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Michael 1:1 adducts by acid catalyzed reaction during synthesis of spiro and spiroketal compounds

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Abstract

Four Michael 1:1 adducts 2-[1,5-bis-(2-methoxyphenyl)-3-oxo-pent-4-enyl]-cyclohexane-1,3-dione 3a, 2-[1,5-bis-(2-methylphenyl)-3-oxo-pent-4-enyl]-cyclohexane-1,3-dione 3b, 2-[1,5-bis-(2-chlorophenyl)-3-oxo-pent-4-enyl]-cyclohexane-1, 3-dione 3c and 2-[1,5-Bis-(2-chloro- phenyl)-3-oxo-pent-4-enyl]-5,5-dimethyl-cyclohexane-1,3-dione 3d have been synthesised by the application of Michael reaction between 1, 3-cyclohexanedione 1a or dimedone (5, 5-dimethylcy clohexane-1, 3-dione) 1b and *trans,trans* diarylideneacetone [1,5-diaryl-1,4-pentadien-3-one] 2a-c using acid catalyst. These adducts may be regarded as the intermediate of spiro [5.5] undecane compounds which can be achieved effectively via intramolecular cyclization of the Michael 1:1 adduct. The structures of the Michael 1:1 adducts 3a-d were determined by their UV, IR, ^{1}H-NMR, ^{13}C-NMR, DEPT-135 spectral data, HRMS and elemental analyses.

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Introduction

The Michael addition reaction (Michael, 1887) is one of the most important organic reactions leading to the formation of carbon-carbon and carbon-hetero atom bonds. The Michael addition reaction, which is also commonly termed as conjugate addition, has recently gained increased attention as a polymer synthesis strategy for tailored macromolecular architectures. The components of a Michael addition reaction include an activated *α, β*-unsaturated molecule (acceptor) and a nucleophile (donor) resulting in a 'Michael adduct', as shown in Fig. 1. In most cases, strong bases (for deprotonation of the donor) or Lewis acid catalysts (for activation of the acceptor) are required to allow the reaction to proceed under mild conditions (Wabnitz *et al*., 2004).

The Michael addition benefits from mild reaction conditions, high functional group tolerance, a large host of polymerizable monomers and functional precursors as well as high conversions and favorable reaction rates (Vernon *et al*., 2003). The Michael reaction lends itself to both step growth (Vaccaro *et al*., 1999) and chain growth polymerization (Vanbeylen *et al*., 1988) and has been employed in the synthesis of linear, graft, hyperbranched, dendritic and network polymers (Sun M *et al.,* 2017). Furthermore, the Michael addition has recently found utility for the synthesis of cross linked polymers such as hydrogels (Rizzi *et al*., 2005), thermoset resins and coatings (Paramarta *et al.,* 2017; Wang *et al.,* 2019), where rapid cure and high

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conversions are necessary for performance. The Michael acceptor possesses an electron withdrawing and resonance stabilizing activating group, which stabilizes the anionic intermediate. The Michael reaction typically refers to the base catalyzed addition of a nucleophile such as an enolate anion (Michael donor) to an activated α, β-unsaturated carbonyl-containing compound (Michael acceptor). However, over the years, the scope of this reaction has increased dramatically to include a broad range of acceptors and the Michael-type additions of non-carbon donors.

Although base-catalysis is most prominently used in the carbon-Michael addition, the reaction is also catalyzed with acids, particularly in the case of Lewis acids (Singh *et al*., 1996; Hassanien *et al*., 1999). Some of the earlier examples include the use of BF_3, $AlCl_3$, and $ZnCl_2$ (Hauser *et al*., 1940). In these cases, the Lewis acid coordinates to the carbonyl of the diarylidene to activate the olefin part. The coordinated complex will then react with the nucleophile to obtain the same adduct as in the base catalyzed Michael addition. Heathcock *et al*. (1986) has shown that silyl enolates will react enantioselectively with α, β-unsaturated ketones in the presence of $TiCl_4$. Phosphines also catalyze the carbon-Michael reaction (Gimbert *et al*., 2005). Shu Jiang *et al*. (2002) reported Michael addition reaction between arylmethylene cyanoacetate with dimedone 1b in ethylene glycol at 80°C without any catalyst.

It was reported that spiro and spiroketal compounds have much importance in the biological system (Ahmed *et al*., 2006; Ahmed *et al*., 2009). Due to their presence as substructures or core skeleton of medicinally and biologically active compounds their demand is increasing over the years. These active compounds occurring in natural products has been isolated from different sources including insects, microbes, plants, fungi and marine organisms (Raju *et al.,* 2008; Zhang *et al.,* 2018). As a result of interesting pharmacological activities and structures of the spiroketal compounds intense interest has stimulated in both of their synthesis and biological acitivity. Our present work has been focused on the synthetic route for the synthesis of spiroketals and spiro compounds. Due to the similarities in the selected structure to other reported medicinally potential spiroketals, our target compounds were also expected to be potentially bioactive.

We reported (Ahmed *et al*., 2006; Ahmed *et al*., 2009) the synthesis of (C_2- symmetric) 2, 2'-spiro bi-(4-aryl-7, 7-dimethyl-5-oxo-5,6,7,8-tetrahydrochromans) from diaryli deneacetones, in which spiroketal rings were fused with substituted cyclohexane ring moiety. In our present work, we used the same method (Ahmed *et al.,* 2006; Ahmed *et al*., 2009) which was previously used to synthesize spiroketal compounds successfully. But interestingly, instead of spiro or spiroketal compounds we got some different compounds 3a-d which were fully characterized by UV, IR, ^{1}H and ^{13}C NMR, DEPT-135, mass and elemental analysis as Michael 1:1 adduct. We used α, β -unsaturated diarylideneacetones as Michael Acceptors and 1, 3 cyclohexanedione 1a and dimedone 1b as Michael donors with acid catalyst.

Materials and methods

The melting points were determined on a MEL-TEMP II, USA apparatus and were uncorrected. UV and IR were recorded on SHIMADZU, UV-160 ultraviolet spectrophotometer and SHIMADZU, IR-470 infrared spectrophotometer in the range of 4000-400 cm^{-1} at the Department of Chemistry, University of Dhaka. NMR spectra were recorded at Analytical Laboratory, BCSIR, Dhaka on Bruker 400 MHz NMR spectrophotometer with TMS as an internal standard and $CDCl_3$ was used as solvent. Chemical shifts are given in ppm and coupling constant *J* is given in Hz.

General procedure

The reaction was carried out between 1,3 cyclohexanedione or dimedone (5,5- dimethylcyclohexane-1,3-dione) 1a-b, and trans, trans-diarylideneacetone 2a-c in molar proportion in a mixture of boiling toluene and n-heptane in presence of anhydrous $ZnCl_2$ or 10% HCl in a mixture of diethyl ether and dichloromethane (DCM) as catalysts under refluxing condition for 15-30 h (depending on the reaction). The water formed in the reaction was removed by using a Dean-Stark attachment. The reaction mixture was cooled, reduced to one-fourth of its volume, neutralized with saturated aqueous $NaHCO_3$ and extracted with ether. The ether extract was dried over anhydrous Na_2SO_4 and the gummy mass obtained from the ether extract was purified by recrystallization from suitable solvents. The compounds 3a-d obtained were characterized by UV, IR, ^{1}H and ^{13}C NMR including DEPT-135, mass and elemental analyses.

3a, (E)-2-[1, 5-bis(2-methoxyphenyl)-3-oxo-pent-4-en-1- yl] cyclohexane-1,3-dione: Yield 4.9%; white crystalline solid; mp 220-221°C; R_f value in TLC 0.65 (Chloroform: EtOAc, 9:1); UV: λ_{max} nm 212, 331 ($\pi\rightarrow\pi^*/n\rightarrow\pi^*$ of C=O); IR (KBr) ($\upsilon_{max}cm^{-1}$): 1630 (C=O inconj. with C=C), 1590 (C=C inconj. with C=O), 1520, 1510 (C=C aromatic); ^{1}H NMR δ (in ppm): 7.03-7.25 (m, ArH, 8H), 7.08 (d, *J* = 16 Hz, H-5, 1H), 6.65 (d, *J* = 4.5 Hz, H-1′, 1H), 6.10 (d, *J* = 16 Hz, H-4, 1H), 4.25 (d, *J* = 4.9 Hz, H-2, 2H), 2.53 (m, H-1, 1H), 2.23 (t, *J* = 6 Hz, H-3′, 5′, 2H), 1.95 (m, H-4′, 1H), 3.74 (s, -OC<u>H</u>$_3$, 6H); ^{13}C NMR δ (in ppm): 197.09 (C-3), 165.51 (C-2′,6′), 158.14 (C-2″,2‴), 157.20 (C-1″), 136.01 (C-6″), 130.97

(C-5), 128.01 (C-4′′,4′′′), 127.74 (C-1′), 127.42 (C-3′′,3′′′), 120.63 (C-5′′, 5′′′), 110.08 (C-4), 55.14 (-O$\underline{C}H_3$), 37.20 (C-3′,5′), 30.48 (C-1), 27.62 (C-2), 20.63 (C-4′); Mass: Calculated 406.47, Experimental m/z: 406.18 (100%), 407.18 (27.5%), 408.18 (4.5%); Anal. Found: C, 73.55; H, 6.64; Calcd. for $C_{25}H_{26}O_5$: C, 73.87; H, 6.45 %.

3b, (E)-2-(3-oxo-1,5-di-o-tolylpent-4-en-1-yl) cyclohexane-1, 3-dione: Yield 5.8%; white crystalline solid; mp 165-166 °C; R_f value in TLC 0.73 (Neat chloroform); UV: λ_{max} nm 211, 289 ($\pi \rightarrow \pi^*/n \rightarrow \pi^*$ of C=O); IR (KBr) (υ_{max}cm^{-1}): 1650 (C=O inconj. with C=C), 1620 (C=C inconj. with C=O), 1520, 1510 (C=C aromatic); ^{1}H NMR δ (in ppm): 7.03-7.41 (m, ArH, 8H), 7.11 (d, *J* = 16 Hz, H-5, 1H), 5.20 (d, *J* = 4.8 Hz, H-1′, 1H), 6.29 (d, *J* = 16 Hz, H-4, 1H), 4.63 (d, *J* = 4.8 Hz, H-2, 2H), 2.69 (m, H-1, 1H), 2.33 (t, *J* = 6.5 Hz, H-3′, 5′, 2H), 2.03 (m, H-4′, 1H), 2.53 (s, -C$\underline{H}_3$, 6H); ^{13}C NMR δ (in ppm): 197.10 (C-3), 166.48 (C-2′,6′), 135.91 (C-2′′,2′′′), 143.11 (C-1′′), 122.24 (C-6′′), 130.40 (C-5), 126.33 (C-4′′,4′′′), 127.68 (C-1′), 128.05 (C-3′′,3′′′), 125.24 (C-5′′,5′′′), 109.05 (C-4), 19.42 (-$\underline{C}H_3$), 37.03 (C-3′,5′), 31.58 (C-1), 27.78 (C-2), 20.48 (C-4′); Mass: Calculated 374.47, Experimental m/z: 374.19 (100%), 375.19 (27.5%), 376.19 (4.1%); Anal. Found: C, 79.98; H, 6.91; Calcd. for $C_{25}H_{26}O_3$: C, 80.18; H, 7.00 %.

3c, (E)-2-[1,5-bis (2-chlorophenyl)-3- oxo-pent-4-en-1-yl] cyclohexane-1,3-dione: Yield 5.2%; white crystalline solid; mp 163-164 °C; R_f value in TLC 0.77 (Neat chloroform); UV: λ_{max} nm 211, 301 ($\pi \rightarrow \pi^*/n \rightarrow \pi^*$ of C=O); IR (KBr) (υ_{max}cm^{-1}): 1650 (C=O inconj. with C=C), 1620 (C=C inconj. with C=O), 1550, 1500 (C=C aromatic); ^{1}H NMR δ (in ppm): 7.10-7.48 (m, ArH, 8H), 7.31 (d, *J* = 16 Hz, H-5, 1H), 5.36 (d, *J* = 4.6 Hz, H-1′, 1H), 6.38 (d, *J* = 16 Hz, H-4, 1H), 4.91 (d, *J* = 4.6 Hz, H-2, 2H), 2.73 (m, H-1, 1H), 2.40 (t, *J* = 6.5 Hz, H-3′, 5′, 2H), 2.05 (m, H-4′, 1H); ^{13}C NMR δ (in ppm): 196.82 (C-3), 167.35 (C-2′,6′), 134.48 (C-2′′,2′′′), 141.47 (C-1′′), 124.88 (C-6′′), 129.88 (C-5), 128.95 (C-4′′,4′′′), 127.19 (C-1′), 128.03 (C-3′′,3′′′), 126.47 (C-5′′,5′′′), 108.83 (C-4), 37.05 (C-3′,5′), 32.82 (C-1), 27.85 (C-2), 20.54 (C-4′); Mass: Calculated 415.31, Experimental m/z: 414.08 (79.1%), 416.08 (27.5%), 415.08 (25.0%); Anal. Found: C, 66.55; H, 4.64; Calcd. for $C_{23}H_{20}Cl_2O_3$: C, 66.52; H, 4.85 %.

3d, (E)-2-[1,5-bis(2-chlorophenyl)-3-oxo-pent-4-en-1-yl]-5, 5-dimethylcyclohexane-1,3-dione: Yield 25%; white crystalline solid; mp 134-136 °C; R_f value in TLC 0.78 (Neat chloroform); UV: λ_{max} nm 213, 301 ($\pi \rightarrow \pi^*/n \rightarrow \pi^*$ of C=O); IR (KBr) (υ_{max}cm^{-1}): 1645 (C=O inconj. with C=C), 1615 (C=C inconj. with C=O), 1520, 1510 (C=C aromatic); ^{1}H NMR δ (in ppm): 7.08-7.37 (m, ArH, 8H), 7.37 (d, *J* = 16 Hz, H-5, 1H), 5.34 (d, *J* = 4.8 Hz, H-1′, 1H), 6.38 (d, *J* = 16 Hz, H-4, 1H), 4.93 (d, *J* = 4.4 Hz, H-2, 2H), 2.60 (m, H-1, 1H), 2.26 (d, *J* = 4.0 Hz, H-3′, 5′, 2H), 1.15 (s, -C$\underline{H}_3$, 6H); ^{13}C NMR δ (in ppm): 196.72 (C-3), 165.67 (C-2′,6′), 133.59 (C-2′′,2′′′), 141.71 (C-1′′), 124.87 (C-6′′), 129.89 (C-5), 128.66 (C-4′′,4′′′), 127.12 (C-1′), 129.35 (C-3′′,3′′′), 126.45 (C-5′′,5′′′), 108.89 (C-4), 50.86 (C-3′,5′), 32.88 (C-1), 41.47 (C-2), 32.07 (C-4’), 29.03(-$\underline{C}H_3$), 28.08(-$\underline{C}H_3$); Mass: Calculated 443.36, Experimental m/z: 442.11 (91.8%), 444.11 (30.5%), 443.11 (27.2%); Anal. Found: C, 66.55; H, 4.64; Calcd. for $C_{25}H_{24}Cl_2O_3$: C, 67.73; H, 4.46 %.

Results and discussion

For our investigation, conjugate addition reaction was carried out between 1,3 cyclohexanedione 1a or dimedone 1b and diarylideneacetones 2a-c in different molar ratio in a mixture of boiling toluene and n-heptane in the presence of anhydrous $ZnCl_2$ acting as catalyst or in a mixture of diethyl ether and dichloromethane (DCM) in the presence of 10% HCl to obtain compounds 3a-d. trans,trans-diarylideneacetones 2a-c were prepared by literature procedure (Furniss *et al*., 1996; Ahmed *et al.,* 1998; Ahmed *et al.,* 2005) with modifications, wherever necessary. Encouraged by the results reported

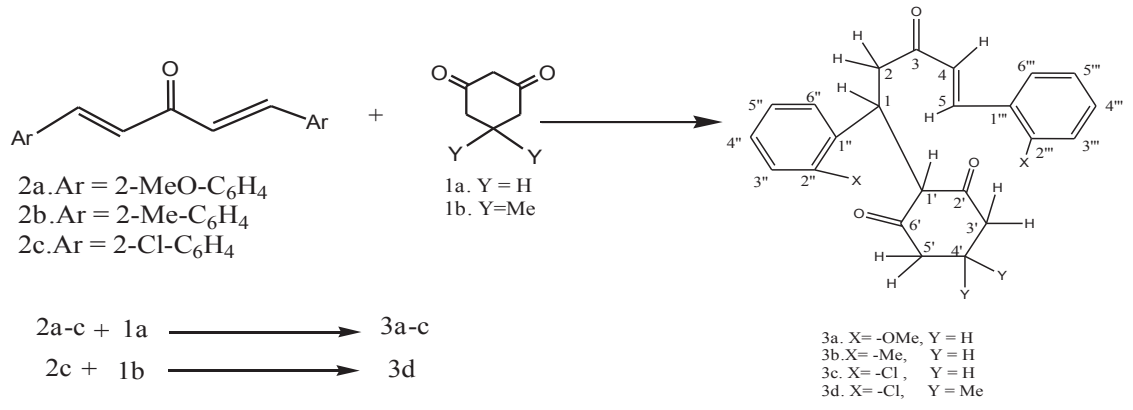

Fig. 1. Preparation of Michael 1:1 adducts

previously (Ahmed *et al.,* 2006; Ahmed *et al.,* 2009), we investigated the reactions of other substituted diarylideneacetones 2a-c with 1,3 cyclohexanedione 1a or dimedone 1b following same procedure to prove their behavior under different reaction conditions (Table-I) . Surprisingly, we didn't get sprioketals instead we got Michael 1:1 adducts 3a-d, which were characterized by UV, IR, ^{1}H and ^{13}C NMR, DEPT-135, HRMS and elemental analyses.

The conjugated ketocarbonyl stretching frequency in the IR spectra of the compounds 3a-d were observed between 1630-1650 cm^{-1} which indicated that the active methylene carbon of 1a and 1b attached with only one carbon (C-1) of diarylideneacetones 2a-c part. Again the absorption bands for the α, β-unsaturated carbonyl system and C=C of aromatic ring in the compounds 3a-d are in good agreement with the standard values reported in the literature for these types of structure (Dinwidde *et al.,* 1962; De Jongh *et al*., 1965) which also proved that the active methylene carbon of 1a and 1b attached with only one β carbon of diarylideneacetones 2a-c.

The UV spectral data of the compounds 3a-d showed a number of absorption bands in the range of 289-331 nm which may be attributed to the $\pi\rightarrow\pi^{*}$ transition of the extended *α, β*-unsaturated carbonyl conjugated system. The remaining absorption bands at 211-212 nm may be accounted for the $\pi\rightarrow\pi^{*}$ transition of the disubstituted benzene rings considering CH=CH-C=O structural unit as a substituents (Fleming *et al*., 1966).

In the ^{1}H-NMR spectra of compounds 3a-d, the chemical shift values of protons at H-1 were found at δ 2.53-2.73 ppm as multiplet and at H-2 were found at δ 4.25-4.93 ppm as doublet having coupling constant 4.4-4.9 Hz. The proton at position H-1' appeared as a doublet due to the vicinal coupling with the proton at position H-1. The chemical shifts were observed at δ 5.20-6.65 ppm with J values 4.6-4.8 Hz. The chemical shift values of protons at H-4 and H-5 of these compounds were at δ 6.10-6.38 ppm and δ 7.08-7.49 ppm respectively having coupling constant 16 Hz, which were in good agreement with the reported data (Ahmed *et al.,* 1998; Ahmed *et al.,* 2005) indicating the presence of vinyl protons. The chemical shifts of the aromatic protons were also good agreement with the reported data (Ahmed *et al.,* 1998; Ahmed *et al.,* 2005; Scheinmann, 1970).

The structures of the compounds 3a-d were further confirmed by their ^{13}C NMR spectra. The chemical shift of the carbonyl carbons (C-3) were found to be at δ 196.72-197.10 ppm. These values are in good agreement with ^{13}C-NMR chemical shifts of carbonyl carbon in *α,β*-unsaturated ketones (Grutzner *et al.,* 1970; Stothers *et al*., 1964; Marr *et al*., 1965; Levy *et al*., 1980).

In these compounds 3a-d the vinyl carbons, *α*(C-4) and *β*(C-5) showed the chemical shifts at δ 108.83-110.08 ppm and δ 129.88-130.97 ppm respectively. These values correlate well with the olefinic chemical shifts in *α,β*-unsaturated ketones (Spiesecke *et al*., 1961). The ^{13}C

Table I. Optimizing the reaction conditions

Entry	Reactant 2	Reactant 1	Medium	Acid catalyst	Time (hrs)	Molar ratio	Amount 2a-c & 1a-b	Product
1.	2a	1a	Diethyl ether (40ml) + DCM (40mL)	10% HCl	23	1:1	(1.45g, 5 mmol) and (0.06g, 5 mmol)	3a
2.	2a	1a	Diethyl ether (40ml) + DCM (40ml)	10% HCl	14	1:2	(0.06g, 2 mmol) and (1.40g, 3 mmol)	3a
3.	2a	1a	n-heptane (30ml) + toluene(30ml)	20 mmol% $ZnCl_2$ with Dean-Stark attachment	18	1:1	(2.94g, 10 mmol) and (1.12g, 10 mmol)	3a
4.	2a	1a	n-heptane (30ml) + toluene(30ml)	20 mmol% $ZnCl_2$ without Dean-Stark attachment	18	1:3	(1.45g, 5 mmol) and (1.70g, 15 mmol)	3a
5.	2b	1a	n-heptane (30ml) + toluene(30ml)	20 mmol% $ZnCl_2$ with Dean-Stark attachment	24	1:6	(1.30g, 5mmol) and (3.36g, 30 mmol)	3b
6.	2c	1a	n-heptane (30ml) + toluene(30ml)	20 mmol% $ZnCl_2$ with Dean-Stark attachment	24	1:6	(1.50g, 5 mmol) and (3.35g, 30 mmol)	3c
7.	2c	1b	n-heptane (30ml) + toluene(30ml)	20 mmol% $ZnCl_2$ with Dean-Stark attachment	22	1:3	(3.05g, 10 mmol) & (4.20g, 30 mmol)	3d

shifts of the carbons of the aromatic ring were assigned based on the correlation chart of ^{13}C spectral data available in the literature (Lauterbur, 1961). The chemical shifts observed for the different carbons in the ring of compounds 3a-d were found to be consistent with the effects of different substituents (Spiesecke *et al*., 1961; Lauterbur, 1961; Maciel *et al*., 1965; Dhami *et al*., 1967).

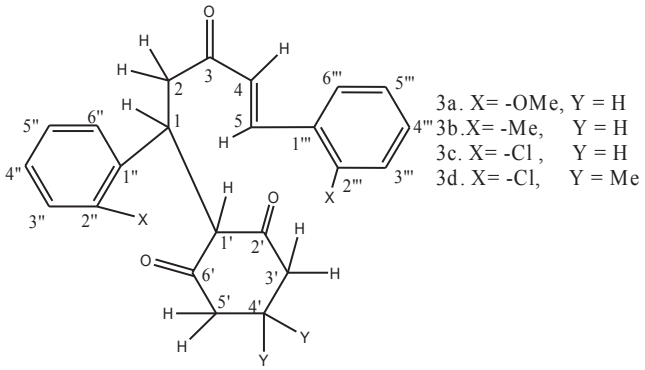

Fig. 2. Structure of Michael 1:1 adduct

The chemical shift values of the carbonyl carbons (C-2' and C-6') of the compounds 3a-d were found to be at δ 165.51-167.35 ppm. These values are in good agreement with ^{13}C-NMR chemical shifts with the reported data (Levy *et al*. 1980, Ahmed *et al*. 2007). The DEPT-135 indicated that there were three types of mythelene carbons (-CH_2-) in the compounds 3a-c (C-2, C-3' & C-5', C-4') and two types of mythelene carbons (-CH_2-) in the compounds 3d (C-2, C-3' and C-5') which were appeared in negative in DEPT-135.

The high resolution mass spectra of the compounds 3a-d contained intense peaks for their molecular ions (M^+) at m/z 406.18, 374.19, 414.08 and 442.11 respectively. The isotopic pattern for Cl atom was observed in the molecular masses of 3c and 3d. In 3c the peak for M^+ was 414.08 and that for M^++2 was 416.08 Similarly, two peaks at 442.11 and 444.11 were found for molecular masses of 3d.

Conclusion

The Michael 1:1 adducts 3a-d were synthesized in one pot which can be used to prepare spiro and spiroketal compounds by further intramolecular cyclization reaction because of their biological activity and medicinal values.

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References

Ahmed MG, Ahmed SA, Romman UKR, Mohsin T and Kiuchi F (1998), Synthesis and characterization of some diarylideneacetones, *Dhaka Univ. J. Sci.* **46**(2): 253-260.

Ahmed MG, Ahmed SA, Romman UKR, Ahmed SM and Uddin MK (2005), Synthesis and characterization of some 1,5-diaryl-1,4-pentadien-3-ones, *Dhaka Univ. J. Sci*. **53**(1): 119-125.

Ahmed MG, Ahmed SA, Uddin MK, Rahman MT, Romman UKR, Fujio M and Tsuda Y (2006), *Tetrahedron Lett.* **46**: 8217-8220.

Ahmed MG, Ahmed SA, Romman UKR, Akther K and Rahman MM (2009), *Dhaka Univ. J. Sci.* **57**(1): 127-128

Ahmed MG, Ahmed SA, Ahmed SM, Sultana T and Uddin MK (2007), Synthesis of substituted and unsubstituted 5-(1,3-diaryl-1-oxopropyl)pyrimidine(1H, 3H, 5H)-2,4, 6-triones, *Ind. J. Chem.* **46**B(1): 122-125.

Dhami KS and Stothers JB **(1967)**, ^{13}C n.m.r Studies. X. ^{13}C spectra of some substituted methyl benzoates, *Canad. J. Chem.* **45**: 233.

De Jongh HAP and Wynberg H (1965), Spiranes—IV: Long range shielding effects by benzene, thiophene and furan rings in the proton magnetic resonance spectra of diarylspiroketones, *Tetrahedron* **21**: 515. DOI: org/10.1016/S0040-4020(01)82223-7

Dinwiddle Jr JG, White, HM and Day WJ (1962), The Geometrical Isomers of 1,5-Diphenylpentadiene-3-one, *J. Org. Chem.* **27**(1): 327.

Fleming I and Williams DH (1966), Spectroscopic Methods in Organic Chemistry, McGraw Hill, p 30-31.

Furniss BS, Hannaford AJ, Smith PWG, Tatchell AR (1996), Vogel's Textbook of Practical Organic Chemistry; ELBS: Longman Scientific & Technical: Singapore, pp 1032-1035.

Gimbert C, Lumbierres M, Marchi C, Moreno-Mañas M, Sebastian RM, Vallribera A (2005), Michael additions catalyzed by phosphines. An overlooked synthetic method, *Tetrahedron* **61**: 8598-8605. DOI: org/10.1016/j.tet.2005.07.005

Grutzner JB, Jautelat M, Dence JB, Smith JA and Roberts JD (1970), Nuclear Magnetic Resonance Spectroscopy ^{13}C

chemical shifts in norbornyl derivatives, *J. Am. Chem. Soc.* **92**: 7107-7120.

Hassanien AA, Zahran MA, El-Gaby MSA and Ghorab MM (1999), Utility of 2-amino-4,5,6,8-tetrahydro-7H-chromene-3-carbonitriles in synthesis of chromeno[2,3-d]pyrimidine and chromeno[3,2-e][1,2,4] triazolo[1,5-c]pyrimidine derivatives of pharmaceutical interest, *J. Indian Chem. Soc.* **76:** 350-354.

Hauser CR and Breslow DS (1940)**,** Condensations. XII. A general theory for certain carbon-carbon condensations effected by acidic and basic reagents, *J. Am. Chem Soc*. **62**: 2389–2392. DOI: org/10.1021/ja01866a036

Heathcock CH, Uehling DE (1986), Acyclic stereoselection. Part 34. Stereoselection in the Michael addition reaction. 4. Diastereofacial preferences in Lewis acid-mediated additions of enolsilanes to chiral enones, *J. Org. Chem.* **51**: 279-280. DOI: org/10.1021/jo00352a040

Lauterbur PC (1961), ^{13}C nuclear magnetic resonance spectroscopy. I. Aromatic hydrocarbons, *J. Am. Chem. Soc.* **83**: 1838-1846.

Levy GC, Lichter RL, Nelson GL (1980), Carbon-13 nuclear magnetic resonance spectroscopy, 2nd Ed., A Wiley Interscience Publication, pp 140-141.

Maciel GE and Natterstad JJ (1965), Study of ^{13}C chemical shifts in substituted benzenes, *J. Chem. Phys.* **42**: 2427-2434.

Marr DH and Stothers JB (1965), ^{13}C N.M.R. studies: Part VI. Carbon-13 spectra of α,β-unsaturated carbonyl compounds, *Can. J. Chem.* **43**: 596-607.

Michael A (1887), On the addition of sodium acetoacetate- and sodium malonic acid esters to the esters of unsaturated acids, *Journal für Praktische Chemie*. 2nd series. **35**: 349–356.

Paramarta A and Webster DC (2017), The exploration of Michael-addition reaction chemistry to create high performance, ambient cure thermoset coatings based on soybean oil, *Progress in Organic Coatings* **108**: 59-67.

Raju BR and Saika AK (2008), Asymmetric synthesis of naturally occuring spiroketals, *Molecules* **13**(8): 1942-2038. DOI: org/10.3390/molecules13081942

Rizzi SC and Hubbell JA (2005), Recombinant protein-co-PEG networks as cell-adhesive and proteolytically degradable hydrogel matrixes. part I: Development and physicochemical characteristics, *Biomacromolecules* **6**: 1226-1238**.**

Scheinmann F (1970), An introduction to the spectroscopic methods for the identification of organic compounds, 1st Ed., Pergamon Press, Vol. 1. p 65.

Singh K, Singh J and Singh H (1996), A synthetic entry into fused pyran derivatives through carbon transfer reactions of 1,3-oxazinanes and oxazolidines with carbon nucleophiles, *Tetrahedron* **52**(45): 14273-14280.

Shu Jiang TU, Xiao Hong LIU, Heng Jun MA, Da Qing SHI and Fang LIU (2002), Michael addition reaction without catalyst: The synthesis of 2-amino-5, 6, 7, 8-tetrahydro-5-oxo-4-aryl-7, 7-dimethyl- 4H-benzo-[b]-pyran Derivatives, *Chinese Chemical Letters* **13**(5): 393-395.

Spiesecke H and Schneider WG (1961), Effect of electronegativity and magnetic anisotropy of substituents on C^{13} and H^{1} chemical shifts in CH_3X and CH_3CH_2X compounds, *J. Chem. Phys*. **35**: 722.

Stothers JE and Lauterbur PC (1964), C^{13} chemical shifts in organic carbonyl groups, *Canad. J. Chem.* **42**: 1563-1576. DOI: org/10.1139/v64-240

Sun M, Yin C, Gu Y, Li Y and Xin Z (2017), Synthesis and characterization of hyperbranched poly(ester-amine) by Michael addition polymerization, *Designed Monomers and Polymers* **20**: 458-467.

Vaccaro E and Scola DA, (1999), New applications of polyaminoquinones. *CHEMTECH* **29**: 15–23.

Vanbeylen M, Bywater S, Smets G, Swarc M and Worsfold DJ (1988), Developments in anionic polymerization—a critical review, *Adv Polym Sci* **86**:87-143.

Vernon B, Tirelli N, Bachi T, Haldimann D and Hubbell JA (2003), Water borne, in situ crosslinked biomaterials from phase segregated precursors, *J Biomed Mater Res* **64**A: 447-456.

Wabnitz TC, Yu JQ and Spencer JB (2004), Evidence that protons can be the active catalysts in Lewis acid mediated hetero Michael addition reactions, *Chem. Eur. J.* **10**: 484-493. DOI: org/10.1002/chem.200305407

Wang T, Wang J, He X, Cao Z, Xu D, Gao F, Zhong J and Shen L (2019), An ambient curable coating materials based on the Michael addition reaction of acetoacetylated castor oil and multifunctional acrylate, *Coatings* **9**(1): 37-44.

Zhang Fu-Min, Zhang Shu-Yu and Tu YQ (2018), Recent progress in the isolation, bioactivity, biosynthesis, and total synthesis of natural spiroketals, *Nat. Prod. Rep.* **35**(1): 75-104.