Ultrasonics Sonochemistry 19 (2012) 1–4

Contents lists available at ScienceDirect

Ultrasonics Sonochemistry

journal homepage: www.elsevier.com/locate/ultsonch

Short Communication

Improved synthesis of 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives catalyzed by urea under ultrasound

Ji-Tai Li [a,*], Yan-Wei Li [a], Ya-Li Song [b], Guo-Feng Chen [a,*]

[a] College of Chemistry and Environmental Science, Hebei University, Baoding 071002, PR China
[b] College of Pharmaceutical, Hebei University, Baoding 071002, PR China

ARTICLE INFO

Article history:
Received 27 March 2011
Received in revised form 25 April 2011
Accepted 4 May 2011
Available online 8 May 2011

Keywords:
2,2′-Arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one)
Synthesis
Condensation
Ultrasound
Catalysis

ABSTRACT

Synthesis of 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives catalyzed by urea *via* the condensation of aromatic aldehydes and 5,5-dimethyl-1,3-cyclohexanedione was carried out in 80–98% yields at 50 °C in aqueous media under ultrasound. This method provides several advantages such as environment friendliness, high yields and simple work-up procedure.

1. Introduction

2,2′-Arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives are important biologically active compounds, which can be evaluated as tyrosinase inhibitors [1]. They are also important synthetic intermediates and can serve as versatile precursors in the synthesis of xanthenes that display biological and therapeutic role such as antioxidants, lipoxygenase inhibitors [2a], antibacterial and antiviral activities [2b], besides they are also used in laser technology [3].

2,2′-Arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) is usually prepared *via* condensation of aromatic aldehydes and 5,5-dimethyl-1,3-cyclohexanedione under different conditions. Jin et al. reported that the condensation can be catalyzed by KF/Al_2O_3 [4] or catalyst-free [5] to give the title compounds in good yields using grinding method. But the reactants were first ground for a period of time (20–40 min) and then needed to be kept for 24 h. In the presence of sodium dodecyl sulfate (SDS), the reaction was stirred at refluxing temperature in water for 3 h, 2,2′-arylmethylene bis(3-hydroxy-2-cyclohexene-1-one) could be obtained in 67–92% yield [6]. Kantevari et al. used $HClO_4{\cdot}SiO_2$ or PPA-SiO_2 as catalyst in aqueous media at 100 °C for 30–60 min to furnish the desired product in 44.5–91% and 41.1–78.1% yields respectively [7]. Bayat et al. reported that the condensation can be finished within 20–60 min using stirring alone at room temperature to provide the product in 96–99% yield [8,9]. In the presence of triethylbenzylammonium chloride (TEBA), the reactions were stirred at 90 °C in water for 6–8 h to result the product in 84–97% yields [10]. Yu et al. carried out the reaction of benzaldehyde and 5,5-dimethyl-1,3-cyclohexanedione by stirring in water at catalyst-free condition to give **3a** in 96% yield within 30 min [11]. Fan et al. synthesized the title compounds in 80–91% yield under the catalysis of $TMSCl/FeCl_3{\cdot}6H_2O$ using $[bmim]^+[BF_4]^-$ as the reaction medium at 80 °C for 4–6 h [12]. Recently, Jung et al. described the condensation catalyzed by ethylenediamine diacetate (EDDA), dimedone reacted with aromatic aldehydes in refluxing THF for 4–6 h, 2,2′-arylmethylene bis(3-hydroxy-2-cyclohexene-1-one) was obtained in 70–97% yields [13]. However, in spite of their potential utility, some of the reported methods suffer from drawbacks such as longer reaction times and lower yields. There still appears a need either to improve the yield or to reduce reaction time.

Ultrasound has been considered as a useful protocol in organic synthesis in the last three decades [14–16]. Compared with traditional methods, this procedure is more convenient. A large number of organic reactions can be carried out in higher yield, shorter reaction time or mild condition under ultrasound [17,18]. Jin et al. reported that in the presence of TBABr (tetrabutylammonium bromide) or CTABr (cetyltrimethylammonium bromide) under

* Corresponding authors. Address: College of Chemistry and Environmental Science, Hebei University, Wusi East Road No. 180, Baoding 071002, PR China. Tel.: +86 312 5079361; fax: +86 312 5079628.
E-mail addresses: lijitai@hbu.cn (J.-T. Li), gfchen2007@yahoo.cn (G.-F. Chen).

1350-4177/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ultsonch.2011.05.001

ultrasound, the reaction of 4-chlorobenzaldehyde and 5,5-dimethyl-1,3-cyclohexanedione was completed within 60 or 90 min to result 2,2′-(4-chlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) in 92% and 95% yield, respectively [19].

Organic reactions catalyzed by small organic molecules have drawn much attention recently [20]. Urea group is known to coordinate to a carbonyl group, and to activate it by hydrogen bond. Computational studies also indicated that hydrogen bond donors are able to provide two or more hydrogen bonds to bind to oxygen atoms in carbonyl groups [21]. Thus, various carbonyl group reactions catalyzed by urea have been developed [22]. In this paper we wish to report an efficient synthesis of 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives catalyzed by urea from aromatic aldehydes and 5,5-dimethyl-1,3-cyclohexanedione in water under ultrasound irradiation (Scheme 1).

2. Methods

2.1. Apparatus and analysis

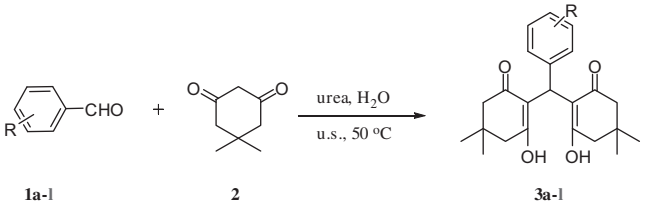
Melting points were uncorrected. The ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker AVANCE III 600 (600 MHz) spectrometer using TMS as internal standard and $CDCl_3$ as solvent. MS were determined on Agilent Technologies 6310 Lon Trap LC/MS. Sonication was performed in Shanghai Branson-BUG40-06 ultrasonic cleaner (with a frequency of 40 kHz and a nominal power 250 W).

2.2. General procedure

A 25 mL Erlenmeyer flask was charged with aromatic aldehydes (**1**,1 mmol), 5,5-dimethyl-1,3-cyclohexanedione (**2**,2 mmol), urea (15 mg, 0.25 mmol) and water (2 mL). The reaction flask was located in the ultrasonic bath, where the surface of reactants is slightly lower than the level of the water, and irradiated at 50 °C (bath temperature, the temperature inside the reactor was also 50 °C) for the period of time (The reaction was monitored by TLC) as indicated in Table 2. The reaction temperature was controlled by addition or removal of water from ultrasonic bath. After completion of the reaction, the mixture was diluted with water (10 mL), the solid was filtered, washed with water and dried to give crude product, which was further purified by column chromatography on silica gel (200–300 mesh) eluted with petroleum ether (b.p. 60–90 °C) or a mixture of petroleum ether and ethyl acetate (petroleum ether/ethyl acetate = 3/1, V/V) or recrystallization from ethanol to offer pure product. The products (**3a–k**) were known compounds, their authenticity was established by ^{1}H NMR and their melting point compared with that reported in literatures. **3l** was unknown and established by ^{1}H NMR, ^{13}C NMR and MS.

2.2.1. Compound *3a*

2,2′-Phenylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.10 (s, 6H, CH_3), 1.23 (s, 6H, CH_3), 2.30–2.47 (m, 8H, CH_2), 5.54 (s, 1H, CH), 7.10 (d, J = 8.4 Hz, 2H, Ph-H), 7.16 (t, J = 7.2 Hz, 1H, Ph-H), 7.27 (t, J = 7.8 Hz, 2H, Ph-H), 11.51 (brs, 1H, OH), 11.89 (s, 1H, OH).



1a-l 2 3a-l

Scheme 1. Synthesis of 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one).

2.2.2. Compound *3b*

2,2′-(2-Nitrophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.01 (s, 6H, CH_3), 1.12 (s, 6H, CH_3), 2.20–2.51 (m, 8H, CH_2), 6.04 (s, 1H, CH), 7.24 (d, J = 7.8 Hz, 1H, Ph-H), 7.33 (t, J = 7.8 Hz, 1H, Ph-H), 7.47 (t, J = 7.8 Hz, 1H, Ph-H), 7.52 (d, J = 7.8 Hz, 1H, Ph-H), 11.16 (brs, 1H, OH), 11.59 (s, 1H, OH).

2.2.3. Compound *3c*

2,2′-(3-Nitrophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.12 (s, 6H, CH_3), 1.28 (s, 6H, CH_3), 2.33–2.52 (m, 8H, CH_2), 5.54 (s, 1H, CH), 7.41–7.46 (m, 2H, Ph-H), 8.01 (s, 1H, Ph-H), 8.05 (d, J = 8.4 Hz, 1H, Ph-H), 11.58 (brs, 1H, OH), 11.86 (s, 1H, OH).

2.2.4. Compound *3d*

2,2′-(4-Nitrophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.12 (s, 6H, CH_3), 1.24 (s, 6H, CH_3), 2.32–2.51 (m, 8H, CH_2), 5.55 (s, 1H, CH), 7.25 (d, J = 8.4 Hz, 2H, Ph-H), 8.13 (t, J = 9.0 Hz, 2H, Ph-H), 11.53 (brs, 1H, OH), 11.80 (s, 1H, OH).

2.2.5. Compound *3e*

2,2′-(2-Chlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.06 (s, 6H, CH_3), 1.15 (s, 6H, CH_3), 2.25–2.46 (m, 8H, CH_2), 5.62 (s, 1H, CH), 7.14 (td, J = 7.8 Hz, J = 1.2 Hz, 1H, Ph-H), 7.21 (td, J = 7.8 Hz, J = 1.2 Hz, 1H, Ph-H), 7.29 (d, J = 7.8 Hz, 1H, Ph-H), 7.38 (d, J = 7.8 Hz, 1H, Ph-H), 10.84 (brs, 1H, OH), 11.89 (s, 1H, OH).

2.2.6. Compound *3f*

2,2′-(3-Chlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid: ^{1}H NMR: δ_H 1.10 (s, 6H, CH_3), 1.23 (s, 6H, CH_3), 2.30–2.48 (m, 8H, CH_2), 5.48 (s, 1H, CH), 6.97 (d, J = 7.8 Hz, 1H, Ph-H), 7.06 (s, 1H, Ph-H), 7.14–7.21 (m, 2H, Ph-H), 11.50 (brs, 1H, OH), 11.90 (s, 1H, OH).

2.2.7. Compound *3g*

2,2′-(4-Chlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.10 (s, 6H, CH_3), 1.22 (s, 6H, CH_3), 2.30–2.47 (m, 8H, CH_2), 5.47 (s, 1H, CH), 7.01 (d, J = 8.4 Hz, 2H, Ph-H), 7.23 (d, J = 8.4 Hz, 2H, Ph-H), 11.56 (brs, 1H, OH), 11.87 (s, 1H, OH).

2.2.8. Compound *3h*

2,2′-(2,4-Dichlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.06 (s, 6H, CH_3), 1.13 (s, 6H, CH_3), 2.26–2.44 (m, 8H, CH_2), 5.56 (s, 1H, CH), 7.18–7.19 (dd, J = 7.8 Hz, J = 2.4 Hz, 1H, Ph-H), 7.30–7.32 (m,2H, Ph-H), 10.88 (brs, 1H, OH), 11.88 (s, 1H, OH).

2.2.9. Compound *3i*

2,2′-(4-Methylphenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.09 (s, 6H, CH_3), 1.23 (s, 6H, CH_3), 2.29 (s, 3H, CH_3), 2.32–2.46 (m, 8H, CH_2), 5.50 (s, 1H, CH), 6.97 (d, J = 7.8 Hz, 2H, Ph-H), 7.07 (d, J = 7.8 Hz, 2H, Ph-H), 11.58 (brs, 1H, OH), 11.91 (s, 1H, OH).

2.2.10. Compound *3j*

2,2′-(4-Methoxylphenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.10 (s, 6H, CH_3), 1.22 (s, 6H, CH_3), 2.29–2.46 (m, 8H, CH_2), 3.79 (s, 3H,

Table 1
The effect of reaction condition on the synthesis of **3a** under ultrasound irradiation.[a]

Entry	Amount of urea (mg)	Frequency (kHz)	Temperature (°C)	Time (min)	Isolated yield (%)
1	0	40	50	60	64
2	10	40	50	60	81
3	15	40	50	60	94
4	20	40	50	60	93
5	30	40	50	60	93
6	15	–	50	60	73[b]
7	15	25	50	60	89
8	15	40	40	150	91
9	15	40	30	240	91
10	0	–	r.t.	60	17[c]

[a] Substrate: benzaldehyde, 1 mmol; 5,5-dimethyl-1,3-cyclohexanedione, 2 mmol; water 2 mL.
[b] Stirring alone without ultrasound.
[c] Repeated the reported method [8,9,11].

Table 2
Synthesis of **3a–l** catalyzed by urea in water at 50 °C with ultrasound or without ultrasound.[a]

Entry	R	Time (min)	Isolated yield (%)		m.p., °C (Lit.)
			A	B	
a	H	60	94	73	189–190 (190–191) [10]
b	2-NO_2	40	94	75	188–189 (188–190) [8]
c	3-NO_2	20	95	80	190–191 (193–195) [10]
d	4-NO_2	30	98	83	188–189 (188–190) [10]
e	2-Cl	90	80	70	199–200 (197–199) [10]
f	3-Cl	70	92	71	189–190 (188–190) [5]
g	4-Cl	120	91	74	137–138 (138–141) [12]
h	2,4-Cl_2	100	95	88	185–186 (188–189) [10]
i	4-CH_3	90	94	69	142–143 (141–143) [4]
j	4-CH_3O	100	93	78	140–141 (142–143) [24]
k	4-OH-3-CH_3O	40	91	71	194–195 (196–197) [5]
l	3,4-Cl_2	100	93	80	163–164

[a] Substrate: aryl aldehyde, 1 mmol; 5,5-dimethyl-1,3-cyclohexanedione, 2 mmol; urea, 15 mg; H_2O, 2 mL. Condition: A, ultrasound; B, stir without ultrasound.

CH_3O), 5.48 (s, 1H, CH), 6.81 (d, J = 8.4 Hz, 2H, Ph-H), 7.00 (d, J = 8.4 Hz, 2H, Ph-H), 11.57 (brs, 1H, OH), 11.92 (s, 1H, OH).

*2.2.11. Compound **3k***

2,2′-(4-Hydroxy-3-methoxyphenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.11 (s, 6H, CH_3), 1.23 (s, 6H, CH_3), 2.31–2.46 (m, 8H, CH_2), 3.77 (s, 3H, CH_3O), 5.47 (s, 1H, CH), 5.49 (s, 1H, OH), 6.58 (d, J = 8.4 Hz, 1H, Ph-H), 6.62 (s, 1H, Ph-H), 6.81 (d, J = 8.4 Hz, 1H, Ph-H), 11.61 (brs, 1H, OH), 11.97 (s, 1H, OH).

*2.2.12. Compound **3l***

2,2′-(3,4-Dichlorophenyl)methylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one): white solid; ^{1}H NMR: δ_H 1.10 (s, 6H, CH_3), 1.22 (s, 6H, CH_3), 2.30–2.48 (m, 8H, CH_2), 5.44 (s, 1H, CH), 6.91 (d, J = 8.4 Hz, 1H, Ph-H), 7.15 (s, 1H, Ph-H), 7.32 (d, J = 8.4 Hz, 1H, Ph-H), 11.55 (brs, 1H, OH), 11.88 (s, 1H, OH); ^{13}C NMR: δ_C 190.8, 189.5, 138.8, 132.3, 130.1, 129.8, 129.1, 126.3, 114.9, 47.0, 46.4, 32.4, 31.5, 29.6, 27.4; m/z (ESI): 437.4 $[M + H]^+$.

3. Results and discussion

To examine the effect of reaction conditions on the synthesis of title compounds, the condensation of benzaldehyde (**1a**) and 5,5-dimethyl-1,3-cyclohexanedione was selected as the model under ultrasound irradiation. The results are summarized in Table 1.

As shown in Table 1, increasing the amount of urea can improve the reaction yield. In the absence of urea, **3a** was obtained in 64% yield only (Table 1, Entry **1**). Whereas using 10 mg (17 mol%) urea, the yield of **3a** was 81% (Table 1, Entry **2**). With the increasing of amount of urea from 10 mg to 15 mg, the yield increased from 81% to 94% (Table 1, Entry **3**). Further increase of the amount of urea to 20 mg or 30 mg, does not modify the yield (Table 1, Entries **4** and **5**).

The effect of reaction temperature on the yield was observed. With the increasing of temperature from 30 °C to 50 °C (Entries **9**, **4** and **3**), the higher yield (94%) was obtained in later case within the shorter time (60 min), and we choose 50 °C as the appropriate temperature.

The effect of irradiation frequency on the reaction was also examined. When the frequency was 40 kHz, the yield of **3a** (94%) (Table 1, Entry **3**) was better than that with 25 kHz irradiation within 60 min (89%, Table 1, Entry **7**). The result showed that 40 kHz was the appropriate frequency for this reaction.

In order to verify the effect of ultrasound irradiation, the reaction was also performed by stirring alone under silent condition at 50 °C, the yield of **3a** was 73% (Entry **6**). While under ultrasound the reaction can be completed in 94% yield (Entry **3**) within the same reaction time. It's clear that ultrasound can accelerate the reaction and improve the result.

Cavitation is the origin of sonochemistry. Liquids irradiated with ultrasound can produce bubbles. Under the proper conditions these bubbles undergo a violent collapse, which generates localized "hot spot" with a transient high temperature and pressures, inducing molecular fragmentation, and highly reactive species are locally produced. In the heterogeneous reactions involving immiscible liquid, the reaction between these species can only occur in the interfacial region between the liquids. Sonication can be used to produce very fine emulsions from immiscible liquids. This is possible because cavitational collapse at or near the interface disrupts it and imples jets of one liquid into the other to form the emulsion [23]. These can cause the reaction to take place rapidly.

From the above results, the optimum reaction conditions were chosen: aromatic aldehyde (**1**,1 mmol), 5,5-dimethyl-1,3-cyclohexanedione (**2**,2 mmol), urea (15 mg, 0.25 mmol), water (2 mL), irradiation frequency 40 kHz, temperature 50 °C. Using this reaction system, we did a series of experiments to prepare 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one). The results are summarized in Table 2.

In preliminary experiment, we tried to prepare **3a** according to the reported method in the literatures [8,9,11], but the result was poor, **3a** was afforded in 17% yield only (Table 1, Entry **10**). Then we decided to investigate the reaction catalyzed by urea under ultrasound. As shown in Table 2, in the presence of urea, excellent yields were achieved in shorter reaction time under ultrasound. From these results, we can deduce that the yields are in general, similar or higher than those described in literatures [4–13,19]. For example, in the previous report [7], the condensation of 2-nitrobenzaldhyde or 4-nitrobenzaldhyde with 5,5-dimethyl-1,3-cyclohexanedione catalyzed by $HClO_4/SiO_2$ in refluxing water for 1 h offered corresponding product in 61.1% and 68.2% yield respectively. Whereas present procedure needed only 40 min and 30 min to result **3e** and **3g** in 94% and 98% yield respectively. In the reaction catalyzed by TEBA in water at 90 °C for 6–8 h, the yield of **3e**, **3g** and **3i** was 84%, 90% and 85% respectively [10], while present procedure needed 70–100 min to offer **3e**, **3g**, **3i** in 90%, 91% and 95% yield, respectively.

Phase transfer catalyst (PTC) can prompt the heterogeneous reaction involving immiscible liquid to give a good result [19].

However, there are two drawbacks to the use of PTS in that the reagents are more expensive than urea and all PTCs are potentially more dangerous than urea since they can, by their very nature, transfer chemicals from water into human tissue [23a]. Compared with the reaction by using phase transfer reagents, the disadvantages of our method include the slightly longer reaction time and a little lower yield. It seems that the reaction catalyzed by urea is a greener process.

In the present procedure, the aromatic aldehyde was substituted with either an electron-withdrawing group or donating group, the formation of **3** was less efficient, and both could react with 5,5-dimethyl-1,3-cyclohexanedione to achieve in good yields within short time.

We also did the experiments for the reactions of benzaldehyde with barbituric acid, acetylacetone and 4-hydroxycoumarin for 4 h at the same other conditions, respectively. Benzaldehyde reacted with 4-hydroxycoumarin to afford the corresponding product in 46% yield. For others, no title product was observed by TLC. It indicates that the method has limitations with respect to these substrates.

4. Conclusion

In conclusion, we have found an efficient procedure for the synthesis of 2,2′-arylmethylene bis(3-hydroxy-5,5-dimethyl-2-cyclohexene-1-one) derivatives *via* the condensation of aromatic aldehyde and 5,5-dimethyl-1,3-cyclohexanedione catalyzed by urea in water under ultrasound irradiation. Compared with some other reported methods the main advantages of this procedure are shorter reaction time, simple work-up and environmental friendly.

Acknowledgement

We thank the Natural Science Foundation of Hebei Province (B2006000969), China, for financial support.

References

[1] K.M. Khan, G.M. Maharvi, M.T.H. Khan, A.J. Shaikh, S. Perveen, S.B. Mild, M.I. Choudhary, Tetraketones: a new class of tyrosinase inhibitors, Bioorg. Med. Chem. 14 (2006) 344–351.

[2] (a) G.M. Maharvi, S. Ali, N. Riaz, N. Afza, A. Malik, M. Ashraf, L. Iqbal, M. Lateef, Mild and efficient synthesis of new tetraketones as lipoxygenase inhibitors and antioxidants, J. Enzyme Inhib. Med. Chem. 23 (2008) 62–69;
(b) R.W. Lambert, J.A. Martin, J.H. Merrett, K.E.B. Parkes, G.J. Thomas, Preparation of pyrimidine nucleosides as thymidine kinase inhibitors and virucides, PCT Int. Appl. WO 9706178 (1997).

[3] O. Sirkecioglu, N. Talinli, A. Akar, Synthesis of 14-Alkyl-14H-dibenzo [a,j]xanthenes, J. Chem. Res. (1995) 502.

[4] T.S. Jin, A.Q. Wang, H. Ma, J.S. Zhang, T.S. Li, The reaction of aromatic aldehydes and 5,5-dimethyl-1,3-cyclohexanedione under solvent-free grinding conditions, Indian J. Chem. 45B (2006) 470–474.

[5] T.S. Jin, J.S. Zhang, A.Q. Wang, T.S. Li, Solid-state condensation reactions between aldehydes and 5,5-dimethyl-1,3-cyclohexanedione by grinding at room temperature, Synth. Commun. 35 (2005) 2339–2345.

[6] L.B. Liu, T.S. Jin, L.S. Han, M. Li, N. Qi, T.S. Li, The reaction of aromatic aldehydes and 1,3-cyclohexanedione in aqueous media, E-J. Chem. 3 (2006) 117–121.

[7] S. Kantevari, R. Bantu, L. Nagarapu, $HClO_4$-SiO_2 and PPA-SiO_2 catalyzed efficient one-pot Knoevenagel condensation, Michael addition and cyclo-dehydration of dimedone and aldehydes in acetonitrile, aqueous and solvent free conditions: Scope and limitations, J. Mol. Catal. A: Chem. 269 (2007) 53–57.

[8] M. Bayat, H. Imanieh, S.H. Hossieni, Synthesis of 2,2'-arylmethylene bis (3-hydroxy-5,5-dimethyl-2-cyclohexeane-1-one) in aqueous medium at room temperature, Chin. Chem. Lett. 20 (2009) 656–659.

[9] M. Byant, H. Imanieh, S.H. Hossieni, An efficient solvent-free synthesis of 1,8-dioxo-octahydroxanthene using *p*-toluene sulfonic acid, Chin. J. Chem. 27 (2009) 2203–2206.

[10] (a) D.Q. Shi, J. Chen, Q.Y. Zhuang, X.S. Wang, H.W. Hu, The condensation of aromatic aldehydes with acidic methylene compounds in water, Chin. Chem. Lett. 14 (2003) 1242–1245;
(b) D.Q. Shi, Q.Y. Zhuang, J. Chen, X.S. Wang, S.J. Tu, H.W. Hu, Reaction of aromatic aldehydes with 5,5-dimethyl-1,3-cyclohexandione in water, Chin. J. Org. Chem. 23 (2003) 684–696.

[11] J.J. Yu, L.M. Wang, J.Q. Liu, F.L. Guo, Y. Liu, N. Ji, Synthesis of tetraketones in water and under catalyst-free conditions, Green Chem. 12 (2010) 216–219.

[12] X.S. Fan, Y.Z. Li, X.Y. Zhang, X.Y. Hu, J.J. Wang, $FeCl_3{\cdot}6H_2O$ catalyzed condensation of aromatic aldehydes with 5,5-dimethyl-1,3-cyclohexanedione in ionic liquids, Chin. Chem. Lett. 16 (2005) 897–899.

[13] D.H. Jung, Y.R. Lee, S.H. Kim, W.S. Lyoo, New and general methods for the synthesis of arylmethylene bis(3-hydroxy-2-cyclohexene-1-ones) and xanthenediones by EDDA and $In(OTf)_3$-catalyzed one-pot domino Knoevenagel/Michael or Koevenagel/Michael/Cyclodehydration reactions, Bull. Korean Chem. Soc. 30 (2009) 1989–1995.

[14] J.L. Luche, Synthetic Organic Sonochemistry, Plenum Press, New York, 1998.

[15] J.T. Li, J.F. Han, J.H. Yang, T.S. Li, An efficient synthesis of 3,4-dihydropyrimidin-2-ones catalyzed by NH_2SO_3H under ultrasound irradiation, Ultrason. Sonochem. 10 (2003) 119–122.

[16] J. Mcnulty, J.A. Steere, S. Wolf, The ultrasound promoted Knoevenagel condensation of aromatic aldehydes, Tetrahedron Lett. 39 (1998) 8013–8016.

[17] J.T. Li, S.X. Wang, G.F. Chen, T.S. Li, Some applications of ultrasound irradiation in organic synthesis, Curr. Org. Synth. 2 (2005) 415–436.

[18] N. Ratoarinoro, A.M. Wilhelm, J. Berlan, H. Delmas, Effects of ultrasound emitter type and power on a heterogeneous reaction, Chem. Eng. J. 50 (1992) 27–31.

[19] T.S. Jin, J.S. Zhang, A.Q. Wang, T.S. Li, Ultrasound-assisted synthesis of 1,8-dioxo-octahydroxanthene derivatives catalyzed by *p*-dodecylbenzenesulfonic acid in aqueous media, Ultrason. Sonochem. 13 (2006) 220–224.

[20] L. Benjamin, Introduction: Organocatalysis, Chem. Rev. 107 (2007) 5413–5415.

[21] (a) W. Nakanishi, Hydrogen bonding-based molecular recognition by urea thiourea and guanidine, J. Synth. Org. Chem. Jpn. 64 (2006) 1073–1074;
(b) D.L. Severance, W.L. Jorgensen, Effects of hydration on the Claisen rearrangement of allyl vinyl ether from computer simulations, J. Am. Chem. Soc. 114 (1992) 10966–10968.

[22] (a) Y. Sohtome, A. Tanatani, Y. Hashimoto, K. Nagasawa, Development of novel chiral urea catalysts for the hetero-michael reaction, Chem. Pharm. Bull. 52 (2004) 477–480;
(b) Q. Sun, L.X. Shi, Z.M. Ge, T.M. Chen, R.T. Li, An efficient and green procedure for the Knoevenagel condensation catalyzed by urea, Chin. J. Chem. 23 (2005) 745–748.

[23] (a) T.J. Mason, Practical Sonochemistry, Ellis Horwood, Limited, New York, 1991;
(b) O. Dahlem, J. Reisse, V. Halloin, The radially vibrating horn: A scaling-up possibility for sonochemical reactions, Chem. Eng. Sci. 54 (1999) 2829–2838.

[24] E.C. Horning, M.G. Horning, Methane derivatives of aldehydes, J. Org. Chem. 11 (1964) 95–99.