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Ultrasound mediation for efficient synthesis of monoarylidene derivatives of homo- and heterocyclic ketones

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Abstract: Ultrasonic irradiation was efficiently used for high yield synthesis of monoarylidene derivatives of cyclic systems directly from the reaction of ketone with various aldehydes under solvent-free conditions. Reactions took place rapidly in the presence of catalytic amounts of pyrrolidine, while no significant formation of the undesired bis by-products was observed. Moreover, the procedure was applicable to both homo- and heterocyclic ketones.

Keywords: α,β-Unsaturated ketones; Ultrasonic irradiation; Heterocyclic synthesis; Aldol condensation

1. Introduction

In recent decades, scientific and industrial activities have focused on designing chemical methodologies and technologies which are more environmentally friendly

and can reduce chemical disposals and energy consumptions. In this regard, an illustrative area of success involves the application of sonochemical irradiation in various science and engineering disciplines [1-3]. In particular, this application in synthetic chemistry has caused increased reactivity and selectivity in many organic transformations [4]. This enhancement occurs either as a result of producing new reacting species or is due to increased mechanical effects in the reaction mixtures [5]. Therefore, many new protocols are offered to conduct synthetic procedures in shorter time intervals and under more environmentally friendly conditions [6].

Compounds possessing carbonyl groups conjugated with α,β-unsaturated carbon–carbon bonds are considered as vary important moieties in synthetic organic chemistry since they are the key substructure of many naturally occurring and biologically active molecules [7-9]. In addition, conjugated enone functionalities are appropriate precursors for other synthetic transformations [10-11]. Synthesis of conjugated enones is usually carried out using aldol condensation reactions [12], a process which often requires the use of strong bases and suffers from undesired double condensation reaction in the case of symmetrical ketones possessing two groups of active methylenes. Like many other synthetic transformations, several methods have been reported in recent years on ultrasound mediated aldol condensation reactions [13-14]. However, the methods have been mainly limited to the synthesis of chalcone [15-20] and bisarylidene [21] derivatives. To the best of our knowledge, so far no one has studied sonochemical preparation of monoarylidenes of cyclic ketones, an important group of α,β-unsaturated ketones which have their own synthetic and biological applications. For example these compounds have been employed as precursors for the synthesis of various products such as chiral odorants [22], phenol derivatives [23], and Baylis-Hillman adducts [24] or as fungicides for the

protection of agricultural products [25], antimycrobacterial agents [26], and antiproliferative active compounds [27].

In the framework of our investigations on the synthesis of arylmethylidenes of different cycloketones [28-31] and based on our previous experiences on the development of green methodologies [32-34], we are encouraged to develop a sonochemical procedure for controlled condensation of various cyclic ketones in the presence of organocatalysts so that the formation of the bis by-products is minimized. As a consequence of our studies, herein we report a novel and high yield sonochemical method for the synthesis of monoarylidene derivatives. The procedure is applicable to both homo- and heterocyclic ketones (Scheme 1).

Scheme 1.

2. Method

2.1. Apparatus and analysis

Reactions were monitored by TLC. FT-IR spectra were recorded using KBr disks on a Bruker Vector-22 infrared spectrometer and absorptions were reported as wave numbers (cm^{-1}). NMR spectra were obtained on a FT-NMR Bruker Ultra Shield^{TM} (500 MHz) instrument as $CDCl_3$ solutions and the chemical shifts were expressed as δ units with Me_4Si as the internal standard. Mass spectra were obtained on a Finnigan Mat 8430 apparatus at ionization potential of 70 eV. All chemicals and reagents were purchased from commercial sources and were purified by standard procedures prior to use. Sonication was performed using a Sartorius Ultrasonic-homogenizer LABSONIC$^{®}$P 230V/50 Hz instrument with a frequency of 24 KHz and nominal power of 460 W/cm^2. The intensity level of irradiation was adjusted at 80% level for the synthesis of the products. In all reactions the tip of the sonotrode

was located in the same position just under the liquid surface in order to obtain optimal sonication and reproducible results. The ultrasonic intensity and ultrasonic density of the instrument were measured by a known calorimetric method [35] (for the synthesis of **3a** from cyclohexanone and benzaldehyde in the presence of pyrrolidine) and were found to be equal to 5.14 W/cm^2 and 0.25 W/cm^3, respectively.

2.2. General procedure

A mixture of an aldehyde (3.00 mmol), a ketone (3.00 mmol), and pyrrolidine (107 mg, 123 μl, 1.5 mmol) was sonicated under inert atmosphere for the given period of time. The progress of the reaction was monitored by TLC using silica gel coated plates and petroleum ether/EtOAc (4:1). At the end, water (5 mL) was added to the mixture and the product was extracted with Et_2O (2×5 mL). The organic layer was dried over Na_2SO_4. Evaporation of the solvent led to a residue which was purified by either column chromatography (using silica gel and petroleum ether/EtOAc (4:1) as the eluent) or recrystallization from EtOAc. The identity of known compounds (**3a-h** [36-38] and **5a** [26,31]) was confirmed by the comparison of their spectral and physical data with those available in the literature. The structure of new products was determined by their physical and spectroscopic specifications and their purity was confirmed by elemental analyses. In temperature controlled experiments, reactions were performed in a water bath at 25±1 ^oC.

2.3. Selected spectral data

(*E*)-3-(Naphthalen-2-ylmethylene)dihydro-2*H*-pyran-4(3*H*)-one (4a). Yellow solid was obtained in 72% yield. Mp 125-127 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.70-2.73 (m, 2H), 4.09-4.11 (m, 2H), 4.97 (d, *J* = 2.0 Hz, 2H), 7.37 (dd, *J* = 1.5, 8.5 Hz, 1H), 7.49-7.55 (m, 2H), 7.73 (s, 1H), 7.78 (dd, *J* = 2.0, 2.0 Hz, 1H), 7.82-7.85 (m, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 40.2, 66.0, 69.3, 127.2, 127.8, 127.9, 128.1,

128.8, 129.0, 131.3, 132.3, 133.4, 133.7, 133.8, 136.6, 196.4 ppm; IR (neat) ν 1682, 1586, 1223 cm^{-1}; MS (70 eV): m/z 238 (M^+), 221, 181, 165, 153. Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H,5.92. Found. C, 80.30; H, 5.91.

(*E*)-3-(4-Methylbenzylidene)dihydro-2*H*-pyran-4(3*H*)-one (4b). White solid was obtained in 71% yield. Mp 115-116 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.37 (s, 3H), 2.66-2.68 (m, 2H), 4.06-4.08 (m, 2H), 4.85 (d, *J* = 2.0 Hz, 2H), 7.18 (d, *J* = 8.2 Hz, 2H), 7.23 (d, *J* = 8.2 Hz, 2H), 7.61 (s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.9, 40.1, 65.9, 69.2, 129.9, 131.2, 132.0, 132.8, 136.6, 140.4, 196.5 ppm; IR (neat) ν 2857, 1681, 1235 cm^{-1}; MS (70 eV): m/z 202 (M^+), 187, 131, 115. Anal. Calcd for $C_{13}H_{14}O_2$: C, 77.20, H, 6.98. Found: C 76.94; H, 7.05.

(*E*)-3-(3-Fluorobenzylidene)dihydro-2*H*-pyran-4(3*H*)-one (4c). White solid was obtained in 77% yield. Mp 116-117 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.68-2.70 (m, 2H), 4.06-4.09 (m, 2H), 4.82 (d, *J* = 1.0 Hz, 2H), 6.95 (d, *J* = 9.5 Hz, 1H), 7.04-7.09 (m, 2H), 7.36 (m, 1H), 7.55 (ap s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 40.2, 65.9, 68.9, 116.7, 116.9, 117.3, 117.4, 126.7, 130.6, 130.7, 134.7, 134.9, 136.8, 196.3 ppm; IR (neat) ν 1682, 1577 cm^{-1}; MS (70 eV): m/z 206 (M^+), 149, 133, 121. Anal. Calcd for $C_{12}H_{11}FO_2$: C,69.89, H, 5.38. Found: C, 70.08; H, 5.69.

(*E*)-3-(4-Bromobenzylidene)dihydro-2*H*-pyran-4(3*H*)-one (4d). White solid was obtained in 74% yield. Mp 119-120 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.67-2.70 (m, 2H), 4.06-4.08 (m, 2H), 4.80 (d, *J* = 1.0 Hz, 2H), 7.13 (d, *J* = 8.5 Hz, 2H), 7.52 (d, *J* = 1.0 Hz, 1H), 7.54 (d, *J* = 8.5 Hz, 2H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 40.2, 65.9, 69.0, 124.4, 132.3, 132.4, 133.6, 134.2, 135.1, 196.3 ppm; IR (neat) ν 1679, 1595 cm^{-1}; MS (70 eV): m/z 267 (M^+), 212, 187, 131. Anal. Calcd for $C_{12}H_{11}BrO_2$: C, 53.96, H, 4.15. Found: C 54.38; H, 4.24.

(*E*)-3-Benzylidene-1-methylpiperidin-4-one (5a). An oil was obtained in 62% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.33 (s, 3H), 2.55-2.58 (m, 2H), 2.68-2.71 (m, 2H), 3.56 (s, 2H), 7.23-7.25 (m, 3H), 7.28-7.31 (m, 2H), 7.49 (s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 39.1, 46.2, 52.6, 57.6, 127.9, 129.1, 130.4, 132.9, 134.4, 135.7, 197.4 ppm.

(*E*)-1-Methyl-3-(3-methylbenzylidene)piperidin-4-one (5b). An oil was obtained in 65% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.33 (s, 3H), 2.40 (s, 3H), 2.61-2.64 (m, 2H), 2.76-2.78 (m, 2H), 3.61 (d, *J* = 1.5 Hz, 2H), 7.10-7.13 (m, 3H), 7.25 (dd, *J* = 7.6, 8.0 Hz, 1H), 7.52 (d, *J* = 1.5 Hz, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.8, 39.5, 46.6, 53.2, 58.1, 127.8, 128.8, 130.3, 131.6, 133.2, 135.3, 136.5, 138.6, 198.1 ppm; IR (neat) ν 1678, 1575 cm^{-1}; MS (70 eV): m/z 215 (M^+), 186, 158, 129. Anal. Calcd for $C_{14}H_{17}NO$: C, 78.10, H, 7.96. Found: C 78.29; H, 8.12.

(*E*)-3-(4-Chlorobenzylidene)-1-methylpiperidin-4-one (5c). An yellow paste was obtained in 70% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.57 (s. 3H), 2.77-2.79 (m, 2H), 2.94-3.00 (m, 2H), 3.81 (d, *J* = 1.8 Hz, 2H), 7.25 (d, *J* = 8.5 Hz, 2H), 7.38 (d, *J* = 8.5 Hz, 2H), 7.58 (ap. s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 39.4, 46.5, 53.0, 57,9, 129.2, 131.3, 132.0, 133.8, 134.8, 135.5, 194.7 ppm; IR (neat) ν1726, 1687 cm^{-1}; MS (70 eV): m/z 235 (M^+), 158, 114, 42. Anal Calcd for $C_{13}H_{14}ClNO$: C, 66.24; H, 5.99. Found: C, 66.20, H, 5.90.

(*E*)-1-Methyl-3-(thiophen-2-ylmethylene)piperidin-4-one (5d). An oil was obtained in 75% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.51 (s, 3H), 2.64-2.66 (m, 2H), 2.80-2.82 (m, 2H), 3.69 (d, *J* = 1.5 Hz, 2H), 7.14 (dd, *J* = 3.8, 5.0 Hz, 1H), 7.31 (d, *J* = 3.8 Hz, 1H), 7.50 (d, *J* = 5.0 Hz, 1H), 7.78 (d, *J* = 1.5 Hz 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 39.3, 46.7, 52.6, 58.1, 128.4, 128.9, 129.7, 131.3, 133.9, 138.6, 197.2 ppm;

IR (neat) ν 1687, 1601 cm^{-1}; MS (70 eV): m/z 207 (M^+), 206, 178, 150, 121. Anal. Calcd for $C_{11}H_{13}NOS$: C, 63.74, H, 6.32. Found: C 63.38; H, 6.55.

(*Z*)-3-(2-Methylbenzylidene)dihydro-2*H*-thiopyran-4(3*H*)-one (6a). Yellow solid was obtained in 70% yield. Mp 62-65 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.88 (s, 3H), 2.88-2.91 (m, 2H), 2.99-3.02 (m, 2H), 3.65 (s, 2H), 7.12 (d, *J* = 7.5 Hz, 1H), 7.17-7.25 (m, 3H), 7.56 (s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.4, 26.5, 29.0, 42.0, 126.1, 129.2, 130.8, 134.4, 135.2, 135.4, 138.2, 199.3 ppm; IR (neat) ν 1728, 1673, 1594 cm^{-1}; MS (70 eV): m/z 218 (M^+), 203, 190, 149, 128. Anal. Calcd for $C_{13}H_{14}OS$: C, 71.52, H, 6.46. Found: C 71.22; H, 6.86.

(*Z*)-3-(3,4,5-Trimethoxybenzylidene)dihydro-2*H*-thiopyran-4(3*H*)-one (6b). Cream colored solid was obtained in 68% yield. Mp 93-95 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.86-2.89 (m, 2H), 2.98-3.00 (m, 2H), 3.83 (s, 2H), 3.84 (s, 6H), 3.85 (s, 3H), 6.55 (s, 2H), 7.43 (s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 26.2, 29.1, 41.6, 56.6, 61.3, 107.6, 130.6, 134.3, 136.4, 139.3, 153.6, 199.0 ppm; IR (neat) ν 1682, 1605, 1576 cm^{-1}; MS (70 eV): m/z 294 (M^+), 263, 205, 191, 60, 45. Anal. Calcd for $C_{15}H_{18}O_4S$: C, 61.20, H, 6.16. Found: C 61.23; H, 6.42.

(Z)-3-(2-Fluorobenzylidene)dihydro-2*H*-thiopyran-4(3*H*)-one (6c). Yellow solid was obtained in 75% yield. Mp 43-45 ^oC; ^1H NMR (500 MHz, $CDCl_3$) δ 2.89-2.91 (m, 2H), 3.00-3.02 (m, 2H), 3.68 (s, 2H), 7.09 (dd, *J* = 9.0, 9.5 Hz, 1H), 7.15 (dd, *J* = 7.5, 7.5 Hz, 1H), 7.26 (dd, *J* = 7.0, 7.5 Hz, 1H), 7.35 (m, 1H), 7.47 (s, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 26.6, 29.5, 42.0, 116.4 (d, *J* = 22.0 Hz), 123.1 (d, *J* = 14.0 Hz), 124.5 (d, *J* = 4.0 Hz), 128.9 (d, *J* = 2.5 Hz), 131.1 (d, *J* = 3.0 Hz), 131.2 (d, *J* = 8.0 Hz), 136.8, 160.9 (d, *J* = 249.0 Hz), 198.8 ppm; IR (neat) ν 1679, 1612, 1479 cm^{-1}; MS (70 eV): m/z 222 (M^+), 165, 133, 107, 60, 45. Anal. Calcd for $C_{12}H_{11}FOS$: C, 64.84, H, 4.99. Found: C 64.56; H, 5.16.

(Z)-3-(3-Nitrobenzylidene)dihydro-2*H*-thiopyran-4(3*H*)-one (6d). Cream colored solid was obtained in 65% yield. Mp 97-99 ^{o}C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.92-2.94 (m, 2H), 3.03-3.05 (m, 2H), 3.77 (s, 2H), 7.46 (s, 1H), 7.58-7.65 (m, 2H), 8.17 (s, 1H), 8.19 (d, *J* = 8.0 Hz, 1H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 26.5, 29.0, 41.9, 123.9, 124.6, 130.2, 132.8, 135.9, 136.8, 137.2, 148.8, 198.7 ppm; IR (neat) ν 1691, 1613, 1529 cm^{-1}; MS (70 eV): m/z 249 (M^{+}), 232, 193, 176, 146, 115. Anal. Calcd for $C_{12}H_{11}NO_3S$: C, 57.82, H, 4.45. Found: C 57.78; H, 4.53.

*2.4. X-ray crystal structure analysis of **4a***

$C_{16}H_{14}O_2$, M = 238.27 g/mol, orthorhombic system, space group *P*bca, *a* = 11.5681(6), *b* = 7.2752(3), *c* = 28.1081(15) Å, V = 2365.6(2) $Å^3$, Z = 8, *Dc* = 1.338 $g.cm^{-3}$, μ(Mo-K*α*)= 0.087 mm^{-1}, crystal dimension of 0.23 x 0.14 x 0.09 mm^3. Data were collected with a STOE IPDS-2T diffractometer and corrected for absorption effects using indexed faces. The structure was solved by using SIR2011. The structure refinement and data reduction was carried out with SHELXL. The non-hydrogen atoms were refined anisotropically by full matrix least-squares on F^2 values to final R_1 = 0.0322, *w*R_2 = 0.0724 and S = 0.840 with 167 parameters using 2148 independent reflection (θ range = 1.45 - 25.25^{o}). The hydrogen atom bonded to C6 was located and refined isotropically. The other hydrogen atoms were located from expected geometry and were not refined. CCDC 894702 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

3. Results and discussion

We first optimized the conditions for the reaction of cyclohexanone (**1**; X = $(CH_2)_2$) with benzaldehyde using various amines, as summarized in Table 1. Under solvent-free conditions and in the presence of ultrasonic irradiation, Et_3N, DABCO, morpholine, and Et_2NH (entries 1-4) did not cause significant formation of **3a** (n = 1) giving the respective bis compound as the major product. The chemoselectivity of the reaction changed dramatically when pyrrolidine was used resulting in the formation of 73% of **3a** (entry 5) in the presence of only 50 mol% of this organocatalyst. In the absence of ultrasound (entry 6) or the amine (entry 7) reaction either gave lower quantities of the product or was completely halted showing the promoting effect of the irradiation and the amine.

Table 1

We then used the optimum solvent-free conditions (pyrrolidine/ultrasonic irradiation) for the reactions of other ketones with various aldehydes (Table 2). Notably, condensation of cyclopentanone (**1**; X = CH_2) with benzaldehyde gave higher amounts of **3a** (n = 0) within the same period of sonication (entry 1). Other aromatic aldehydes bearing electron releasing (entries 2-3), electron withdrawing (entries 4-5), and heterocyclic residues (entries 6-7) behaved similarly and gave their respective products within 4-7 minutes. Relatively lower yields were obtained when an aliphatic aldehyde (entry 8) was used due to possible competitive side reactions. Cyclopentanone showed higher reactivity in all cases resulting in more efficient synthesis of its respective monoarylidenes and less amounts of the bis counterparts.

Table 2

We next extended the scope of the method by subjecting synthetically important heterocyclic pyran-4-one (**1**; X = CH_2O), piperidin-4-one (**1**; X = CH_2NMe), and thiopyran-4-one (**1**; X = CH_2S) systems to the same reaction conditions. As a results, condensations of these three ketones with various aldehydes gave good yields of products **4-6**, respectively, within short time periods of sonication (Table 3).

Table 3

The interesting point observed here is the chemoselectivity of the reaction which is due to the use of equimolar amounts of the reactants and non-thermal energy source provided by ultrasonic irradiation. These conditions help control the direction of the process by mainly producing the desired products. In other words, if the reactions are stopped at appropriate point of time, monoarylidenes are obtained as the major products with no significant formation of their bis counterparts. This is due to the mild conditions (a relatively weak base and ultrasound) of the reaction which selectively cause deprotonation of **1** in competition with **3** so that formation of bis products is avoided. This selectivity can be attributed to the fact that **3** is less prone to deprotonation because of having less α hydrogens and already being conjugated. To support this hypothesis, a 1:1 mixture of **1** and **3d** (n = 1) was subjected to compete for 4-ClC_6H_4CHO. As a result, **3e** (n = 1) was exclusively obtained while TLC showed no detectable formation of unsymmetrical bis product **3de** after 15 minutes sonication. Alternatively, **3de** itself could be obtained by the reaction of **3d** with 4-ClC_6H_4CHO using similar conditions and longer irradiation time (Scheme 2).

Scheme 2.

The structure of known compounds was confirmed by comparison of their spectroscopic and physical data with those reported in the literature. For new products the doublet signals in their ^{1}H NMR spectra appearing at chemical shift of about 3.5, 3.7, or 4.8 ppm for piperidin-4-one, thiopyran-4-one. or pyran-4-one products, respectively, were particularly useful. These signals are realted to the O-CH_2 methylenes of position 2 and show $^{4}J_{H}$ allylic couplings with the exocyclic methyne hydrogens. The value of these couplings are about 2 Hz which is proportional to the *E* absolute stereochemistry of the olefinic bonds. To validate the structure and the stereochemistry of the products, a single crystal of **4a** was prepared and subjected to X-ray crystalography. The results shown in Figure 1 clearly supports the proposed structure.

Fig. 1.

4. Conclusion

In summary, we have presented an efficient method for the preparation of monoarylidenes of various homo- and heterocyclic ketones under ultrasonic conditions using equimolar amounts of reactants. Products are prepared in one pot with an easy workup, while no expensive or commercially unavailable reagents are employed. It seems that ultrasonic irradiation has a key role in controlling the selectivity of the reaction. In other words, since the reaction mixtures are mainly homogeneous, the mechanical effects of ultrasonic irradiation can be excluded and therefore one can conclude that a cavitational chemistry is responsible for the progress of the reactions leading to a selective condensation, as was earlier discussed (scheme 2). As a result, formation of unwanted bis byproducts is avoided, a side reaction which has always been a major limitation in other related methods. The procedure can

be used as a convenient platform for controlled and efficient synthesis of unsymmetrical bis products.

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ultsonch.xxxx.xx.xxx.

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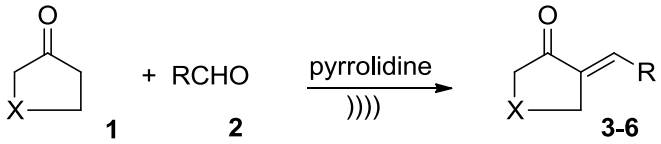


1 **2** **3-6**

X = CH_2, $(CH_2)_2$, CH_2O, CH_2NMe, CH_2S

Scheme 1. General reaction for the synthesis of monoarylidenes.

Table 1

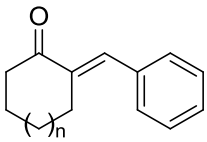
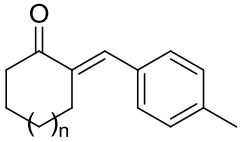
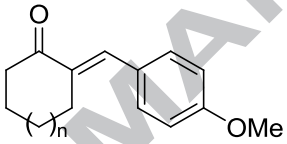
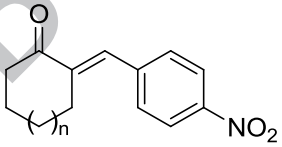
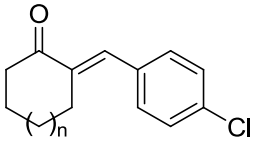
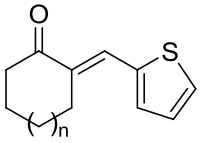
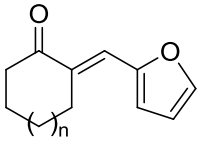
Optimization of the reaction conditions for the synthesis of **3a.**

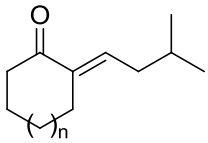
Entry	Conditions	Amine	Yield (%)[a]
1	))))), 10 min	Et_3N	< 5
2	))))), 10 min	DABCO	< 5
3	))))), 10 min	morpholine	< 5
4	))))), 10 min	Et_2NH	15
5	))))), 4 min	pyrrolidine	73
6	60 min	pyrrolidine	18
7	60 min	none	nil

[a] GC yields.

Table 2

Ultrasound promoted reactions of cycloalkanones with aldehydes**.**

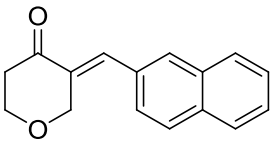
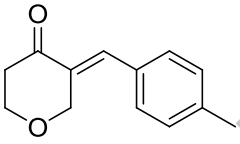
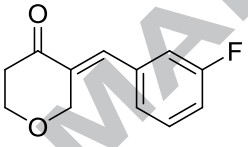
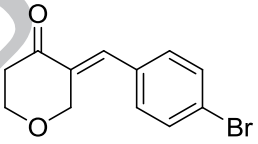
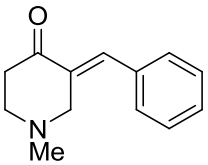
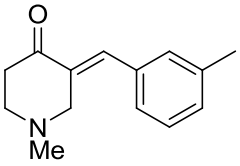
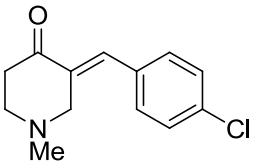
Entry	Aldehyde	Product	Time (min) n = 0/1	Yield (%)[a] n = 0/1
1	C_6H_5CHO	 **3a**	4/4	91/73
2	4-MeC_6H_4CHO	 **3b**	5/5	85/65
3	4-$MeOC_6H_4CHO$	 **3c**	5/5	83/71
4	4-$NO_2C_6H_4CHO$	 **3d**	4/4	84/69
5	4-ClC_6H_4CHO	 **3e**	5/7	88/70
6	thienyl-2-carbaldehyde	 **3f**	4/6	81/66
7	furan-2-carbaldehyde	 **3g**	4/6	79/70

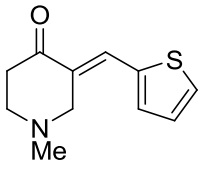
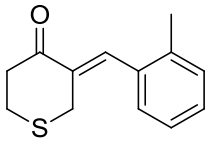
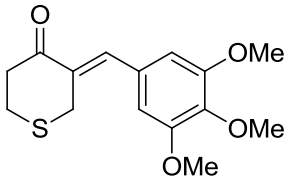
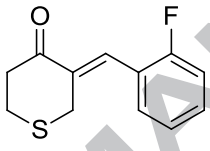
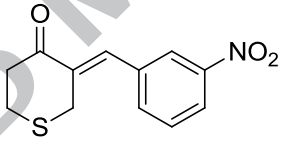
8	Me_2CHCH_2CHO	 **3h**	8/8	61/53

[a] Isolated yields.

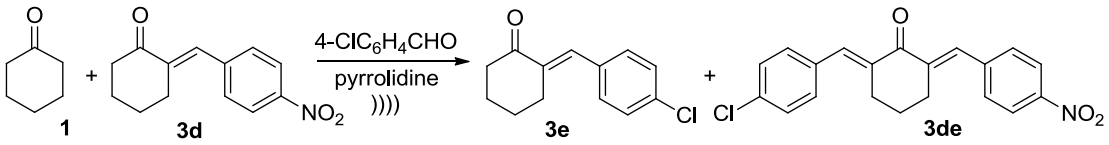
Table 3

Ultrasound promoted reactions of heterocyclic ketones with aldehydes.

Entry	Aldehyde	Product	Time (min)	Yield (%)[a]
1	2-naphthaldehyde	 **4a**	4	72
2	4-MeC_6H_4CHO	 **4b**	5	71
3	3-FC_6H_4CHO	 **4c**	3	77
4	4-BrC_6H_4CHO	 **4d**	4	74
5	C_6H_5CHO	 **5a**	10	62
6	3-MeC_6H_4CHO	 **5b**	8	65
7	4-ClC_6H_4CHO	 **5c**	5	70

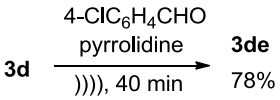
8	thienyl-2-carbaldehyde	 **5d**	8	75
9	2-MeC_6H_4CHO	 **6a**	3	70
10	3,4,5-$(MeO)_3C_6H_2CHO$	 **6b**	3	68
11	2-FC_6H_4CHO	 **6c**	2	75
12	3-$O_2NC_6H_4CHO$	 **6d**	3	65

[a] Isolated yields.



Time (min)	Yield (%)[a] **3e**
2	5
4	20
6	60
8	70

[a] GC yields.



Scheme 2. A mechanistic study using competitive reactions.

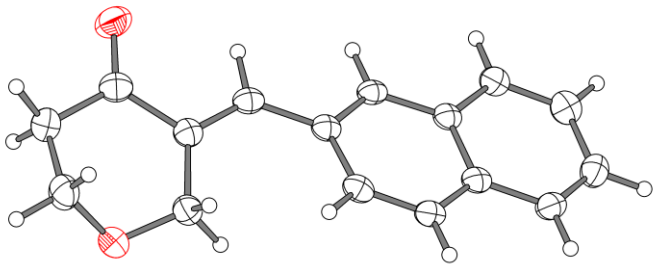


Fig. 1. Crystal structure of **4a**. Displacement ellipsoids at 50% probability level.

- Ultrasonic irradiation causes efficient synthesis of monoarylidenes of ketones.
- Various products are directly obtained under solvent-free conditions.
- Catalytic amounts of the organocatalyst are enough for the reaction to proceed.
- No significant formation of the undesired bis by-products is observed.
- The procedure is applicable to both homo- and heterocyclic ketones.