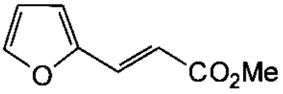
REGIO- AND STEREOCHEMICAL CONTROL IN THE PHOTODIMERIZATION OF METHYL 3-(2-FURYL)ACRYLATE

Maurizio D'Auria

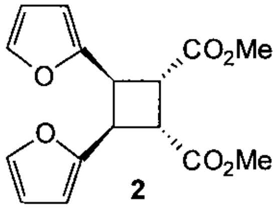
Dipartimento di Chimica, Università della Basilicata, Via N. Sauro 85, 85100
Potenza, Italy

Abstract - The photochemical dimerization of methyl 3-(2-furyl)acrylate in acetonitrile in the presence of benzophenone as triplet sensitizer was reinvestigated in order to understand regio- and stereochemical control. Hplc purification of the dimers and ^{1}H-nmr data allow to correct a wrong structural assignment for a dimer found in the reaction. Regiochemical control can be understood on the of frontier orbitals interaction. Stereochemical control depends on the stability of the dimers. All these data were obtained by the use of the AM1 semiempirical method.

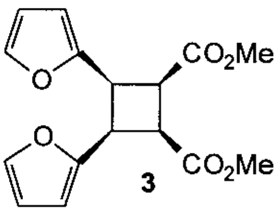
Some years ago we reported that the irradiation of methyl 3-(2-furyl)acrylate (**1**) in acetonitrile in the presence of benzophenone gave the dimeric products (**2**) and (**3**).[1]



1



2



3

It was the first example of photochemical dimerization of arylacrylic derivatives in solution in the absence of Lewis acids.[2,3] Subsequently, we studied the photophysical behaviour of compound (**1**) in order to obtain informations on the reaction mechanism.[4] The most important results of this study showed that 1. the direct irradiation of **1** gave only *cis-trans* isomerization: the reaction mixture reached a photostationary equilibrium of *cis* and *trans* isomers in 25 and 75%; 2. in the presence of benzophenone a mixture of dimers were obtained showing a zero order kinetics, depending on the benzophenone concentration; 3. electron transfer processes or exciplexes can be excluded considering that DCA was unable to sensitize the conversion of **1** into the dimeric products and that both the reaction kinetics and the composition of the product mixture were not affected by changing the solvent; 4. finally, laser flash photolysis experiments showed only the formation under the sensitized condition of the lowest excited triplet state of **1**. All these data are in agreement with the hypothesis that sensitized triplet state reacted with another molecule of **1** to give a biradical that collapses to the dimers.

In this paper we want to give some indications useful to solve the last problem connected with this research field. We have to answer to the question regarding the observed regio- and stereoselectivity of the reaction. We have to explain the reason of the formation of only two isomers from eleven possible dimers.

RESULTS AND DISCUSSION

In order to solve the problems suggested above, we have performed the reaction again. We wanted to verify if some other isomers could be isolated from the reaction mixture. Thus, we have purified the reaction mixture *via* semipreparative hplc using LichroSpher C-18 column and eluting with acetonitrile - water mixtures. This way, we could verify that we obtained only two products as described before.[1] The

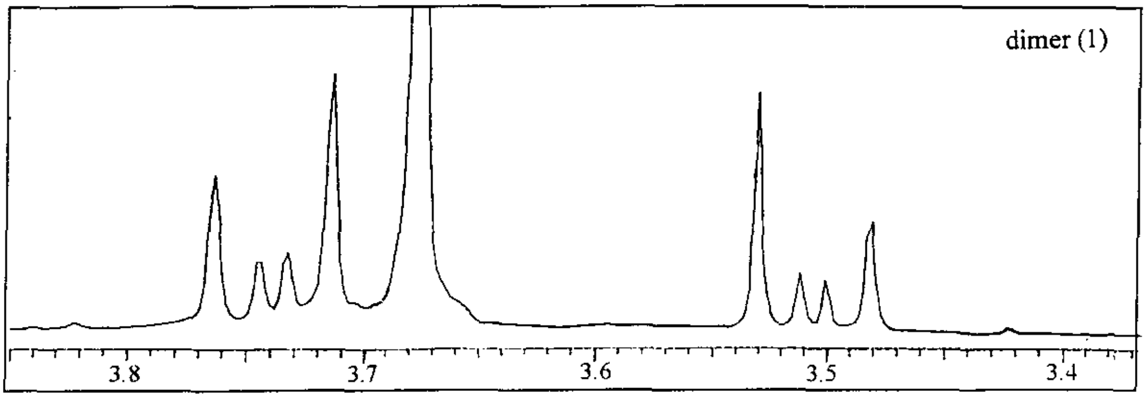


Figure 1 - A_2B_2 part of ^{1}H-nmr spectrum of dimer (1)

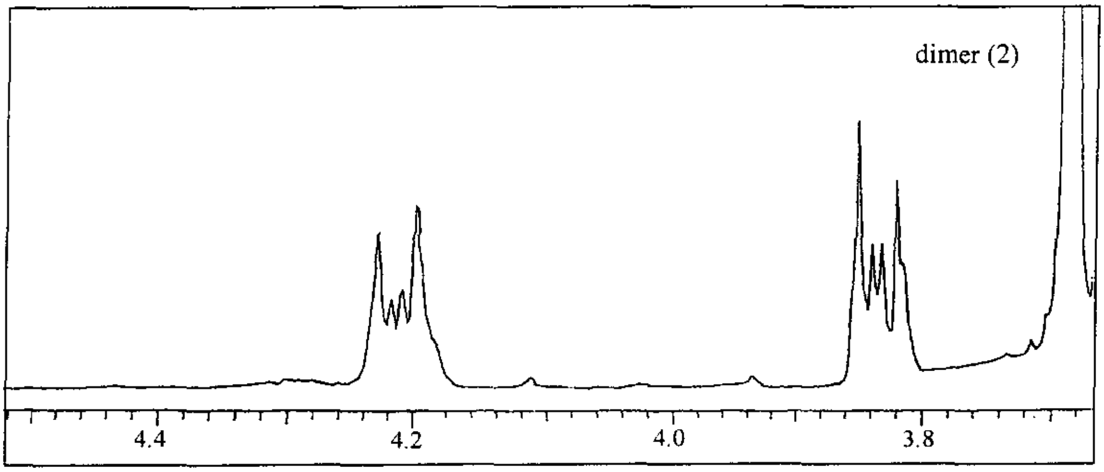


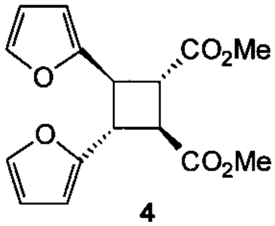
Figure 2 - A_2B_2 part of ^{1}H-nmr spectrum of dimer (2)

first (dimer 1) was obtained in 60% yield and the second (dimer 2) in 26% yield. Nevertheless, we observed some modifications in the A_2B_2 part of ^{1}H-nmr of the dimers. The A_2B_2 part of the ^{1}H-nmr spectra in $CDCl_3$ of these two dimers are reported in Figures 1 and 2. Mass spectra clearly showed that all the dimers are head-to-head dimers. The analysis of the nmr spectra is reported in Table 1. We used *N*, *L*, *K*, and *M* parameters as reported in other studies on this field.[5-7] This treatment of the data allows us to obtain the following information: 1. J (J_{AB}) is 9.9 Hz for the dimer 1 and 10.1 Hz for the dimer (2): these data are in agreement with a *trans* relationship between A (furan) and B (ester) substituents; 2. J_A (J_{AA}) and J_B (J_{BB}) are 7.7 Hz for the dimer (1) and 10.1 Hz for the dimer (2): these data can be in agreement with a *cis* relationship between A (and B) substituents in the dimer (1) and with a *trans* relationship in the dimer (2). These data are in agreement with the reported structure (**2**) for the dimer (1) while, for the dimer (2), structure (**4**) seems to be in agreement with ^{1}H-nmr data.

Table 1 - ^{1}H-Nmr data for dimers of methyl 3-(2-furyl)acrylate

Compound	N	L	K	M	J	J'	J_A	J_B
dimer 1	10.0	9.8	15.4	0	9.9	0.1	7.7	7.7
dimer 2	10.5	9.6	20.0	0	10.1	0.5	10.0	10.0

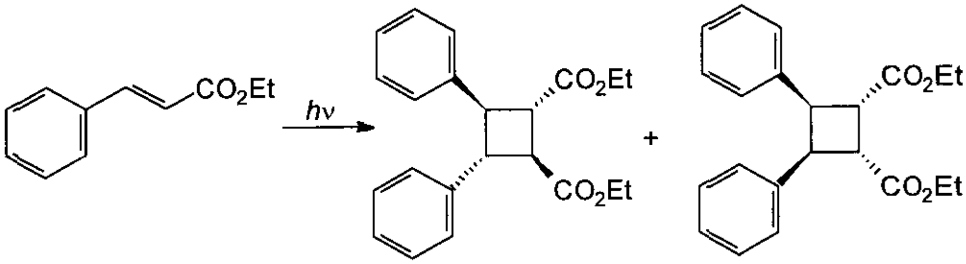
All data are reported in Hertz



4

The ^{1}H and ^{13}C-nmr spectra of our obtained dimers can be compared with those obtained in the photodimerization of cinnamate esters. Thus, the irradiation of pure liquid ethyl cinnamate gave a 2:1

mixture of **6** and **7**.[8] The ^{1}H-nmr spectrum of the dimer (**7**) was very similar to the spectrum of the dimer (**2**). In fact, while we observed the cyclobutane protons at lower fields that in **2** (we observed a multiplet at δ 4.31 and a multiplet at δ 4.28 ppm), the analysis of the spectrum showed the same trend observed for **2**



5 **6** **7**

(J = 10 Hz, J' = 0.2 Hz, J_A = J_B = 8 Hz). ^{13}C-Nmr spectrum of **7** showed cyclobutane absorptions at δ 47.82 and 45.72 ppm. Also in this case the absorptions were shifted to lower fields in comparison with those observed with the dimer (**2**) (see experimental section). Compound (**6**) showed in the ^{1}H-nmr spectrum multiplets at δ 3.78 and 3.46 ppm due to the cyclobutane protons. The analysis of the multiplets showed coupling constant very similar to those described for compound (**4**). In fact, we obtained J = 9.8 Hz, J' = 0.3 Hz, and J_A = J_B = 9.6 Hz. In the ^{13}C-nmr spectrum cyclobutane carbons showed peaks at δ 46.11 and 43.96 ppm. We observed the same trend shown in the ^{13}C-nmr spectrum of **4**. Also in this case, in fact, the cyclobutane carbons are shifted to higher fields in comparison with the peaks showed by the dimer (**2**).

All these data are in agreement with the structure proposed for the dimers (**2**) and (**4**).

In order to explain the formation of only head-to-head dimers we have examined the possibility of frontier orbital control in the stereochemical behaviour of methyl 3-(2-furyl)acrylate. We have estimated the HOMO and LUMO energy for this compound by using the AM1-UHF semiempirical method[9,10] and the results are collected in Table 2.

Clearly, the best interaction occurs between the HOMO of the excited triplet state and the LUMO of the fundamental singlet state. The SOMO for the triplet state of **1** and the LUMO fot the fundamental singlet state of the same molecule are depicted in Figure 3.

Table 2 - HOMO and LUMO for methyl 3-(2-furyl)acrylate.

Electronic State	HOMO (eV)	LUMO (eV)
S_0	- 8.903	- 0.677
T_1	- 7.467	0.820

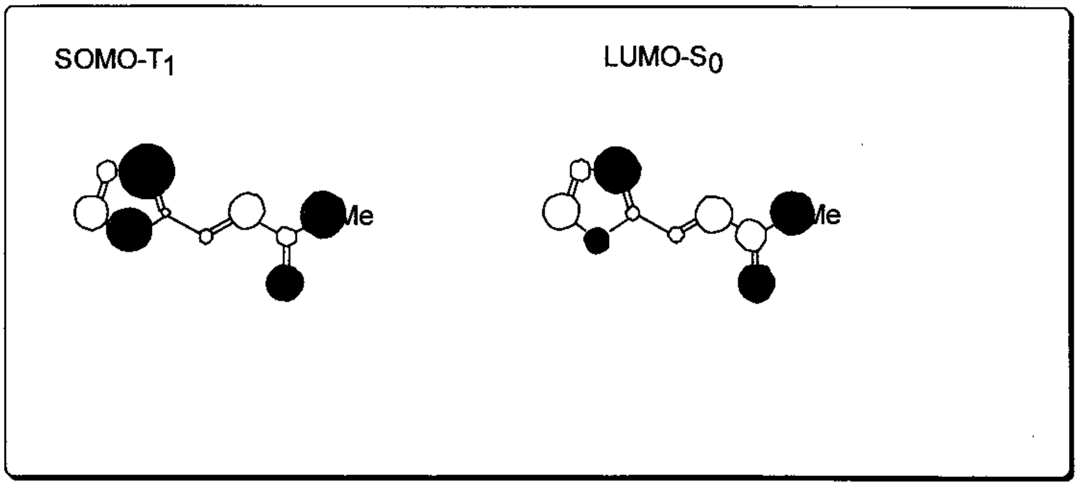


Figure 3 - SOMO of T_1 and LUMO of S_0 state of **1**.

We can see clearly that, in this case, we have the total superposition between the molecules of the reagents. These data can explain the formation of only head-to head dimers, because, in the case of head-to-tail dimers, the same superposition is not allowed. While the frontier orbitals allows us to explain regiochemical behaviour of the photochemical reaction, the stereochemistry of the reaction can not be explained on the basis of this theory.

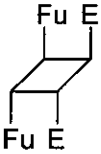
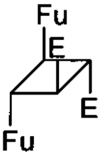
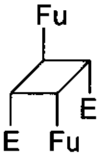
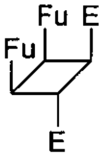
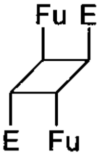
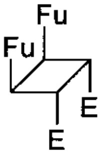
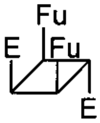
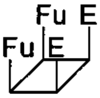
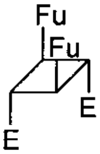
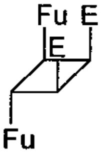
Recently, studying the photodimerization reaction of methyl cinnamate, molecular mechanics calculations showed that the relative stabilities of the dimers are in the order δ (27.12 kcal mol^{-1}) > ξ (28.81 kcal mol^{-1}) > μ (29.48 kcal mol^{-1}) > β (31.98 kcal mol^{-1}). δ-Truxinate ester is the dimer (**6**) while the β-isomer is the dimer (**7**).[11] In our case, we performed molecular mechanics calculations by using MM+ program in HyperChem packet. In this case we observed a completely different trend. In fact, the dimer (**2**) showed a steric energy of 63.86 kcal mol^{-1}, while the dimer (**4**) showed a value of 52.04 kcal mol^{-1}. We observed very different values in the steric energy in comparison with those reported for truxinate esters and these values were higher than those previously reported for the cinnamate dimers.[11] In particular the bending energy was the main cause of this difference. This effect is probably due to the presence of the more polar furan ring in the molecule.

Nevertheless, on the basis of this calculations, the main product of the photochemical dimerization of **1** is less stable than the other product. Then, this approach does not allow us to solve the problem of the stereochemistry of the dimerization reaction.

In order to solve this problem, we calculated the electronic total energy for all the possible dimers. Calculations were performed by using, also in this case, AM1-UHF semiempirical method. The data are collected in Table 3.

We can see that head-to-head dimers are usually more stable than head-to-tail isomers. This could be second justification of the regiochemical control of the reaction. Furthermore, within head-to-head

Table 3 - Total electronic energy of dimers of methyl 3-(2-furyl)acrylate

Substrate[a]	-E (kcal mol^{-1})	Substrate[a]	-E (kcal mol^{-1})
	96448		96265
	96472		96268
	96461		96277
	96482		96272
	96235		96472
	96465		

a) Fu = 2-Furyl, E = CO_2Me

dimers, the more stable dimers are the obtained ones. Different stability between these two dimers accounts for the different yields observed.

In conclusion, a more accurate purification of the reaction products allowed us to correct the structure of the second dimer obtained in the photochemical dimerization of **1**. Regiochemical control of the reaction can be explained assuming a frontier orbital interactions between the SOMO of the excited triplet state and the LUMO of the S_0 of **1**. Stereochemical behaviour of the reaction can be understood considering the different stability of the possible dimers, where more stable dimers were obtained.

EXPERIMENTAL

Photochemical Dimerization of Methyl 3-(2-Furyl)acrylate. 3-(2-Furyl)acrylic acid was converted into the methyl ester by reaction of the corresponding acyl chloride[12] with MeOH in the presence of pyridine.[13] Compound (**1**) (1 g, 6.6 mmol) was dissolved in acetonitrile (300 ml) in the presence of benzophenone (100 mg). The solution was outgassed with nitrogen for 1 h and was irradiated in an immersion apparatus with a 500 W high-pressure mercury arc (Helios-Italquartz) surrounded by a Pyrex water-jacket. After 7 h removal of the solvent under reduced pressure yielded a crude product which was chromatographed on C-18 hplc semipreparative column eluting with acetonitrile - water (98:2). Compound (**2**)[1]: 602 mg (60%) very viscous oil. Compound (**4**)[1]: 261 mg (26%) very viscous oil.

Photochemical Dimerization of Ethyl Cinnamate. Ethyl cinnamate (Aldrich) (100 mg, 0.56 mmol) was irradiated in a cuvette (17 x 17 x 1 mm) by using a 125 W high pressure mercury arc (Helios-Italquartz) surrounded by a Pyrex water-jacket. After 24 h, the crude product was chromatographed on a preparative tlc using *n*-hexane/Et_2O (8:2) as eluent. Compound (**6**)[8]: 50 mg (50%); very viscous oil. Compound (**7**)[8]: 25 mg (25%); mp 131 - 132 °C (lit.,[14] 131 - 132 °C).

REFERENCES

1. M. D'Auria, G. Piancatelli, and A. Vantaggi, *J. Chem. Soc., Perkin Trans. I*, 1990, 2999.
2. F. D. Lewis and J. D. Oxman, *J. Am. Chem. Soc.*, 1984, **106,** 466.
3. F. D. Lewis, S. L. Quillen, D. D. Hale, and J. D. Oxman, *J. Am. Chem. Soc.*, 1988, **110**, 1261.
4. M. D'Auria, A. D'Annibale, and T. Ferri, *Tetrahedron*, 1992, **48,** 9323.
5. D. M. Grant, R. C. Hirst, and H. J. Gutowsky, *J. Chem. Phys.*, 1963, **38**, 470.
6. C. H. Krauck, S. Farid, and G. O. Schenck, *Chem. Ber.*, 1966, **99**, 625.
7. G. Montaudo, S. Caccamese, and V. Librando, *Org. Magn. Res.*, 1974, **6**, 534.
8. P. L. Egerton, E. M. Hyde, J. Trigg, A. Payne, P. Beynon, M. U. Mijovic, and A. Reiser, *J. Am. Chem. Soc.*, 1981, **103**, 3859.
9. M. J. S. Dewar, E. G. Zoebisch, and E. F. Healy, *J. Am. Chem. Soc.*, 1985, **107**, 3902.
10. M. J. S. Dewar and Y. C. Yuan, *Inorg. Chem.*, 1990, **29**, 3881.
11. G. Robinet, J. Devillers, C. de Bourayne, M. Riviere, and M. Barthelat, *N. J. Chem.*, 1987, **11**, 51.
12. T. Sasaki, *Biochem. Z.*, 1910, **25**, 272.
13. P. D. Bartlett and S. D. Ross, *J. Am. Chem. Soc.*, 1947, **69**, 460.
14. H. I. Bernstein and W. C. Quimby, *J. Am. Chem. Soc.*, 1943, **65**, 1845.

Received, 11th December, 1995