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SiO_2 Catalysed Expedient Synthesis of [*E*]-3-Alkenoic Acids in Dry Media

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Abstract : **Aliphatic aldehydes with α-hydrogens and malonic acid undergo decarboxylative condensation on the surface of SiO_2 when subjected to microwave irradiation generating βγ-unsaturated acids in high yields.** © 1999 Published by Elsevier Science Ltd. All rights reserved.

Key words : Aldehydes, βγ-unsaturated acids, SiO_2, Microwave irradiation.

The reaction of malonic acid with carbonyl compounds (the Knoevenagel condensation) is an important synthetic route to valuable unsaturated acids and αβ-unsaturated acids can be prepared in high yields following Doebner modification[1] (heating in presence of bases like pyridine and piperidine). However less readily available βγ-unsaturated acids can be prepared only in low yields from this route and the product is obtained as a mixture of isomeric acids with the αβ-congener as the minor component.[2] Further the ratio of the isomeric acids (αβ : βγ) in the product mixture depends largely upon the base strength and polarity of the medium. The Linstead modification[3] (heating the reactants in the presence of tertiary organic bases like triethanolamine) involves cumbersome experimental work-up procedures with prolonged reaction times and affords βγ-unsaturated acids only in moderate yields (10-35%). Several attractive methods[3] have been reported in recent years for the preparation of βγ-unsaturated acids and their derivatives, however none of these methods has the simplicity and elegance of the Knoevenagel

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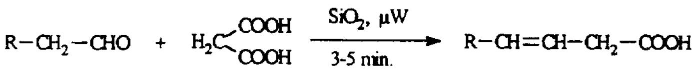
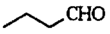
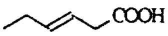
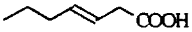
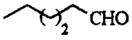
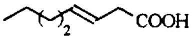
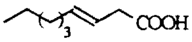
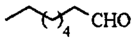
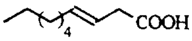
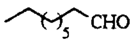
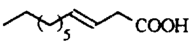
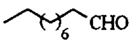
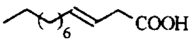
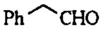
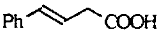
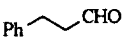
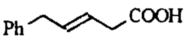
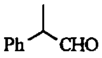
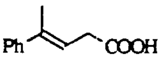
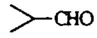
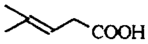
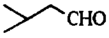
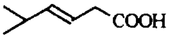
condensation.[4] There is scope for improvement of product selectivity and yields to develop this method into high yielding preparative protocol for βγ-unsaturated acids. We present here microwave promoted Knoevenagel condensations of malonic acid and aldehydes, catalysed by SiO_2 for the selective and high yield preparation of βγ-unsaturated acids under solvent-free conditions.

Scheme-1



$$R{-}CH_2{-}CHO + H_2C(COOH)_2 \xrightarrow[3\text{-}5\ \text{min.}]{SiO_2,\ \mu W} R{-}CH{=}CH{-}CH_2{-}COOH$$

Table-1 : SiO_2 catalysed synthesis of (E)-3-alkenoic acids

Entry	Substrate	Product^{a,b}	Irradiation time (min.)^c	Yield (%)^d
a.			3	84
b.			4	83
c.			4	84
d.			5	84
e.			5	88
f.			5	86
g.			5	90
h.			4	92
i.			4	89
j.			5	40^e
k.			4	36^e
l.			4	80

a) Characterised by IR, ^1H NMR and also by comparision of physical characteristics with literature data[2]; b) Geometry determined by comparative GLC analysis with authentic samples (Carbowax 20°C, 10 x 1/8, 10% on chromosorb, w 80-100 mesh, 70°C x 10 min. Program 2°C/min. up to 230°C. Nitrogen 30 ml/min.; Schimadzu GC-17A. c) Pulsed irradiation (1 min with 20 sec. interval) at output of 600 watts; d) Isolated yields after distillation; purity G.C. ≥ 98%. e) Corresponding αβ-isomeric acids were isolated in 45% (j) and 48% (k) yields respectively.

[*E*]-3-Alkenoic acids were obtained in high yields and stereochemical purity when equimolar quantities of aliphatic aldehydes with an α-hydrogen and malonic acid adsorbed on SiO_2 were subjected to microwave irradiation.[5] The reaction mixture in a Pyrex test tube was irradiated with an output of 600 watts using a domestic microwave oven. The condensation was complete within 3-5 minutes of microwave irradiation as indicated by TLC. The crude product obtained after extraction with dichloromethane was distilled under reduced pressure to afford the βγ-unsaturated acids in high yields (80-92%; Table) in the cases of aldehydes unbranched at the Cα postion. However, with substrates having α-branching (α,α-disubstituted aldehydes, table, eg. j,k), a mixture of isomeric acids was isolated as indicated by proton NMR studies of the crude products. The double-bond geometry and the purity of products were determined by their comparative GLC analysis with the authentic [*E*]- and [*Z*]-alkenoic acids obtained by standard literature methods[3,6] and the products found to match with the authentic [*E*]-isomeric acids. This was further supported by the IR absorptions of the products at 970 cm^{-1}, characteristic of a *trans*-olefin. Based on this precedent, it is likely that the product 2j may also bear [*E*]-geometry, even though it was not established from the GLC analysis or the available spectral data. Ketones did not react under the above conditions as no condensation product could be detected even after long irradiation times (10 min.). Further, heating the reactants in the absence of SiO_2 did not yield any condensation product. This reaction proceeds only to a minor extent (5-8% in 1 hour) when conducted under conventional conditions in an oil bath preheated to 120°C (highest observed temperature during irradiation) which confirms the rate augmentation during microwave heating. The formation of the βγ-unsaturated acid during SiO_2 catalysed Knoevenagel condensation of malonic acid with aliphatic aldehydes may be attributed to the preferential mode of proton capture at the Cα position of the mesomeric anion generated by decarboxylation of βγ-unsaturated malonic acid (the common intermediate for both αβ and βγ unsaturated acids) as explained by Corey et al.[7]

In conclusion, the microwave assisted Knoevenagel condensation catalysed by SiO_2 presented in this paper is a convenient method for the preparation of [*E*]-3-alkenoic acids in high yields and stereochemical purity. Merits such as high product selectivity in the case of unbranched (at Cα) aliphatic aldehydes, use of inexpensive catalyst that can be readily separated and reused, simple experimental and workup protocols and a very short reaction time, makes our method a useful and attractive synthetic procedure for the βγ-unsaturated acids.

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References & Notes

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5. In a typical experiment, freshly distilled octanal (1e, 6.4 g, 0.05 mol) and malonic acid (5.2 g, 0.05 mol) were mixed thoroughly with chromatography grade SiO_2 (200 mesh, 18 g) and the resulting powder in a pyrex test tube was subjected to microwave irradiation at an output of 600 watts for 5 min. The reaction mass was allowed to cool to room temperature and extracted with dichloromethane (30 ml). The organic layer was concentrated and the crude oily residue was distilled (110-112°C / 1 mm) to afford pure [*E*]-3-decenoic acid (7.65 g, 88% yield) as a colourless oil. ^1H NMR ($CDCl_3$) : δ 0.9 (t, 3H, J = 7.0 Hz), 1.4 (m, 8H), 2.05 (m, 2H), 3.0 (d, 2H, J = 5.0 Hz), 5.5 (m, 2H), 10.84 (brs, 1H).
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