HETEROCYCLES, Vol. 37, No. 3, 1994

TRANSMISSION OF ELECTRONIC EFFECTS THROUGH THE VINYL GROUP. REACTIVITIES OF THE (*E*)-α-4-SUBSTITUTED PHENYL-β-PYRIDINEACRYLIC ACIDS

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Abstract — The reactivities of a series of 18 (*E*)-α-4-substituted phenyl-β-(3N and 4N)pyridineacrylic acids, with a wide range of substituent effects, were investigated in their reaction with diazodiphenylmethane, in dimethylformamide at 30 °C, by the known spectrophotometric method. The Hammett equation in its original form has been applied to the results, using the sum of substituent constants from the both aromatic nuclei, but the overall correlation was only fair. Better insight into the transmission of substituent effects was obtained using Taft's Dual Substituent Parameter (DSP) method, where it was possible to distinguish the contributions from the inductive and resonance effects of the substituents.

INTRODUCTION

In a previous investigation[1] we studied the transmission of electronic effects through the vinyl group in substituted cinnamic and pyridineacrylic acids, employing the standard probe for the investigation of the effect of substituents on the reactivity of carboxylic acids, the reaction with diazodiphenylmethane (DDM). This reaction has already been used to investigate the transmission of substituent effects through three types of double bonds, an open chain, in a ring and delocalized double bonds, in (*Z*)- and (*E*)- 3-substituted acrylic acids,[2,3] 2-substituted cyclohex-1-enecarboxylic acids,[4] and *ortho*-substituted benzoic acids,[5,6] respectively.

The reaction of DDM with carboxylic acids has been studied, in both protic and aprotic solvents, and dimethylformamide (DMF) was emploed whenever the low solubility of an acid prevented the use of other usual solvents.[7] On the basis of available data it has been suggested that the mechanism of

$$RCOOH + Ph_2CN_2 \xrightarrow{slow} RCOO^- Ph_2CN_2H^+$$

$$RCOO^- Ph_2CN_2H^+ \xrightarrow{fast} RCOO^- Ph_2CH^+ + N_2$$

$$RCOO^- Ph_2CH^+ \xrightarrow{fast} RCOOCHPh_2$$

Scheme. Mechanism of the reaction of carboxylic acids with diazodiphenylmethane in DMF.

this reaction involved a reactive ion-pair intermediate, which in aprotic solvents collapses to the ester only (Scheme),while in hydroxylic solvents yields the corresponding diphenylmethylether as well[1,7] (and references therein).

The transmission of electronic effect and the influence of different aspects of steric effects in compounds similar to those studied in the present work, using the principles of linear free energy relationships, have been reported.[8-11] Bowden and Parkin,[8] determined the rate constants for the reaction with DDM and the pKa values for a number of substituted (*E*)- and (*Z*)-α-phenylcinnamic acids, and established the prime importance of the field effect, augmented where possible, by a π-inductive effect. In connection with the study of the kinetics and mechanism of the isomerization of some diarylacrylonitriles, Maccarone et al. also determined the dissociation constants of the (*E*)- and (*Z*)-α, β-diarylacrylic acids, and successfully applied the LFER principles to the results from both reactions.[10,11] From the point of view of our own work the second paper is most interesting because of the similarity of the investigated system and the established combination of polar and steric effects.[11]

The stereochemistry of the α,β-diarylacrylic acids has been extensively studied.[10-13] It was concluded that in the (*Z*)- acids both aromatic rings are coplanar with the ethylenic fragment while the carboxy group is non-coplanar. In the (*E*)- acids, the β-aromatic ring is almost coplanar with the carbonyl group, while the α-aryl group is out of plane of the rest of the molecule or even perpendicular to it.[13] Conformational preferences of (*E*)-α-phenyl-β-2-thienylacrylic acids and (*E*)-α-phenyl-β-2-furylacrylic acids, with various substituents in the phenyl ring, have been the subjects of a nmr study, and it has been established that these acids exist in only one rotamer *s-trans* and *s-cis*, respectively.[12] The *s-cis* conformation in the latter was explained by an electrostatic repulsion between the negative charged heterocyclic oxygen and the π-cloud of the benzene nucleus.

RESULTS AND DISCUSSION

Keeping in mind the structural and stereochemical characteristics of the (*E*)-diarylacrylic acids, we believed that the high sensitivity of the reaction with DDM shoud be suitable for a study of substituent effects in this model system. In the present investigation we determined the second order rate constants for the three series of α,β-diarylacrylic acids, namely, (*E*)-α-4-substituted phenyl*-β-3-pyridineacrylic acids, (*E*)-α-4-substituted phenyl* -β-4-pyridineacrylic acids, and for comparision, (*E*)-α-4-substituted *phenyl*-β-phenylacrylic acids*. Rate data are given in the Table. The values for the corresponding Hammett substituent constants are taken from the literature for heteroaromatic[14] and phenyl[15] ring.

The Hammett equation in its original form (1), applied to the results in the Table , using the sum of substituent constants

$$\log k_2 = \log k_0 + \rho\,(\sigma_X + \sigma_Y) \qquad (1)$$

yielded only a fair overall correlation:

$$\log k_2 = -3.185 + 0.404\,(\sigma_X + \sigma_Y) \quad (r=0.943, s=0.084, n=18) \qquad (2)$$

Separate treatment of the investigated series of the (*E*)-α,β-diarylacrylic acids, 1-6, 6-12 and 13-18 gave better correlation coefficients, but the lower sensitivity of the reaction constant for the 4-pyridine β-substituent is difficult to explain by this approach.

β-phenyl: $\log k_2 = -3.165 + 0.605\,\sigma_Y \quad (r=0.962, s=0.066, n=6)$ (3)

β-3-pyridine: $\log k_2 = -3.431 + 0.634\,(\sigma_X + \sigma_Y) \quad (r=0.991, s=0.033, n=6)$ (4)

β-4-pyridine: $\log k_2 = -3.294 + 0.472\,(\sigma_X + \sigma_Y) \quad (r=0.993, s=0.023, n=6)$ (5)

If an extended form of the Hammett equation (6) is used to calculate the polar contribution of the substituents in both aromatic rings with the aid of multiple regression analysis, a very good correlation is obtained(7):

$$\log k_2 = \log k_0 + \rho_X \sigma_X + \rho_Y \sigma_Y \qquad (6)$$

$$\log k_2 = -3.167 + 0.324\,\sigma_X + 0.573\,\sigma_Y \quad (r=0.982, s=0.050, n=18) \qquad (7)$$

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* One substituent, the methoxy group, was in position 3 in the all three series.

The value of ρ_X which could be expected to a measure the transmission of polar effects from the β-aryl substituent is much lower than ρ_Y , which is probably due to the attenuation through the ethylenic bond. However, its magnitude $\rho_X / \rho_Y = 0.565$, implicates the contribution of some other effect as well, possibly the attenuation caused by the ring nitrogen, already observed in the correlation

Table. Rate constans for the reaction of (*E*)-α-4-substituted phenyl-β-pyridineacrylic acids with DDM, in DMF at 30 °C

$X\text{-}C_6H_4\text{-}CH{=}C(C_6H_4\text{-}Y)COOH$

Acids	Substituents		10^{-4} k_2	- $\log k_2$
	X	Y	$dm^3 mol sec^{-1}$	
1	H	H	8.37	3.077
2	H	Cl	9.35	3.029
3	H	Br	10.52	2.975
4	H	OCH_3	3.95	3.403
5	H	3-OCH_3	7.67	3.115
6	H	NO_2	18.65	2.729
7	3N	H	10.58	2.976
8	3N	Cl	14.41	2.841
9	3N	Br	17.50	2.757
10	3N	OCH_3	7.29	3.137
11	3N	3-OCH_3	12.89	2.890
12	3N	NO_2	33.23	2.478
13	4N	H	16.12	2.793
14	4N	Cl	22.25	2.653
15	4N	Br	21.69	2.664
16	4N	OCH_3	13.13	2.882
17	4N	3-OCH_3	17.80	2.750
18	4N	NO_2	40.47	2.393

analysis of the results of alkaline hydrolysis of substituted pyridine carboxylates[16] and the reaction of substituted pyridine- and pyridine-*N*-oxide carboxylic acids with DDM.[17]

With the idea of obtaining more insight into the finer points of the interplay of polar and steric effects, we used Taft's Dual Substituent Parameter (DSP) equation in the form:

$$\log k_2 = \log k_0 + \rho_X\sigma_X + \rho_{IY}\sigma_{IY} + \rho_{RY}\sigma_{RY} \qquad (8)$$

to dissect the electronic effects from the α-phenyl ring into inductive and resonance components. The values for σ_I and σ_R employed in equation (8) are taken from the literature[18] and are as follows: $\sigma_I = 0.47$ and $\sigma_R = -0.24$ (p-Cl); $\sigma_I = 0.45$ and $\sigma_R = -0.22$ (p-Br); $\sigma_I = 0.23$ (m- and p-OCH_3) $\sigma_R = -0.50$ (p-OCH_3) and $\sigma_R = -0.17$ (m-OCH_3); $\sigma_I = 0.63$ and $\sigma_R = 0.15$ (p-NO_2). The following relationships (9)-(11) were obtained for the three series of investigated acids:

β-phenyl: $\log k_2 = -3.089 + 0.463\,\sigma_{IY} + 0.741\,\sigma_{RY}$ (r=0.980, s=0.057, n=6) (9)

$\lambda = \rho_R/\rho_I = 1.60$

β-3-pyridine: $\log k_2 = -2.964 + 0.648\,\sigma_{IY} + 0.607\,\sigma_{RY}$ (r=0.990, s=0.042, n=6) (10)

$\lambda = \rho_R/\rho_I = 0.94$

β-4-pyridine: $\log k_2 = -2.793 + 0.522\,\sigma_{IY} + 0.434\,\sigma_{RY}$ (r=0.999, s=0.009, n=6) (11)

$\lambda = \rho_R/\rho_I = 0.83$

The overall correlation, for all available date is as follows:

$$\log k_2 = -3.148 + 0.324\,\sigma_X + 0.544\,\sigma_{IY} + 0.594\,\sigma_{RY} \quad (r=0.983, s=0.05, n=18) \qquad (12)$$

$\lambda = \rho_R/\rho_I = 1.09$

Contrary to the stereochemical evidence of the non-coplanarity of the α-aryl group[9,11,12] the DSP treatment of the investigated acids shows an appreciable contribution of the resonance effect, which is very pronounced if the β-aryl group is the unsubstituted phenyl ring. Comparison of the correlation for these acids (9) to those for β-pyridine substitution, is possibly due to the smaller out-of-plane angle of the former, due to a less "thick" electronic cloud around the benzene than the pyridine nucleus. The difference in the λ values of the 3- and 4-pyridine acids could be explained by the acid strenghtening delocalization induced by the 4-nitrogen in the pyridine nucleus, which reduces the extension of the already poor delocalisation of the system, due to non-coplanarity, and hence the diminished resonance component.

The overall correlation (12) by the DSP method shows a relative balance of the inductive and resonance effects in the α-aryl group, and a low sensitivity to the effect of substituents from the β-aryl group. This indicate a reduced coplanarity of the system as a whole, with a degree of relaxation which, however, allows the resonance transmission of substituent effects to the reaction centre, through a partly delocalised system.

We believe that through our further investigations of the ^1H and ^{13}C nmr chemical shifts of the same compounds additional information could be obtained about the stereochemically controlled transmission of electronic effects through the ethylenic bond.

EXPERIMENTAL

Materials.- The α,β-diarylacrylic acids examined in this work were synthesized by a Perkin reaction as described.[12,18,19] Known compounds, acids (1, 2, 4, 6, 7, 8, 9, 10 and 12) had melting points in agreement with those given in the literature.[13,19,20] The melting points and elemental analysis of the new compounds in the Table, are given below:

3 had mp 189-191 °C (benzene - hexane) Anal.Calcd for $C_{15}H_{11}O_2Br$: C, 59.43; H, 3.65.
Found : C, 59.39; H, 3.64.

5 had mp 158-159 °C (ethanol) Anal.Calcd for $C_{16}H_{14}O_3$: C, 75.60; H, 5.51.
Found : C, 75.58; H, 5.60.

11 had mp 189-190 °C (ethanol - water) Anal.Calcd for $C_{15}H_{13}NO_3$: C, 70.59; H, 5.10; N, 5.49.
Found : C, 70.41; H, 5.15; N, 5.54.

13 had mp 260-261 °C (ethanol - water) Anal.Calcd for $C_{14}H_{11}NO_2$: C, 74.67; H, 4.90; N, 6.20.
Found : C, 74.85; H, 5.10; N, 6.34.

14 had mp 273-275 °C (ethanol) Anal.Calcd for $C_{14}H_{10}NO_2Cl$: C, 64.74; H, 3.85; N, 5.40.
Found : C, 64.40; H, 3.90; N, 5.20.

15 had mp 276-277 °C (ethanol) Anal.Calcd for $C_{14}H_{10}NO_2Br$: C, 55,26; H, 3.29; N, 4.60.
Found : C, 55.12; H, 3.32; N, 4.72.

16 had mp 244-245 °C (ethanol) Anal.Calcd for $C_{15}H_{13}NO_3$: C, 70.59; H, 5.10; N, 5.49.
Found : C, 70.10; H, 5.20; N, 5.50.

17 had mp 210-212 °C (ethanol) Anal.Calcd for $C_{15}H_{13}NO_3$: C, 70.59; H, 5.10; N, 5.49.
Found : C, 69.95; H, 5.32; N, 5.61.

18 had mp 278-280 °C (ethanol) Anal.Calcd for $C_{14}H_{10}N_2O_4$: C, 62.22; H, 3.70; N, 10.37. Found : C, 62.50; H, 3.92; N, 9.85.

DDM was prepared by the method of reference,[7] and recrystallized from absolute methanol. Stock solution (*ca.* 0.06 M) was stored in a refrigerator and diluted for use.

Solvent. *N,N*-Dimethylformamide for ultraviolet spectroscopy (Fluka).

Rate measurements. The rate constants for a series of (*E*)-α-substituted phenyl-β-pyridineacrylic acids with diazodiphenylmethane in dimethylformamide were determined by the known spectrophotometric method used by us in our previous investigations in the solvent DMF.[1] Absorbance measurements were performed at 525 nm with 1 cm cells at 30 °C. A Varian Superscan 3 spectrometer was used. For acids which were sufficiently soluble in DMF, the reactions were studied as a first order process, the concentration of acid being 0.06 M, and of DDM 0.006 M, and the second order rate constants were calculated from the observed first order rate coefficients. For other acids, the reaction was performed under the conditions of the secod order process, the concentrations of both reactants were 0.006 M. These values are given in the Table.

ACKNOWLEDGEMENT

We are grateful to the Serbian Republic Research Fund for financial support.

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Received, 16th September, 1993