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Substituent Effects on the Enantioselective Hydrocyanation of Aryl Aldehydes

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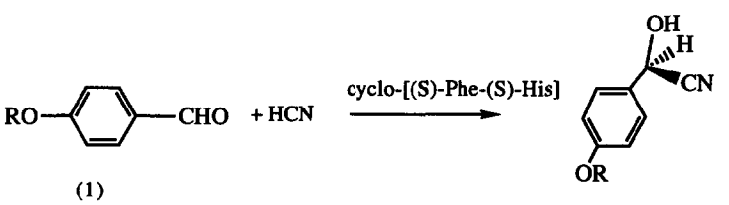
Abstract: A detailed study of the dipeptide catalysed enantioselective hydrocyanation of a series of O-substituted 4-hydroxybenzaldehydes has shown that adverse steric effects can occur leading to low enantiomeric excess (e.e.) values when the substituent is long and flexible. Similar hydrocyanation of several derivatives of 3,4-dihydroxybenzaldehydes have been shown to give very variable values of e.e. Hydrocyanation of 3,5-dimethoxy and 3,4,5-trimethoxybenzaldehyde consistently gave low values of e.e.

Our continuing interest in the application of enantioselective cyanohydrin formation from aryl aldehydes to organic synthesis[1,2] using the 'Inoue' dipeptide[3] has led us to study reactions of a wide range of O-substituted 4-hydroxy, 3,4- and 3,5-dihydroxy and 3,4,5-trihydroxybenzaldehydes. In a previous paper[4] we noted that asymmetric hydrocyanation of aryl aldehydes bearing electron-donating substituents in *m*- or *p*-positions relative to the aldehyde gave high e.e. values. We recently required a number of chiral cyanohydrins for use in the syntheses of chiral side chain liquid crystal polymers[5] and some biologically active hydroxyamides[6]. These preparations have involved hydrocyanation of a range of O-substituted hydroxybenzaldehydes and the results from these reactions are presented in this paper and throw some light on the geometric constraints which are imposed on transition states leading to highly enantioselective reactions.

Reactions of O-substituted 4-hydroxybenzaldehydes



(1) (R) - (2)

A series of O-substituted 4-hydroxybenzaldehydes (1) was prepared by standard literature procedures. Reactions with hydrogen cyanide were carried out at -10° in toluene using the 'Inoue' catalyst[3] which was activated prior to use by one of two established methods. The most successful method (method a) involved rapid precipitation of the catalyst from a solution in methanol by addition of ether[7]. Slightly worse results were obtained when the catalyst was activated by freeze-drying [2,8] (method b). The conversion was estimated from the ^{1}H n.m.r. spectrum of the total product and the e.e. values were determined by esterification using (R) - (+) - cyhalothrin acid[4]. Reactions of the alkenyloxybenzaldehydes

(1; R = $H_2C{=}CH(CH_2)_n$)where n = 1, 3, and 6 were carried out using the precipitated catalyst (entries 1, 3 and 4) under standard conditions. (Table 1). The allyloxy compound consistently gave the corresponding (R)-cyanohydrin (2; R=$H_2C{=}CHCH_2$) which contained no detectable amounts of the (S)-enantiomer.

Table 1 Hydrocyanation reactions of O-substituted 4-hydroxybenzaldehydes (1)†

Entry	Aldedyde (1) R	Reaction Time h	Conversion %	E.E. %	Activation Method*
1	$H_2C{=}CHCH_2$	24	88	≥98‡	a
2	$H_2C{=}CHCH_2$	24	58	78‡	b
3	$H_2C{=}CH(CH_2)_3$	24	70	71	a
4	$H_2C{=}CH(CH_2)_6$	24	65	50	a
5	CH_3OCH_2	24	90	88	a
6	CH_3OCH_2	24	89	85‡	b
7	CH_3OCH_2	48	95	80	b
8	$CH_3OCH_2CH_2OCH_2$	48	42	5	a
9	$H_2C{=}CHCH_2O$-C$_6$H$_4$-CO	24	85	80‡	a
10	$H_2C{=}CHCH_2O$-C$_6$H$_4$-CO	48	95	75	a
11	$H_2C{=}CHCH_2O$-C$_6$H$_4$-CO	24	73	72	b
12	$H_2C{=}CH(CH_2)_4O$-C$_6$H$_4$-CO	24	60	90	a
13	$H_2C{=}CH(CH_2)_9O$-C$_6$H$_4$-CO	24	80	84	a
14	$H_2C{=}CH(CH_2)_9O$-C$_6$H$_4$-CO	48	95	78	a
15	$(CH_3)_3Si$	24	< 50	<5	a,b

† Reactions at -10° for solutions of aldehyde in toluene

* Activation methods: **a** rapid precipitation of catalyst, **b** freeze dried catalyst

‡ Average of three of more experiments

The freeze-dried catalyst gave e.e. values of 78% with this substrate. Reactions of the longer chain alkenyloxy compounds (1; R = $H_2C{=}CH(CH_2)_3$) (entry 3) and (1; R = $H_2C{=}CH(CH_2)_6$) (entry 4) gave slightly lower conversions (70 & 65% respectively) and e.e. values which decreased with increasing chain length (71 and 50% for the compounds with n = 3 and n = 6 respectively). It thus appeared as though the longer flexible chains which could be expected to cause adverse steric interactions above and around the aryl ring were causing a decrease in enantioselectivity.

Support for this suggestion came from the results of hydrocyanation of other substituted 4-hydroxybenzaldehydes. Reaction of the MOM-protected compound (1; R =CH_3OCH_2) gave good yields and e.e.'s under a variety of conditions (entries 5,6 & 7). In contrast the MEM - protected compound (1; R = $CH_3OCH_2CH_2OCH_2$) gave both a low yield and e.e. value. This dramatic decrease in yield and e.e.. appears to be connected with other than steric effects as the results are much lower than would be expected for a hydrocarbon substituent of comparable chain length (see entries 3 & 4).

The ability of the mobile side chain to interact with catalyst surfaces in the vicinity of the aryl ring in the above reactions has been suggested to be the reason for obtaining low yields and e.e. values with several of the above compounds. Introduction of an alkenyl substituent in such a manner that it is not free to occupy space near the aryl aldehyde ring should therefore not lead to as significant a decrease in e.e. values.

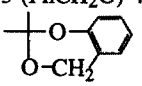
Accordingly the *p*-alkenyloxybenzoyl derivatives (1; R = $H_2C{=}CH(CH_2)n$–C6H4–C(=O)–) where n =1,4 and 9 were prepared. Reactions of these compounds where alkenyl side chain is remote from the aryl aldehyde ring under a range of conditions gave yields and e.e. values which did not show any correlation with the length of the side chain (entries 9 to 14).

Reactions of silyloxy derivates consistently gave both low yields and e.e's. One example for (1; R = $(H_3C)_3Si$) is included in the table (entry 15). It is possible that O → N silyl transfer occurs under the reactions conditions thus leading to catalyst deactivation.

Reactions of O-substituted 3,4 and 3,5-dihydroxybenzaldehydes

Previous work by us[4] gave cyanohydrins from reactions of 3,4-dibenzoyloxybenzaldehyde and 3,4-methylenedioxybenzaldehyde in both good yield (ca 70%) and e.e. (ca 75%). Reactions of other closely related compounds e.g. 3,4-dimethoxybenzaldehyde, 3-methoxy-4-benzyloxybenzaldehyde, and the methylene acetal from 3-hydroxymethyl-4-hydroxybenzaldehyde gave very variable results. Thus e.g. although a result comparable with the literature values was obtained for a reaction of 3,4-dimethoxybenzaldehyde using a precipitated catalyst (entry 16, Table 2), another worker obtained cyanohydrin with much lower e.e. values (entry 16). The activity of the catalyst in reactions of 4-allyloxybenzaldehyde was shown to be consistently high giving e.e. values ≥ 98% in all cases. Very variable results were obtained for other aldehydes even when reactions were carried out by the same worker using the same catalyst (entries 16-19). If thus appears that the enantioselective cyanohydrin formation from these 3,4-disubstituted benzaldehydes is difficult to reproduce and should not be depended on as part of a synthetic plan. Reactions of 3,5-dimethoxy and 3,4,5-trimethoxybenzaldehydes consistently gave both low values of conversion and e.e. (entries 20,21).

Table 2 Hydrocyanation reactions of O-substituted 3,4- and 3,5-dihydroxybenzaldehydes (ArCHO)†

Entry	Substituent in ArCHO	Conversion %	E.E. %
16	3,4-$(CH_3O)_2$-	60-80	20-73
17	3,4-$(PhCH_2O)_2$-	70	79[4]
18	3-$(PhCH_2O)$-4-(CH_3O)-	70-90	<10
19		0-80	0-65
20	3,5-$(CH_3O)_2$-	50	0-10
21	3,4,5-$(CH_3O)_3$-	20-50	0-10

† Reactions carried out at -10 to -5° for 12 to 24h with catalysts of proven activity

Mechanistic Comments

We believe that the sensitivity of the enantioselection to the presence of long, flexible substituents in the *para*-position of the reacting aryl aldehyde, the very low reactivity and e.e. values displayed in reactions of 3,5-disubstituted aryl aldehydes, and the lack of reproducibility of reactions of 3,4-disubstituted aryl aldehydes are in keeping with a U-shaped conformation of the dipeptide in the transition state of the type discussed by us previously[9] and shown in the Figure. Conformational rigidity in the transition state leading

to high enantioselectively is provided by two hydrogen bonds and an aryl-aryl interaction. It is easy to see how 3,5-(R^1,$R^3 \neq H$) or 3,4,5- (R^1,R^2,$R^3 \neq H$) substitutents could cause adverse interactions and disrupt the above transition state. The presence of *para*-substituents ($R^2 \neq H$) would not be expected to cause adverse interactions unless they are both long and flexible e.g. as seen in the decrease in e.e. with increasing chain length noted above, (e.g. entries 1,3 and 4). First inspection of the proposed transition state suggests that 3,4-disubstituted aryl aldehydes (R^1,$R^2 \neq H$, $R^3 = H$) could be accommodated in the transition state. However, it is recognised that this transition state picture is probably an oversimplification as Danda has provided strong evidence for the involvement of a molecule of cyanohydrin[7].

The reason for the apparent enantiospecific formation of cyanohydrin from 4-allyloxybenzaldehyde (e.e. ≥ 98%) is difficult to explain. The result is significantly better than for reactions of any other aldehyde so far studied where maximum e.e. values are no greater than 92%.[4]

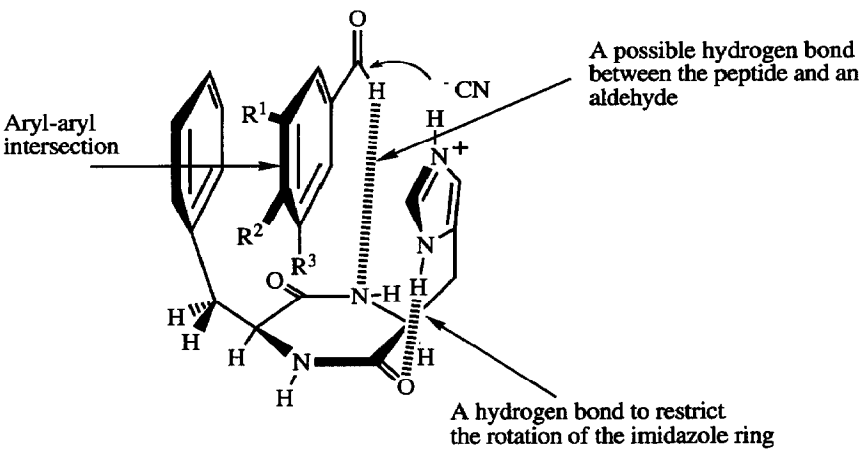


Figure The possible transition state between the U shape dipeptide and the aldehydes

EXPERIMENTAL

General

General conditions are as described previously.[9]

Preparation of 4-substituted benzaldehydes

Protected 4-hydroxybenzaldehydes

4-Trimethylsilyloxybenzaldehyde (1; R = Me_3Si). A typical preparation is described. 4-Hydroxybenzaldehyde (1.00 g, 8.2 mmol) was added to a solution of triethylamine (1.25g, 12.3 mmol) in dichloromethane (40 mL). Trimethylsilyl chloride (1.02g, 9.3 mmol) was added to the solution dropwise at room temperature. The solution was refluxed for 6 h under nitrogen gas, then cooled, washed with sodium carbonate solution (1M, 40 mL), water (3 x 40 mL), dried (Na_2SO_4) and the solvent was removed. The residue was chromatographed (SiO_2, dichloromethane) to afford the title product (1; R = Me_3Si) as a yellow oil (1.35 g, 85%). (Found: C, 62.0; H, 7.3. $C_{10}H_{14}O_2Si$ requires C, 61.9; H, 7.2%). ^1H n.m.r. (200 MHz)

δ 0.29, s, 9H, $SiCH_3$; 6.92, d, *J* 8.6 Hz, 2H, ArH; 7.78 d, *J* 8.6 Hz, 2H, ArH, 9.86, s, 1H, ArCHO. In a similar manner reaction of chloromethylmethyl ether gave 4-methoxymethyloxybenzaldehyde (1; R = CH_3OCH_2)[10] (72%) and methoxyethoxymethyl chloride gave methoxyethoxymethylbenzaldehyde (1; R = $CH_3OCH_2CH_2OCH_2$)[11] (75%).

Preparation of 4-(ω-Alkenyloxy)benzaldehydes

4-Allyloxybenzaldehyde. (1; R = CH_2=$CHCH_2$). Allyl bromide (21.82 g, 0.18 mol) was added dropwise at roon temperature to a solution of 4-hydroxybenzaldehyde (20.01 g, 0.164 mol), potassium hydroxide and potassium iodide (0.20 g) in ethanol (300 mL) and water (100 mL) and solution was refluxed for 24 h. Workup followed by chromatography (SiO_2, dichloromethane) gave *4-allyloxybenzaldehyde* (1; R = CH_2=$CHCH_2$) as a pale yellow oil (2.34 g, 90%). (Found: C, 73.9; H, 6.6. $C_{10}H_{10}O_2$ requires C, 74.1; H, 6.2%). ^{1}H n.m.r. (200 MHz) δ 4.63, m, 2H, CH_2OAr; 5.30-5.40, m, 2H, **CH_2**=CH; 5.96-6.15, m, 1H, CH_2-**CH**; 7.03, m, 2H, ArH; 7.84, m, 2H, ArH; 9.89, s, 1H, ArCHO.

A similar preparation was used for the following compounds:

4-(4-Pentenyloxy)benzaldehyde. (1; R = CH_2=$CH(CH_2)_3$) was obtained as a pale yellow oil (1.21 g, 47%). (Found: C, 75.5; H, 7.4. $C_{12}H_{14}O_2$ requires C, 75.8; H, 7.4%). ^{1}H n.m.r. (200 MHz) δ 1.82-1.98, m, 2H, CH_2; 2.18-2.31, m, 2H, CH_2; 4.06, t, *J* 6.4 Hz, 2H, OCH_2; 4.93-5.12, m, 2H, **CH**-CH_2; 5.79-5.95, m, 1H, **CH**=CH_2; 7.00, m, 2H, ArH; 7.83, m, 2H, ArH; 9.88, s, 1H, ArCHO.

4-(7-Octenyloxy)benzaldehyde. (1; R = CH_2=$CH(CH_2)_6$) was obtained as a pale yellow oil (1.55 g, 50 %). (Found:C, 77.4; H, 8.9. $C_{15}H_{20}O_2$ requires C, 77.6; H, 8.6%). ^{1}H n.m.r. (200 MHz) δ 1.25-2.10, m, 10H, $(CH_2)_5$; 4.04, t, *J* 6.5 Hz, 2H, OCH_2; 4.88-5.05, m, 2H, CH=**CH_2**; 5.72-5.90, m, 1H, **CH**=CH_2; 7.00, m, 2H, ArH; 7.84, m, 2H, ArH; 9.88, s, 1H, ArCHO.

Preparation of 4-[4-(ω-Alkenyloxy)phenylcarboxy]benzaldehydes

4-(4-Allyoxyphenycarboxy)benzaldehyde. (1; R= H_2C=$CHCH_2O$-C$_6$H$_4$-CO) 4-Allyoxybenzoic acid (3.04 g, 16.8 mmol) and 4-hydroxybenzaldehyde (2.06g, 16.8 mmol) were dissolved in dichloromethane (30 mL). The mixture was cooled to 0° and 1,3-dicyclohexylcarbodiimide (3.81 g, 16.8 mmol) and 4-dimethylaminopyridine (30 mg) were added to the solution. After 30 min, the solution was allowed to warm to ambient temperature and stirred for a further 4 h. The 1,3-dicyclohexylurea formed was removed by filtration. The resulting solution was washed with water (3x30 mL), dried (Na_2SO_4) and the solvent was removed. The residue was chromatographed (SiO_2, dichloromethane) to afford *4-(4-allyoxyphenycarboxy)benzaldehyde* as white crystals (4.50 g, 95%), m.p. 80-85°. (Found: C, 72.1; H, 5.3. $C_{17}H_{14}O_4$ requires C, 72.3; H, 5.0%). ^{1}H n.m.r. (200 MHz) δ 4.56, m, 2H, CH_2O; 5.30-5.48, m, 2H, **CH_2**=CH; 6.0-6.11, m, 1H, CH_2=**CH**; 7.0-8.17, m, 8H, ArH; 10.02, s, 1H, ArCHO.

4-[4-(5-Hexenyloxy)phenycarboxy]benzaldehyde. (1; R = CH_2=$CH(CH_2)_4O$-C$_6$H$_4$-CO) was obtained in a similar manner as white crystals (1.36 g, 93%), m.p. 51-52°. (Found: C, 74.2; H, 6.0. $C_{20}H_{20}O_4$ requires C, 74.1; H, 6.2%). ^{1}H n.m.r. (200 MHz) δ 1.15-2.25, m, 6H, $(CH_2)_3$; 4.07, t, *J* 6.3 Hz, 2H, CH_2O; 4.96-5.11, m, 2H, **CH_2**=CH; 5.74-5.94, m, 1H, CH_2=**CH**; 6.98, m, 2H, ArH: 7.39-8.14, m, 6H, ArH; 10.02, s, 1H, ArCHO.

4-[4-(10-Undecenyloxy)phenylcarboxy]benzaldehyde. (1; R=CH_2 = CH $(CH_2)_9O$⟨⟩CO) was obtained as white crystals (1.66 g, 72%), m.p. 58-60°. (Found: C, 76.0; H, 7.9. $C_{25}H_{30}O_4$ requires C, 76.2; H, 7.6%). ^{1}H n.m.r. (200 MHz) δ 1.28-2.10, m, 16H, $(CH_2)_8$; 4.05, t, *J* 6.5 Hz, 2H, CH_2O; 4.91-5.02, m, 2H, CH_2=CH; 5.74-5.88, m, 1H, CH_2=CH; 6.97, d, *J* 8.8 Hz, 2H, ArH; 7.39, d, *J* 8.5 Hz, 2H, ArH; 7.96, m, 2H, ArH; 8.12, m, 2H, ArH; 10.01, s, 1H, ArCHO.

Hydrocyanation procedure

The hydrocyanation procedure described previously[9] was used. The e.e. values of the resulting cyanohydrins were determined using (R) - (+) - cyhalothrin acid[4].

Cyanohydrins

Key spectral data for the cyanohydrins and their cyhalothrin esters are summarised below.

2-Hydroxy-2-(4-methoxymethyloxyphenyl)acetonitrile. (2; R = MOM) υ_{max}(film): 3400 br.s, 2250 cm-1. ^{1}H n.m.r. δ 3.47, s, 3H, OCH_3; 5.19, s, 2H, OCH_2OPh; 5.46, s, 1H, CH(OH)CN; 7.08, d, *J* 8.8 Hz, 2H, ArH; 7.43, d, *J* 8.7 Hz, 2H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz): (1'R,3'R,2R)-isomer δ 6.32, s, CH(CN),. (1'R,3'R,2S)-isomer δ 6.39, s, CH (CN), e.e. 85%.

2-Hydroxy-2-(4-methoxyethoxymethyloxyphenyl)acetonitrile. (2; R = MEM) υ_{max}(film): 3400 br.s, 2250 cm-1. ^{1}H. n.m.r. (200 MHz) δ 3.36, s, 3H, CH_3O; 3.52, m, 4H, OCH_2CH_2O; 5.29, s, 2H, OCH_2O; 5.47, s, 1H, CHCN(OH); 7.11, d, *J* 8.8 Hz, 4H, ArH; 7.41, d, *J* 8.8 Hz, 2H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz): (1'R,3'R,2R)-isomer δ 6.33, s, CH(CN). (1'R,3'R,2S)-isomer δ 6.38, s, CH(CN), e.e. 5%.

2-Hydroxy-2-(4-trimethysilyloxyphenyl)acetonitrile. (2; R = Me_3Si) υ_{max}(film) 3400 br.s, 2250w cm-1. ^{1}H n.m.r. (200MHz) δ 0.07, s, 9H, $Si(CH_3)_3$; 5.80, s, 1H, CH(OH)CN,; 7.92, d, *J* 8.6 Hz, 2H, ArH; 7.81, d, *J* 8.7 Hz, 2H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz): (1'R,3'R,2R)-isomer d 6.36, s, CH(CN). (1'R,3'R,2S)-isomer δ 6.41, s, CH(CN) e. e. 2%.

2-Hydroxy-2-[4-[4-(2-propenyloxy)phenylcarboxy]phenyl]acetonitrile. (2; R = CH_2=$CHCH_2O$⟨⟩CO) υ_{max}(film): 3400 br.s, 2250w cm^{-1}. ^{1}H n.m.r. (200MHz) δ 4.64, m, 2H, CH_2O; 5.32-5.39, m, 2H, CH_2=CH; 5.56, s, 1H, CH(OH)CN; 5.98-6.17, m, 1H, CH_2=CH; 6.97-8.17, m, 8H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (200 MHz): (1'R, 3'R, 2R)-isomer δ 6.40, s, CH(CN). (1'R, 3'R, 2S)-isomer δ 6.45, s, CH(CN), e.e. 78%.

2-Hydroxy-2-[4-[4-(5-hexenyloxy)phenylcarboxy]phenyl]acetonitrile. (2; R = CH_2=$CH(CH_2)_4O$⟨⟩CO) υ_{max}(film): 3400 br.s, 2250 cm^{-1}. ^{1}H n.m.r. (200 MHz) δ 1.55-1.62, m, 2H, CH_2, 1.79-1.90, m, 2H, CH_2; 2.1-2.2, m, 2H, CH_2; 4.08, m, 2H, CH_2O; 4.95-5.10, m, 2H, CH_2=CH; 5.55, s, 1H, CH(OH)CN; 5.75-5.95, m, 1H, CH_2=CH; 6.98-8.61, m, 8H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz) (1'R,3'R,2R) -isomer δ 6.32, s, CH(CN). (1'R,3'R,3S)-isomer δ 6.38, s, CH(CN), e.e.90%

2-Hydroxy-2-[4-[4-(10-undecenyloxy)phenylcarboxy]phenyl]acetonitrile. (2; R=CH_2=$CH(CH_2)_9$ O⟨⟩-CO) υ_{max}(film): 3400 br.s, 2250w cm^{-1}. ^{1}H n.m.r. (200 MHz) δ 1.31-2.08, m, 16H, $(CH_2)_8$; 4.04, t, *J* 6.5Hz, 2H, CH_2O; 4.92-5.03, m, 2H, CH_2=CH; 5.56, s, 1H, CH(OH)CN; 5.74-5.88, m, 1H, CH_2=CH; 6.94-7.0, 2H, m, 2H, ArH, 7.27-7.31, m, 2H, ArH; 7.57-7.62, m, 2H, ArH; 8.10-8.15, m, 2H, ArH.

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz): ('R, 3'R, 2R)-isomer δ 6.32, s, CH(CN). (1'R,3'R,2S)-isomer δ 6.48, s, CH(CN), e.e. 78%

2-Hydroxy-2-[4-(2-propenyloxy)phenyl]acetonitrile. (2; R = CH_2=$CHCH_2$) m.p. 57.5-59°, υ_{max}(film): 3400 br.s, 2250w cm^{-1}. ^{1}H n.m.r. δ 4.54, m, 2H, CH_2O, 5.27-5.40, m, 2H, CH_2=CH; 5.46, s, 1H, CH(OH)CN; 5.93-6.15, m, 1H, CH_2=CH; 6.90, m, 2H, ArH; 7.43, m, 2H, ArH. $[\alpha]_D^{22}$ = + 45.3 (*C* = 1, $CHCl_3$).

(R)-(+)-Cyhalothrin ester. ^{1}H n.m.r. (300 MHz): (1'R,3'R,2R)-isomer δ 6.32, s, CH(CN), e.e. ≥98%. (R,S)-isomer was not found.

To check the apparent enantiomeric purity an (R)-(+)-MTPA ester was also prepared. ^{1} H n.m.r. (300 MHz): (R,R)-isomer δ 3.56, d, *J* 1.15 Hz, 3H, OCH_3; 4.55, m, 2H, CH_2; 5.28-5.45, m, 2H, CH_2=CH; 5.96-6.11, m, 1H, CH_2=CH; 6.54, s, 1H, CH(CN); 6.90-7.93, m, 9H, ArH, e.e. ≥98%. (R,S)-isomer was not found.

2-Hydroxy-2- [4-(4-pentenyloxy)phenyl]acetonitrile. (2; R = CH_2=$CH(CH_2)_3$) υ_{max} (film): 3400 br.s, 2250w cm^{-1}. ^{1}H n.m.r. (200 MHz) δ 1.82-2.0, m, 2H, CH_2; 2.18-2.31, m, 2H, CH_2; 3.98, t, *J* 6.4 Hz, 2H, OCH_2; 4.97-5.10, m, 2H, CH=CH_2; 5.47, s, 1H, CH(OH)CN; 5.80-5.93, m, 1H, CH=CH_2; 6.95, m, 2H, ArH; 7.43, m, 2H, ArH.

(R)-(+)-Cyhalothrin ester: ^{1}H n.m.r. (300 MHz) : (1'R,3'R,2R)-isomer δ 6.31, s, CH(CN). (1'R,3'R,2S)-isomer δ 6.37, s, CH(CN) e.e. 80%.

2-Hydroxy-2-[4-(7-octenyloxy)phenyl]acetonitrile. (2; R = CH_2=$CH(CH_2)_6$) υ_{max}(film): 3400 br.s, 2250 cm^{-1}. ^{1}H n.m.r. (200 MHz) δ 1.25-2.15, m, 10H, $(CH_2)_5$; 3.97, t, 6.5 Hz, 2H, OCH_2; 4.90-5.10, m, 2H, CH=CH_2; 5.46, s, 1H, CH(OH)CN; 5.70-5.92, m, 1H, CH=CH_2; 6.95, m, 2H, ArH; 7.45, m, 2H, ArH.

(R)-(+)-Cyhalothrin ester: ^{1}H n.m.r. (300 MHz): (1'R,3'R,2R)-isomer δ 6.31, s, CH(CN). (1'R,3'R,2S)-isomer δ 6.37, s, CH(CN), e.e. 80%.

Reactions of di- and tri - substituted benzaldehydes

The aldehydes summarised in Table 2 were reacted under the standard conditions and the e.e. values determined using (R)-(+)cyhalothrin acid. Catalyst which gave e.e. values ≥ 98% for reactions of 4-allyloxybenzaldehyde were used and gave the wide spread of results recorded in Table 2.

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