-NMR, and IR.

Spectral Data for Selected Compounds

2,2’-(Phenylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3 a): ^1H NMR (400 MHz, $CDCl_3$): δ 1.10 (s, 6 H, $2CH_3$), 1.23 (s, 6 H, $2CH_3$), 2.17–2.48 (m, 8 H, $4CH_2$), 5.54 (s, 1 H, CH), 7.08–7.28 (m, 5 H, Ar-H), 11.91 (s, 1 H, OH).

2,2’-(4-Methoxyphenylmethylene)-bis-(3-hydroxy-5,5- dimethyl-2-cyclohexene-1-one) (3b): ^1H NMR (400 MHz, $CDCl_3$): δ 1.02 (s, 6 H, $2CH_3$), 1.15 (s, 6 H, $2CH_3$), 2.21–2.40 (m, 8 H, $4CH_2$), 3.70 (s, 3 H, OCH_3), 5.41 (s, 1 H, CH), 6.72–6.75 (d, 2 H, Ar-H), 6.93–6.91 (d, 2 H, Ar-H), 11.84 (s, 1 H, OH).

2,2’-(4-Chlorophenylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3 d): ^1H NMR (400 MHz, $CDCl_3$): δ 1.02 (s, 6 H, $2CH_3$), 1.14 (s, 6 H, $2CH_3$), 2.21–2.41 (m, 8 H, $4CH_2$), 5.40 (s, 1 H, CH), 6.93–6.95 (d, 2 H, Ar-H), 7.14–7.17 (d, 2 H, Ar-H), 11.80 (s, 1 H, OH).

2,2 ’-(4-Nitrophenylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3f): ^1H NMR (400 MHz, $CDCl_3$): δ 1.04 (s, 6 H, $2CH_3$), 1.16 (s, 6 H, $2CH_3$), 2.24–2.44 (m, 8 H, $4CH_2$), 5.57 (s, 1 H, CH), 7.03-7.51(m, 4 H, Ar-H), 11.87 (s, 1 H, OH).

2,2 ’-(3-Nitrophenylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3 g):^1H NMR (400 MHz, $CDCl_3$): δ 1.05 (s, 6 H, $2CH_3$), 1.20 (s, 6 H, $2CH_3$), 2.24–2.45 (m, 8 H, $4CH_2$), 5.47 (s, 1 H, CH), 7.32–7.98 (m, 4 H, Ar-H), 11.79 (s, 1 H, OH).

2,2 ’-(4-Methylphenylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3j): ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.02 (s, 6 H, $2CH_3$), 1.15 (s, 6 H, $2CH_3$), 2.22 (s, 3 H, CH_3), 2.25–2.40 (m, 8 H, $4CH_2$), 5.42 (s, 1 H, CH), 6.89–6.91 (d, 2 H, Ar-H), 6.99–7.19 (d, 2 H, Ar-H), 11.83 (s, 1 H, OH).

2,2 ’-(Furan-2-ylmethylene)-bis-(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) (3 l): ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.10-1.18 (d, 12 H, $2CH_3$), 2.36 (s, 8 H, $4CH_2$), 5.39 (s, 1 H, CH), 5.95 (s, 1 H, CH), 6.30 (s, 1 H, CH), 7.26 (s, 1 H, CH), 12.17 (s, 1 H, OH).

2,2 ’-(Phenylmethylene)-bis-(cyclopentane-1,3-dione) (7 a): ^{1}HNMR ($CDCl_3$, 400 MHz): δ 2.60-2.66 (m, 8 H, $4CH_2$), 5.37 (s, 1 H, CH), 7.11-7.24 (m, 5 H), 8.17 (brs, 2 H, OH).

2,2 ’-(Phenylmethylene)-bis-(1 H-indene-1,3(2 H)-dione) (8 a): ^{1}HNMR ($CDCl_3$, 400 MHz): δ 3.94 (t, 1 H), 4.28 (d, 2 H), 7.19 (t, 1 H), 7.22 (t, 1 H), 7.38 (d, 2 H),7.79-7.83 (m, 4 H), 7.89-7.94 (m, 4 H).

Acknowledgments

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References

1. P. T. Ananstas, and J. C. Warner, *Green Chemistry: Theory and Practice*, Oxford University Press, New York, 1998.
2. K. Tanaka, *Solvent-free Organic Synthesis*, Wiley-VCH, New York, 2005.
3. R. S. Varma, *Green Chem.*, **1**, 43 (1999).
4. C. J. Li, and T.H. Chan, *Organic Reactions in Aqueous Media*, John Wiley & Sons, New York, 1997.
5. P. G. Jessop, and W. Leitner, *Chemical Synthesis using Supercritical Fluids*, Wiley-VCH, New York, 1999.
6. B. Maleki, S. Sedigh Ashrafi, and R. Tayebee, *RSC Adv.*, **4**, 41521 (2014).
7. P. Wasserscheid, T. Welton, *Ionic Liquids in Synthesis*, Wiley-VCH, Weinheim, 2003.
8. B. Maleki, G. Esmailian Kahoo, and R. Tayebee, *Org. Prep. Proced. Int.*, **47**, 461 (2015).
9. A. R. Hajipour, and F. Rafiee, *Org. Prep. Proced. Int.*, **47**, 249 (2015).
10. B. Maleki, M. Baghayeri, S. M. Vahdat, A. Mohammadzadeh, and S. Akhoondi, *RSC Adv.*, **5**, 46545 (2015).
11. H. Veisi, R. Ghorbani-Vaghei, S. Hemmati, M. Haji Aliani, and T. Ozturk, *Appl. Organomet. Chem.*, **29**, 26 (2015).
12. C. J. Li, *Chem. Rev.*, **105**, 3095 (2005).
13. H. Veisi, B. Maleki, F. Hosseini Eshbala, H. Veisi, R. Masti, S. Sedigh Ashrafi, and M. Baghayeri, *RSC Adv.*, **4**, 30683 (2014).
14. V. Polshettiwar, and R. S. Varma, *Green Chem.*, **12**, 743 (2010).
15. B. Maleki, E. Rezaei-Seresht, and Z. Ebrahimi, *Org. Prep. Proced. Int.*, **47**, 149 (2015).

16. B. Maleki, and S. Sedigh Ashrafi, *RSC Adv.*, **4**, 42873 (2014).

17. B. Maleki, S. Barat Nam Chalaki, S. Sedigh Ashrafi, E. Rezaei Seresht, F. Moeinpour, A. Khojastehnezhad, and R. Tayebee, *Appl. Organomet. Chem.*, **4**, 290 (2015).

18. A. Banerjee, and A. K. Mukherjee, *Stain Technol.*, **56**, 83 (1981).

19. G. M. Maharvi, S. Ali, N. Riaz, N. Afza, A. Malik, M. Ashraf, L. Iqbal, and M. Lateef, *J. Enzym. Inhib. Med. Chem.*, **23**, 62 (2008).

20. K. M. Khan, G. M. Maharvi, M. T. H. Khan, A. Jabbar Shaikh, S. Perveen, S. Begum, and M. I. Choudhary, *Bioorg. Med. Chem.*, **14**, 344 (2006).

21. G. Merling, *Just. Liebig Annal. Chem.*, **278**, 20 (1894).

22. D. Vorlander, and F. Kalkow, *Just. Liebig Annal. Chem.*, **309**, 356 (1899).

23. L. B. Liu, T. S. Jin, L. S. Han, Li, M. Qina, and T. S. Li, *E. J. Chem.*, **3**, 117 (2006).

24. S. Kantevari, R. Bantu, and L. Nagarapu, *J. Mol. Catal. A: Chem.*, **269**, 53 (2007).

25. M. Kidwai, V. Bansal, P. Mothsra, S. Saxena, R. K. Somvanshi, S. Dey, and T. P. Singh, *J. Mol. Catal. A: Chem.*, **268**, 76 (2007).

26. Y. Zhang, and Z. Shang, *Chin. J. Chem.*, **28**, 1184 (2010).

27. A. Ilangovan1, S. Malayappasamy, S. Muralidharan, and S. Maruthamuthu, *Chem. Cent. J.*, **5**, 81 (2011).

28. J. M. Khurana, and K. Vij, *J. Chem. Sci.*, **124**, 907 (2012).

29. T. S. Jin, A. Q. Wang, H. Ma, J. S. Zhang, and T. S. Li, *Indian J. Chem.*, **45B**, 470 (2006).

30. T. S. Jin, J. S. Zhang, A. Q. Wang, and T. S. Li, *Synth. Commun.*, **35**, 2339 (2005).

31. J. J. Yu, L. M. Wang, J. Q. Liu, F. L. Guo, Y. Liu, and N. Jiao, *Green Chem.*, **12**, 216 (2010).

32. D. Q. Shi, J. Chen, Q. Y. Zhuang, X. S. Wang, and H. W. Hu, *Chin. Chem. Lett.*, **14**, 1242 (2003).

33. D. Q. Shi, Q. Y. Zhuang, J. Chen, X. S. Wang, S. J. Tu, and H. W. Hu, *Chin. J. Org. Chem.*, **23**, 694 (2003).

34. X. S. Fan, Y. Z. Li, X. Y. Zhang, X. Y. Hu, and J. J. Wang, *Chin. Chem. Lett.*, **16**, 897 (2005).

35. D. H. Jung, Y. R. Lee, S. H. Kim, and W. S. Lyoo, *Bull. Korean Chem. Soc.*, **30**, 1989 (2009).

36. V. K. Rao, M. M. Kumar, and A. Kumar, *Indian J. Chem.*, **50B**, 1128 (2011).

37. Z. Ren, W. Cao, W. Tong, and X. Jing, *Synth. Commun.*, **32**, 1947 (2002).

38. M. Saha, A.K. Pal, and S. Nandi, *RSC Adv.*, **2**, 6397 (2012).

39. N. Azizi, S. Dezfooli, and M. M. Hashemi, *C. R. Chim.*, **16**, 997 (2013).

40. S. Ray, A. Bhaumik, M. Pramanik, R. J. Butcher, S. O. Yildirim, and C. Mukhopadhyay, *Catal. Commun.*, **43**, 173 (2014).

41. J. T. Li, Y. W. Li, Y. L. Song, and G. F. Chen, *Ultrason. Sonochem.*, **19**, 1 (2012).

42. J. J. Yu, L. M. Wang, J. Q. Liu, F. L. Guo, Y. Liu, and N. Jiao, *Green Chem.*, **12**, 216 (2010).

43. B. Maleki, M. Raei, E. Akbarzadeh, H. Ghasemnejad-Bosra, A. Sedrpoushan, S. Sedigh Ashrafi, and M. N. Dehdashti, *Org. Prep. Proced. Int.*, **48**, 62 (2016).

44. B. Maleki, S. Sheikh, *RSC Adv.*, **5**, 42997 (2015).

45. B. Maleki, and S. Sheikh, *Org. Prep. Proced. Int.*, **47**, 368 (2015).
46. B. Maleki, *Org. Prep. Proced. Int.*, **47**, 173 (2015).
47. B. Maleki, and F. Taimazi, *Org. Prep. Proced. Int.*, **46**, 252 (2014).
48. B. Maleki, E. Akbarzadeh, and S. Babaee, *Dyes Pigm.*, **123**, 222 (2015).
49. B. Maleki, H. Eshghi, A. Khojastehnezhad, R. Tayebee, S. Sedigh Ashrafi, G. Esmailian Kahoo, and F. Moeinpour, *RSC Adv.*, **5**, 64850 (2015).
50. B. Maleki, *Org. Prep. Proced. Int.*, **48**, 81 (2016).
51. B. Maleki, S. Hemmati, A. Sedrpoushan, S. Sedigh Ashrafi, and H. Veisi, *RSC Adv.*, **4**, 40505 (2014).
52. B. Maleki, *Org. Prep. Proced. Int.*, **48**, 303 (2016).
53. H. Veisi, A. Naeimi, B. Maleki, S. Sedigh Ashrafi, and A. Sedrpoushan, *Org. Prep. Proced. Int.*, **47**, 1 (2015).
54. B. Maleki, F. Mohammadi Zonoz, and H. A. Akhlaghi, *Org. Prep. Proced. Int.*, **47**, 361 (2015).
55. A. Elmakssoudi, K. Abdelouahdi, M. Zahouily, J. Clark, and A. Solhy, *Catal. Commun.*, **29**, 53 (2012).
56. M. Zahouily, Y. Abrouki, and A. Rayadh, *Tetrahedron Lett.*, **43**, 7729 (2002).
57. B. Maleki, N. Nasiri, R. Tayebee, A. Khojastehnezhad, and H. A. Akhlaghi, *RSC Adv.*, **6**, 79128 (2016).
58. A. Solhy, A. Elmakssoudi, R. Tahir, M. Karkouri, M. Larzek, M. Bousmina, and M. Zahouily, *Green Chem.*, **12**, 2261 (2010).