Pergamon

Tetrahedron Vol. 50, No. 41, pp. 12001-12008, 1994

0040-4020/94 $7.00+0.00

0040-4020(94)00749-7

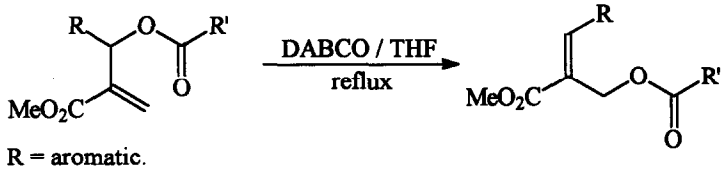
Some Mechanistic and Synthetic Aspects of the DABCO Catalysed Rearrangement of Allylic Esters.

Paul H.Mason and Neville D. Emslie*

Department of Chemistry, University of Natal, Private Bag X01, Scottsville, 3209, Republic of South Africa

Abstract: Experimental evidence shows that the DABCO catalysed rearrangement of allylic esters proceeds *via* a two path mechanism, rather than a single path, as has been previously proposed. The effectiveness of other catalysts as well as E : Z ratios for these DABCO catalysed reactions have also been determined.

Over the last few years, 1,4-diazabicyclo-[2,2,2]-octane (DABCO) has been shown to catalyse a number of reactions, with the Baylis-Hillman reaction[1] and polyurethane synthesis[2] being, perhaps, the best known. An interesting DABCO catalysed allylic rearrangement was reported in 1989[3], which is shown in Scheme 1.



R = aromatic.

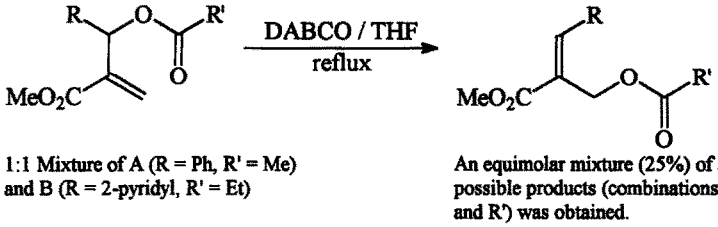
Scheme 1

This rearrangement is particularly useful since the Baylis-Hillman reaction, which is used to prepare α-hydroxyalkyl acrylates from an aldehyde and an acrylate, fails, except for a few examples where the reaction is carried out at high pressures, when the acrylate has a substituent in the β-position (*i.e.* one needs a terminal alkene). The rearrangement concerned conveniently yields an α-hydroxyalkyl acrylate with an aryl group in the β-position.

Foucaud and El Guemmout[3] proposed an intramolecular mechanism, but did not give any experimental evidence to support their proposal, nor did they give any E : Z ratios for the trisubstituted double bond in the product. Our interest in the mechanism of the Baylis-Hillman reaction[1] prompted us to investigate this rearrangement further with the view to gaining more insight into the mechanisms of DABCO catalysed reactions.

Our findings support the mechanism proposed by Foucaud and El Guemmout, but a second pathway is also thought to operate. A simple cross-over reaction (Scheme 2), using a mixture of two allylic esters with different Ar and R groups, gave all four possible products, indicating an intermolecular mechanism, where

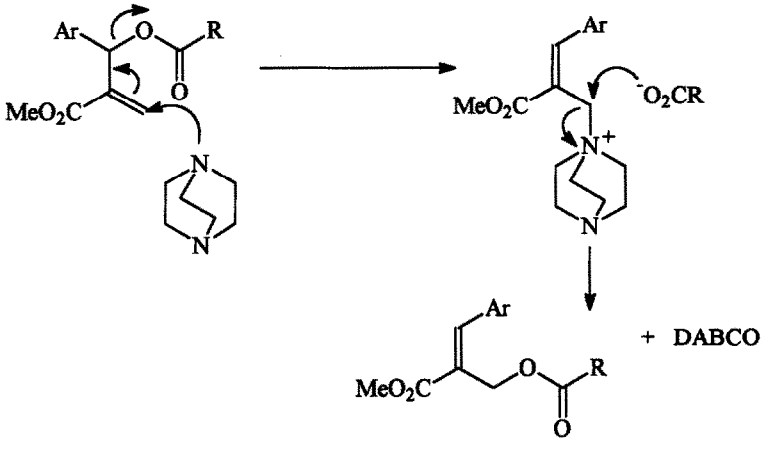
DABCO substitutes the ester group by an S_N2' reaction, followed by the S_N2 substitution of the DABCO by the fugitive ester group to give the rearranged product (Scheme 3).



1:1 Mixture of A (R = Ph, R' = Me) and B (R = 2-pyridyl, R' = Et)

An equimolar mixture (25%) of all four possible products (combinations of R and R') was obtained.

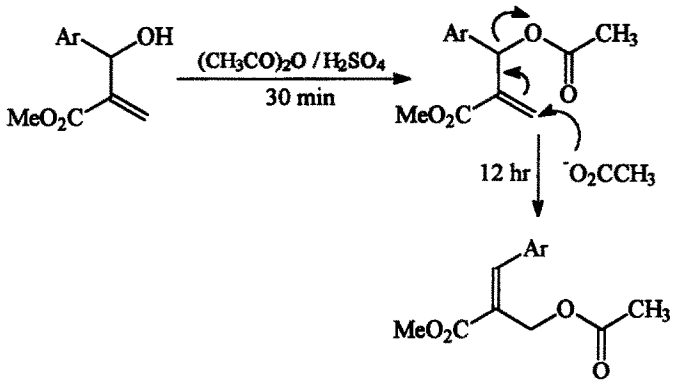
Scheme 2



Scheme 3

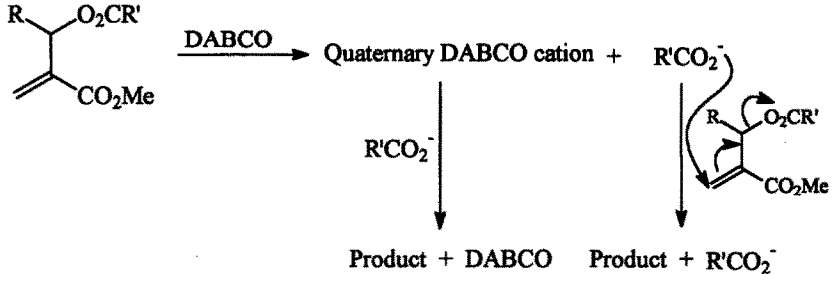
We have observed that esterification of aromatic allylic alcohols with simple acid anhydrides, such as acetic and propionic anhydride using sulfuric acid as the catalyst, leads to the unrearranged ester after about 30 minutes, but if the reaction is allowed to proceed for 12 hours, only the rearranged ester is isolated.

The mechanism, in this case, clearly occurs in two steps: the first is the formation of the unrearranged ester, and then the S_N2' substitution of the ester group by the carboxylate anion, which is produced by the reaction of the anhydride (Scheme 4).



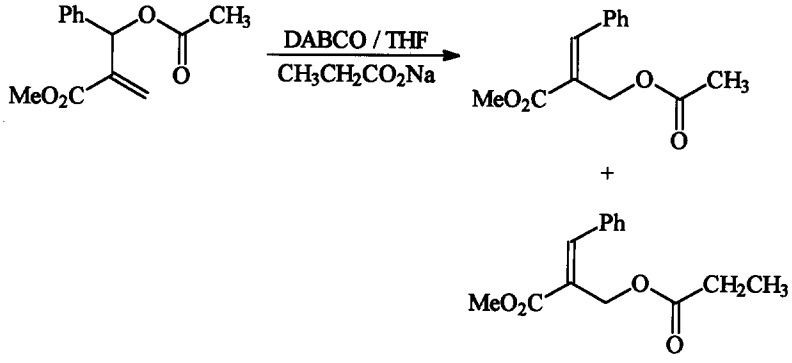
Scheme 4

It is possible that the reaction may proceed *via* an allylic cation, but we feel that this is unlikely due to the long reacion time required to affect rearrangement, and that no rearranged product can be detected before 1 hr. The reaction also proceeds without the presence of an acid catalyst, although the initial esterification is much slower. This indicates the possibility that, after initialisation of the reaction by DABCO, the fugitive carboxylate ion can undergo direct S_N2' displacement of the starting material to give the rearranged product without further involvement of DABCO (Scheme 5, Scheme 7 (route 2)).



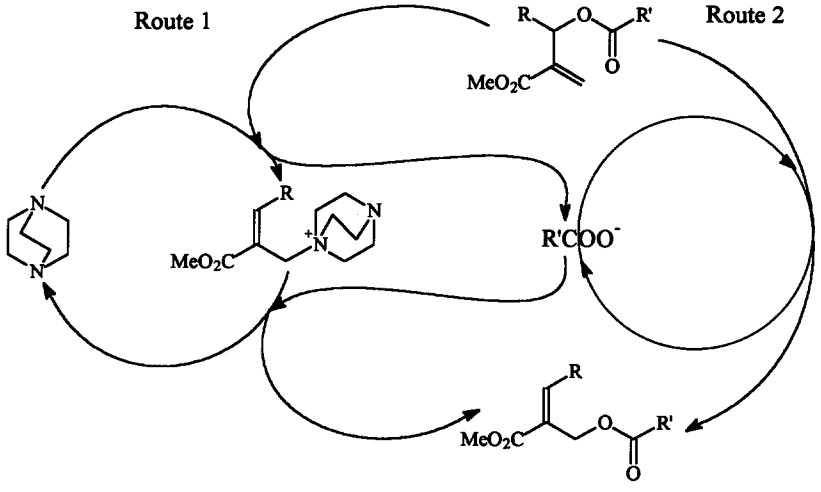
Scheme 5

The addition of the sodium salt of a carboxylic acid (in low concentration, due to low solubility) results in some of the cross-over product being isolated, indicating that two carboxylate ions compete for the same quaternary DABCO intermediate (Scheme 6).



Scheme 6

The overall reaction is best shown as a catalytic cycle (Scheme 7), where the two step DABCO catalysed rearrangement occurs faster than the carboxylate catalysed rearrangement (DABCO is needed to initiate the reaction, however).

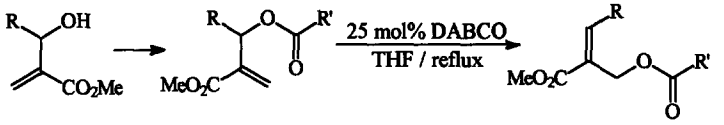


Scheme 7

Various other tertiary amine catalysts were investigated (triethylamine, pyridine, DMAP, quinuclidinol and quinine), but only DABCO and quinuclidinol (reaction is about ten times slower than using DABCO) showed fair catalytic activity. Solvent effects are marked, with THF being superior to other common solvents (CH_2Cl_2, $CHCl_3$, Et_2O, methanol, ethyl acetate), possibly due to its coordinating effect on the charged quaternary DABCO intermediate. The nature of the aryl and the ester group appear to have little effect on the

rate of the reaction, and E : Z ratios are generally greater then 90 : 10 (Table). Only esters with an aryl (R) group rearrange under these conditions, while those with simple alkyl groups do not.

Table. E : Z Ratios for the DABCO Catalysed Rearrangement.



(1) (2) (3)

(3)	R	R'	E : Z ratio	% Yield
a	Ph	Me	93 : 7	95
b	2-pyridyl	Me	95 : 5	93
c	2-furfuryl	Me	93 : 7	90
d	2-nitrophenyl	Me	94: 6	90
e	Ph	Et	95 : 5	94
f	Ph	$CH{=}CH_2$	88 : 12	91
g	Ph	CH_2CO_2Et	90 : 10	96

Experimental.

General procedure for the preparation of the allylic acetates (2a - d).

To a mixture of allylic alcohol (1)[1] (0.026 mol) and acetic anhydride (30 ml), was added 2 drops of concentrated sulfuric acid. The mixture was stirred for 30 min and the poured into a cold solution of 2M NaOH (200 ml) and stirred for 1 hr. The mixture was extracted with chloroform (3x 50 ml) and the combined extracts washed with 10% aq. $NaHCO_3$ until all the acetic anhydride is removed. The crude product was purified by column chromatography.

(**2a**). Colourless oil; 81%; δ_H($CDCl_3$, 200 MHz) 2.08 (3H, s, O_2CCH_3), 3.68 (3H, s, CO_2CH_3), 5.86 and 6.39 (2H, 2x s, $C{=}CH_2$), 6.69 (1H, s, *CH*-O), 7.34 (5H, m, Ar-*H*); δ_C(50 MHz) 21.03 (q, O_2CCH_3), 51.95 (q, CO_2CH_3), 73.09 (d, *C*H-O), 125.73 (t, $C{=}CH_2$), 127.66, 128.38 and 128.45 (3x d, Ar-*C*), 137.79 (s, Ar-*C*), 139.66 (s, $C{=}CH_2$), 165.36 (s, CO_2CH_3), 169.35 (s, O_2CCH_3); m/z 234 (M^+, <1%), 191 (79), 159 (36), 115 (93), 105 (100), 77 (50), 43 (67). (Anal. Calcd. for $C_{13}H_{14}O_4$: C, 66.66; H, 6.02. Found : C, 66.82; H, 5.93 %).

(**2b**). Colourless oil; 77%; δ_H($CDCl_3$, 200 MHz) 2.12 (3H, s, O_2CCH_3), 3.70 (3H, s, CO_2CH_3), 5.95 and 6.47 (2H, 2x s, $C{=}CH_2$), 6.78 (1H, s, *CH*-O), 7.10 - 8.70 (4H, m, Ar-*H*); δ_C(50 MHz) 20.82 (q, O_2CCH_3), 51.94 (q, CO_2CH_3), 73.69 (d, *C*H-O), 122.49, 122.60, 136.71 and 149.45 (4x d, Ar-*C*), 127.40 (t, $C{=}CH_2$),

138.30 (s, *C*=CH_2), 157.04 (s, Ar-*C*), 165.42 (s, *C*O_2CH_3), 169.55 (s, O_2*C*CH_3); m/z 220 (M^+ - 15, <1%), 176 (100), 160 (19), 144 (32), 117 (70), 89 (17), 78 (44), 43 (51). (Anal. Calcd. for $C_{12}H_{13}NO_4$: C, 61.27; H, 5.57; N, 5.95. Found : C, 61.17; H, 5.38; N, 6.01 %).

(2c). Colourless oil; 86%; δ_H($CDCl_3$, 200 MHz) 2.11 (3H, s, O_2CCH_3), 3.74 (3H, s, CO_2CH_3), 6.00 and 6.33 (2H, 2x s, C=CH_2), 6.34 (1H, s, C*H*-O), 6.47 (1H, t, furfuryl-*H*), 6.75 (1H, q, furfuryl-*H*), 7.39 (1H, t, furfuryl-*H*); δ_C(50 MHz) 20.91 (q, O_2CCH_3), 52.14 (q, CO_2CH_3), 66.12, 109.81 and 110.52 (3x d, furfuryl-*C*), 126.76 (t, C=CH_2), 136.99 (s, *C*=CH_2), 143.22 (d, *C*H-O), 150.42 (s, furfuryl-*C*), 165.09 (s, *C*O_2CH_3), 169.34 (s, O_2*C*CH_3); m/z 224 (M^+, 3%), 181 (100), 149 (48), 122 (29), 113 (32), 95 (54), 77 (26), 43 (49). (Anal. Calcd. for $C_{11}H_{12}O_5$: C, 58.93; H, 5.39. Found: C, 58.81; H, 5.33%).

(2d). Pale yellow solid (CH_2Cl_2); m.p. 70 °C; 85%; δ_H($CDCl_3$, 200 MHz) 2.13 (3H, s, O_2CCH_3), 3.75 (3H, s, CO_2CH_3), 5.60 and 6.42 (2H, 2x s, C=CH_2), 7.32 (1H, s, C*H*-O), 7.40 - 8.10 (4H, m, Ar-*H*); δ_C(50 MHz) 20.69 (q, O_2CCH_3), 52.22 (q, CO_2CH_3), 68.62 (d, *C*H-O), 124.99, 128.83, 129.42 and 133.71 (4x d, Ar-*C*), 128.03 (t, C=CH_2), 133.09 (s, *C*-NO_2), 138.62 (s, *C*=CH_2), 148.01 (s, Ar-*C*), 165.16 (s, *C*O_2CH_3), 169.20 (s, O_2*C*CH_3); m/z 248 (M^+ - 31 , 1%), 188 (11), 160 (18), 132 (37), 104 (27), 77 (38), 43 (100). (Anal. Calcd. for $C_{13}H_{13}NO_6$: C, 55.92; H, 4.69; N, 5.02. Found: C, 55.81; H, 4.67; N, 5.17%).

(2e). Compound **(2e)** was prepared using propionic anhydride by the same procedure outlined for the preparation of the acetates as a colourless oil; 81%; δ_H($CDCl_3$, 200 MHz) 1.14 (3H, t, CH_2CH_3), 2.38 (2H, q, CH_2CH_3), 3.69 (3H, s, CO_2CH_3), 5.85 and 6.39 (2H, 2x s, C=CH_2), 6.70 (1H, s, C*H*-O), 7.33 (5H, m, Ar-*H*); δ_C(50 MHz) 9.04 (q, CH_2CH_3), 27.69 (t, CH_2CH_3), 51.97 (q, CO_2CH_3), 72.88 (d, *C*H-O), 125.72 (t, C=CH_2), 127.64, 128.34 and 128.45 (3x d, Ar-*C*), 137.90 (s, Ar-*C*), 139.79 (s, *C*=CH_2), 165.81 (s, *C*O_2CH_3), 172.81 (s, O_2*C*CH_2CH_3); m/z 248 (M^+, <1%), 191 (98), 159 (63), 115 (100), 105 (81), 57 (88). (Anal. Calcd. for $C_{14}H_{16}O_4$: C, 67.73; H, 6.50. Found: C, 67.64; H, 6.74%).

(2f). Allylic alcohol **(1f)** (5.00 g, 0.026 mol) and triethylamine (2.63 g, 0.026 mol) were dissolved in dry dichloromethane (100 ml) and cooled in ice. Acryloyl chloride (2.35 g, 0.026 mol) was added dropwise and the mixture stirred at room temperature for 4 h. The reaction was quenched with water and the organic phase washed with 2N HCl (2x 50 ml) and then 10% aq. $NaHCO_3$ (2x 50 ml). The organic phase was dried ($MgSO_4$), the solvent removed and purified by column chromatography. (5.38 g, 84%); δ_H ($CDCl_3$, 200 MHz) 3.64 (3H, s, CO_2CH_3), 5.70 and 6.50 (5H, m, C=CH_2 and C*H*=CH_2), 6.78 (1H, s, C*H*-O), 7.31 (5H, m, Ar-*H*); δ_C(50 MHz) 51.90 (q, OCH_3), 73.20 (d, *C*H-O), 125.74 (t, C=CH_2), 127.65, 128.41 and 128.46 (3x d, Ar-*C*), 128.10 (d, *C*H=CH_2), 131.46 (t, CH_2=CHCO$_2$), 137.70 (s, Ar-*C*), 139.60 (s, *C*=CH_2), 164.45 (s, CH_2=*C*HCO$_2$), 165.26 (s, *C*O_2CH_3); m/z 246 (M^+, <1%), 191 (73), 159 (43), 115 (93), 105 (96), 55 (100). (Anal. Calcd. for $C_{14}H_{14}O_4$: C, 68.22; H, 5.79. Found: C, 68.07; H, 5.85%).

(2g). Allylic alcohol **(1g)** (3.00 g, 0.016 mol) was added to a solution of DCC (3.61 g, 0.018 mol) in dry dichloromethane (50 ml), followed by ethyl malonic acid[4] (2.31 g, 0.018 mol) at 0 °C. The mixture was

allowed to warm to room temperature and stirred for 6 h. The dicyclohexyl urea was filtered off and the solvent removed. The residue was dissolved in diethyl ether, washed with 2N HCl (2x 50 ml) and 10% aq. $NaHCO_3$ (2x 50 ml) and then purified by column chromatography. (5.09 g, 90%); δ_H ($CDCl_3$, 200 MHz) 1.22 (3H, t, OCH_2CH_3), 3.41 (2H, s, $O_2CCH_2CO_2$), 3.68 (3H, s, OCH_3), 4.16 (2H, q, OCH_2CH_3), 5.93 and 6.41 (2H, 2x s, $C=CH_2$), 6.72 (1H, q, CH-O), 7.35 (5H, m, Ar-*H*); δ_C(50 MHz) 14.00 (q, OCH_2CH_3), 41.69 (t, $O_2CCH_2CO_2$), 51.99 (q, CO_2CH_3), 61.56 (t, OCH_2CH_3), 74.19 (d, CH-O), 126.14 (t, $C=CH_2$), 127.70, 128.48 and 128.57 (3x d, Ar-*C*), 137.18 (s, Ar-*C*), 139.04 (s, $C=CH_2$), 164.98 and 165.20 (2x s, $O_2CCH_2CO_2$), 166.20 (s, CO_2CH_3); m/z 306 (M^+, <1%), 191 (78), 159 (47), 115 (100), 105 (77), 59 (10). (Anal. Calcd. for $C_{16}H_{18}O_6$: C, 62.74; H, 5.92. Found: C, 62.59; H, 6.12%).

General procedure for the DABCO catalysed rearrangement of allylic esters (3a - g).

Allylic ester (2) (0.002 mol) and DABCO (25 mol%) were dissolved in dry THF and refluxed for 30 min. The DABCO was removed by eluting the reaction mixture through a silica gel plug and then the solvent was removed. Purification by column chromatography (silica, 20% diethyl ether / hexane) yielded the rearranged product in >90% yield.

(**3a**). Colourless oil; 95%; E : Z = 93 : 7; δ_H($CDCl_3$, 200 MHz) 2.09 (3H, s, CH_3CO_2), 3.82 (3H, s, OCH_3), 4.95 (2H, s, CH_2O), 7.38 (5H, s, Ar-*H*), 7.98 (1H, s, C=C*H*); δ_C(50 MHz) 20.91 (q, CH_3CO_2), 52.26 (q, OCH_3), 59.32 (t, CH_2O), 126.64 (s, C=CH), 128.72, 129.45 and 129.59 (3x d, Ar-*C*), 134.16 (s, Ar-*C*), 145.43 (d, CH=C), 167.23 (s, CO_2CH_3), 170.61 (S, CH_3CO_2); m/z 234 (M^+, 4%, 191 (67), 159 (100), 115 (58), 77 (19), 43 (39). (Anal. Calcd. for $C_{13}H_{14}O_4$: C, 66.66; H, 6.02. Found : C, 66.91; H, 5.98 %).

(**3b**). Colourless oil; 93%; E : Z = 95 : 5; δ_H($CDCl_3$, 200 MHz) 2.06 (3H, s, CH_3CO_2), 3.86 (3H, s, OCH_3), 5.46 (2H, s, CH_2O), 7.20 - 8.80 (5H, m, Ar-*H*, C=C*H* (7.81)); δ_C(50 MHz) 21.01 (q, CH_3CO_2), 52.39 (q, OCH_3), 58.85 (t, CH_2O), 126.41 (s, C=CH), 123.60, 126.48, 136.52 and 149.94 (4x d, Ar-*C*), 141.50 (d, CH=C), 153.36 (s, Ar-*C*), 167.43 (s, CO_2CH_3), 170.84 (S, CH_3CO_2); m/z 235 (M^+, 1%, 176 (59), 160 (100), 132 (68), 104 (53), 78 (49), 43 (42). (Anal. Calcd. for $C_{12}H_{13}NO_4$: C, 61.27; H, 5.57; N, 5.95. Found : C, 60.98; H, 5.41; N, 6.05 %).

(**3c**). Colourless oil; 90%; E : Z = 93 : 7; δ_H($CDCl_3$, 200 MHz) 2.07 (3H, s, CH_3CO_2), 3.83 (3H, s, CO_2CH_3), 5.24 (2H, s, CH_2O), 6.40 - 7.70 (4H, m, furfuryl-*H*, C=C*H* (7.61)); δ_C(50 MHz) 21.02 (q, CH_3CO_2), 52.30 (q, CO_2CH_3), 59.47 (t, CH_2O), 112.43, 118.20 and 130.40 (3x d, furfuryl-*C*), 121.76 (s, C=CH), 145.93 (d, C=CH), 150.30 (s, furfuryl-*C*), 167.49 (s, CO_2CH_3), 171.04 (s, O_2CCH_3); m/z 224 (M^+, 10%), 181 (52), 149 (100), 122 (41), 43 (66). (Anal. Calcd. for $C_{11}H_{12}O_5$: C, 58.93; H, 5.39. Found: C, 58.65; H, 5.42%).

(**3d**). Pale yellow solid (CH_2Cl_2); m.p. 104 °C; 90%; E : Z = 94 : 6; δ_H($CDCl_3$, 200 MHz) 2.01 (3H, s, O_2CCH_3), 3.88 (3H, s, CO_2CH_3), 4.74 (2H, s, CH_2O), 7.30-8.30 (5H, m, Ar-*H*, C=C*H* (8.23)); δ_C(50 MHz) 20.77 (q, O_2CCH_3), 52.48 (q, CO_2CH_3), 59.00 (t, CH_2O), 125.07, 130.02, 130.87 and 133.90 (4x d,

Ar-*C*), 128.12 (s, *C*=CH), 130.58 (s, *C*-NO_2), 142.22 (d, C=*C*H), 147.36 (s, Ar-*C*), 166.24 (s, *C*O_2CH_3), 170.30 (s, O_2*C*CH_3); m/z 248 (M^+ - 31, 2%), 159 (20), 92 (24), 77 (27), 43 (100). (Anal. Calcd. for $C_{13}H_{13}NO_6$: C, 55.92; H, 4.69; N, 5.02. Found: C, 55.64; H, 4.91; N, 5.22%).

(3e). Colourless oil; 94%; E : Z = 95 : 5; δ_H($CDCl_3$, 200 MHz) 1.16 (3H, t, CH_2CH_3), 2.37 (2H, q, CH_2CH_3), 3.83 (3H, s, CO_2CH_3), 4.97 (2H, s, CH_2O), 7.38 (5H, s, Ar-*H*), 7.98 (1H, s, C=C*H*); δ_C(50 MHz) 9.16 (q, CH_2CH_3), 27.54 (t, CH_2CH_3), 52.25 (q, OCH_3), 59.21 (t, CH_2O), 126.80 (s, *C*=CH), 128.71, 129.46 and 129.57 (3x d, Ar-*C*), 134.22 (s, Ar-*C*), 145.34 (d, C=*C*H), 167.29 (s, *C*O_2CH_3), 174.07 (s, O_2*C*CH_2CH_3); m/z 248 (M^+, 1%), 191 (54), 159 (100), 131 (25), 115 (66), 77 (19), 57 (70). (Anal. Calcd. for $C_{14}H_{16}O_4$: C, 67.73; H, 6.50. Found: C, 67.52; H, 6.61%).

(3f). Colourless oil; 91%; E : Z = 88 : 12; δ_H($CDCl_3$, 200 MHz) 3.84 (3H, s, OCH_3), 5.05 (2H, s, CH_2O), 5.80 - 6.50 (3H, m, CH_2=C*H*), 7.39 (5H, s, Ar-*H*), 8.02 (1H, s, C=C*H*); δ_C(50 MHz) 52.30 (q, OCH_3), 59.40 (t, CH_2O), 126.51 (s, *C*=CH), 128.14 (d, CH_2=*C*H), 128.74, 129.47 and 129.63 (3x d, Ar-*C*), 131.17 (t, CH_2=CH), 134.13 (s, Ar-*C*), 145.69 (d, C=*C*H), 165.82 (s, O_2*C*CH=CH_2), 167.25 (s, *C*O_2CH_3); m/z 246 (M^+, 1%), 191 (56), 159 (100), 131 (26), 115 (63), 77 (21), 55 (79). (Anal. Calcd. for $C_{14}H_{14}O_4$: C, 68.28; H, 5.73. Found: C, 68.07; H, 5.85%).

(3g). Colourless oil; 96%; E : Z = 90 : 10; δ_H($CDCl_3$, 200 MHz) 1.27 (3H, t, CH_2CH_3), 3.43 (2H, s, O_2*C*CH_2*C*O_2), 3.84 (3H, s, OCH_3), 4.20 (2H, q, OCH_2CH_3), 5.02 (2H, s, CH_2O), 7.40 (5H, s, Ar-*H*), 8.01 (1H, s, C=C*H*); δ_C(50 MHz) 14.07 (q, OCH_2CH_3), 41.53 (t, OCH_2CH_3), 52.31 (q, OCH_3), 60.32 (t, CH_2O), 61.55 (t, O_2*C*CH_2*C*O_2), 125.95 (s, *C*=CH), 128.79, 129.54 and 129.75 (3x d, Ar-*C*), 134.00 (s, Ar-*C*), 146.10 (d, C=*C*H), 166.27 and 166.39 (2x s, O_2*C*CH_2*C*O_2), 167.08 (s, *C*O_2CH_3); m/z 306 (M^+, 1%), 191 (39), 160 (67), 159 (92), 115 (100), 103 (25), 59 (17). (Anal. Calcd. for $C_{16}H_{18}O_6$: C, 62.74; H, 5.92. Found: C, 62.81; H, 5.90%).

Acknowledgements.

The authors wish to thank the University of Natal and the Foundation for Research Development (FRD) for financial assistance.

References.

1. Drewes, S. E. and Roos, G. H. P. *Tetrahedron*, **1988**, 44, 4653.
   Drewes, S. E. and Emslie, N. D. *J. Chem. Soc., Perkin Trans. 1*, **1982**, 2079.
2. Hegarty, A. F. *Comprehensive Organic Chemistry*; Pergamon Press: Oxford. 1985; 1067.
3. Foucaud, A. and El Guemmout, F. *Bull. De La Soc. Chim. de France*, **1989**, 403.
4. Strube, R. E. *Organic Syntheses*, **1957**, 37, 34.

(*Received in UK* 11 *July* 1994; *revised* 19 *August* 1994; *accepted* 26 *August* 1994)