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Enantioselective vinylogous aldol reaction of Chan's diene catalyzed by hydrogen-bonding

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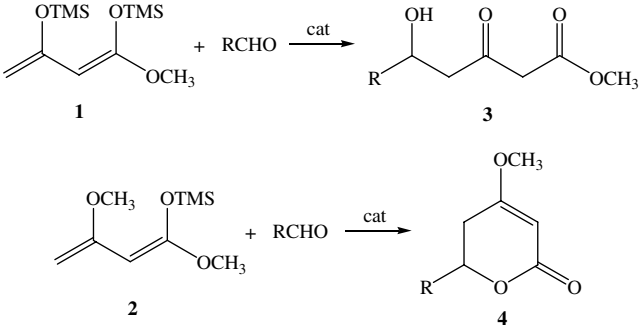
Abstract—Hydrogen-bonding activation of aromatic aldehydes by a TADDOL-derivative promotes the vinylogous aldol reaction of Chan's diene in moderate efficiency and enantioselectivity. Electron-poor aromatic aldehydes show an enhanced reactivity and a competing asymmetric hetero-Diels–Alder reaction takes place in comparable (or higher) yields and enantiomeric excesses.

Chan's diene **1**[1] and Brassard's diene **2**[2] represent masked forms of acetoacetate ester and, in spite of their close structural analogy they can exhibit a very different reactivity with aldehydes in metal-catalyzed processes. In fact, Brassard's diene **2** was found to react with aliphatic and aromatic aldehydes, respectively, in the presence of chiral $Eu(hfc)_3$[3] and Ti(IV)/tridentate Schiff-base complexes,[4] to give the corresponding δ-lactones **4** through a hetero-Diels–Alder (HDA) reaction with a good efficiency and high enantioselectivity. Conversely, in the presence of Ti(IV)/BINOL complexes both aliphatic, unsaturated, heteroaromatic and aromatic aldehydes showed to suffer a vinylogous aldol reaction by Chan's diene **1** leading to chiral polyketide derivatives **3** in high yields and ees (Scheme 1).[5]

In these last years an ever increasing interest has been devoted to the organocatalysis[6] and, particularly, carbonyl activation by hydrogen bonding has been conveniently exploited for the achievement of a variety of preparatively important enantioselective procedures,[7] such as aldol reactions, HDA reactions, epoxidations, conjugate addition. Very interestingly, the conversion **2** → **4** has been recently reported to take place in moderate to good yields and high enantioselectivity by using **5a** (Fig. 1).[8]



Scheme 1.

Taking in mind the different reactivities of dienes **1** and **2** in metal-catalyzed reactions with aldehydes (Scheme 1), we decided to investigate the viability of an enantioselective vinylogous aldol reaction of Chan's diene **1** under organocatalytic conditions.

In order to verify the possibility of a competing non-asymmetric reaction, a control experiment was performed on benzaldehyde, chosen as the representative substrate, in the absence of any chiral activator. Chan's diene **1** confirmed its notable nucleophilic properties so that, under the conditions reported in Scheme 2 and Table 1 (entry 1), the formation of vinylogous aldol **3a**, as an exclusive product, took place in non-negligible way (25% yield).

Successively, a set of chiral hydrogen bond donors has been used as organocatalysts in the reaction of diene **1**

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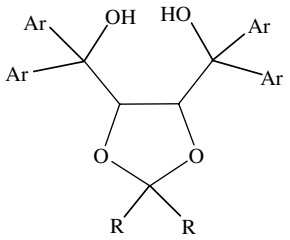


5a: Ar = 1-naphthyl

5b: Ar = 1-phenyl

Figure 1.

with benzaldehyde. As reported in Table 1, very poor results both in terms of efficiency and enantioselectivity were obtained with (*R*)-BINOL and (*R*,*R*)-phenyl-TADDOL **5b** (respectively entries 2 and 3) and no improvement was observed by using an increased amount of activator (entry 4). Furthermore, the employment of a poorly acidic hydrogen bond donor, as (2*R*,3*R*)-(−)-2,3-butanediol, led to a completely racemic **3a** in 33% yield.

A more interesting result was afforded by the employment of TADDOL derivative (*S*,*S*)-**5a**, as catalyst: in fact, although the reaction was preferentially carried out at room temperature because of the high viscosity of the reaction mixture at lower temperature, the formation of the vinylogous aldol **3a**, again as only product, took place with a notable enhancement of the level of enantioselectivity (entry 5). Comparable yields and ees were observed after more prolonged reaction times (entry 6). The sense of asymmetric induction observed by using (*S*,*S*)-**5a** can be explained through the involvement of a highly ordered transition state, generated by hydrogen-bonding between TADDOL derivative and the aldehydic oxygen, according to the general models developed by Ding and co-workers[8] and Rawal and co-workers.[7e,9] As known,[7e,8,9] temperature often represents a determining factor for the achievement of a high enantioselectivity in processes promoted by organocatalysts. Consequently, the reaction of entry 5 was repeated at 0 °C in the presence of toluene (0.1 ml) in order to circumvent the disadvantage of the high viscosity of the reagents mixture. However, a slight increase of ee was obtained at the expense of the efficiency of the reaction (entry 7).

Therefore, the experimental conditions used in entry 5 were chosen to assess the scope of the reaction.

A set of aldehydes was submitted to the usual treatment and the procedure was found to be successful with aromatic and heteroaromatic aldehydes affording the corresponding vinylogous aldols **3** as exclusive products (Table 2, entries 1–5).

Table 1. Vinylogous aldol reaction of Chan's diene **1** on PhCHO promoted by organocatalysts

Entry	Catalyst	Reaction time (h)	**3a** Yield[a] (%)	**3a** ee[b] (%)
1	—	72	25	—
2	(*R*)-BINOL	72	25	8 (*S*)
3	(*R*,*R*)-**5b**	72	43	11 (*S*)
4[c]	(*R*,*R*)-**5b**	48	40	11 (*S*)
5[d]	(*S*,*S*)-**5a**	24	42	61 (*R*)
6[d]	(*S*,*S*)-**5a**	72	42	58 (*R*)
7[e]	(*S*,*S*)-**5a**	24	32	65 (*R*)

[a] In all entries 1/1.3/0.1 aldehyde/**1**/catalyst ratios were used under solvent-free conditions. All the yields refer to isolated chromatographically pure compounds, whose structures were confirmed by spectroscopic data (^{1}H NMR, ^{13}C NMR, MS, IR).

[b] Determined by chiral-phase HPLC analysis (CHIRALPAK AD, Hexane/EtOH 95/5 + 0.1% TFA, 1 ml/min, $\lambda = 254$ nm). Absolute configurations of **3a** were assigned by comparison of the signs of the optical rotation with the ones reported in the literature.[5d]

[c] The experiment was performed with a catalyst loading of 30 mol %.

[d] The experiment was performed at room temperature.

[e] The experiment was performed at 0 °C.

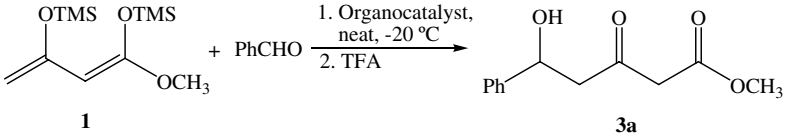
Table 2. Vinylogous aldol reaction of Chan's diene **1** on RCHO promoted by **5a**[10,11]

Entry	R	Product	**3** Yield[a] (%)	**3** ee[b] (%)
1	Ph	**3a**	42	61
2	*p*-Tol	**3b**	39	57
3	2-Furyl	**3c**	40	37
4	*p*-MeOC$_6$H$_4$	**3d**	18	11
5	*o*-MeOC$_6$H$_4$	**3e**	57	40
6	*n*-C$_9$H$_{19}$	**3f**	—	—

[a] In all entries 1/1.3/0.1 aldehyde/**1**/**5a** ratios were used under solvent-free conditions. All the yields refer to isolated chromatographically pure compounds, whose structures were confirmed by spectroscopic data (^{1}H NMR, ^{13}C NMR, MS, IR).

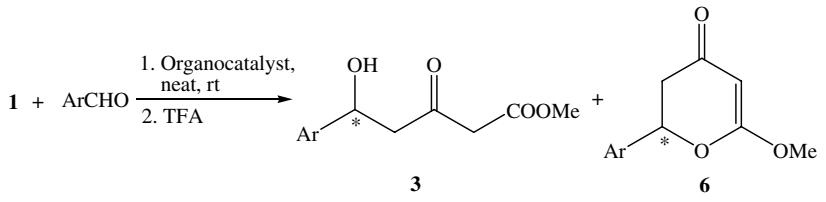
[b] ees were determined by HPLC with a CHIRALPAK AD column. Absolute configuration of compounds **3a**,[5d] **3b**,[12] **3c**[12] and **3d**[5d] was assigned as (*R*) by comparison of the sign of the optical rotation with the one reported in the literature.

Conversely, aliphatic aldehydes showed to be completely unreactive, so that, for example, decanal (entry 6) was recovered completely unchanged after more prolonged reaction times too. The results reported in entries 4 and 5 pointed out a strong dependence of the efficiency and enantioselectivity on the pattern of substitution of the aromatic nucleus. A similar discrepancy in the reactivity of *o*- and *p*-anisaldehyde has been recently observed by Rawal in the Mukaiyama aldol reaction of *O*-silyl-*N*,*O*-ketene acetals promoted by the cyclohexylidene TADDOL-derivative of type **5** [R = –(CH$_2$)$_5$–].[9]



1 **3a**

Scheme 2.



Scheme 3.

Table 3.

Entry	Ar	Product **3**	Yield[a] (%)	ee[b] (%)	Product **6**	Yield[a] (%)	ee[b] (%)
1	*p*-$NO_2C_6H_4$	**3g**	39	54	**6g**	32	57
2	*o*-$NO_2C_6H_4$	**3h**	30	21	**6h**	64	53
3[c]	*o*-$NO_2C_6H_4$	**3h**	32	46	**6h**	30	60
4	*p*-$CF_3C_6H_4$	**3i**	52	31	**6i**	38	51
5	*o*-CNC_6H_4	**3j**	46	56	**6j**	39	59

[a] In all entries 1/1.3/0.1 aldehyde/**1**/**5a** ratios were used under solvent-free conditions. All the yields refer to isolated chromatographically pure compounds, whose structures were confirmed by spectroscopic data (^{1}H NMR, ^{13}C NMR, MS and IR).
[b] Determined by chiral-phase HPLC analysis.
[c] Reaction conditions: 72 h/−20 °C and 0.1 ml of toluene.

The presence of an electron-withdrawing substituent on the aromatic ring caused a notable modification in the behaviour of the aldehydic substrates (Scheme 3).

In fact, under the usual conditions *p*-nitrobenzaldehyde exhibited an enhanced reactivity and afforded a mixture of the expected vinylogous aldol **3g** and pyrone **6g** in a rather good overall yield and moderate ees (Table 3, entry 1).

The formation of **6g** could be reasonably explained through the occurrence of a competing hetero-Diels–Alder (HDA) reaction leading to a cycloadduct of type **A**, whose evolution to pyrone **6** took place by the acidic treatment (Scheme 4). On the ground of this result, the alternative attainment of pyrones **4** or **6** by the same organocatalyst (*S*,*S*)-**5a** showed to depend on the protecting group R (and consequently on the use either of Chan's or Brassard's diene).

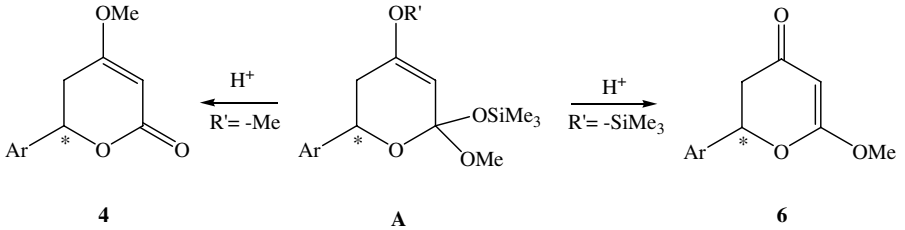
As already observed in the case of *p*- and *o*-anisaldehyde, *o*-nitrobenzaldehyde exhibited an enhanced reactivity (with respect to *p*-nitrobenzaldehyde) so that the corresponding products **3h** and **6h** could be isolated in an overall 94% yield, being the HDA reaction the prevailing process (entry 2).

The experimental conditions proved to exert a deep influence on the preparative and stereochemical aspects. In fact, when the reaction of entry 2 was carried out at −20 °C for 72 h in the presence of toluene (0.1 ml) (entry 3), **3h** and **6h** were isolated in comparable yields (respectively 32% and 30%) and a notable enhancement of the ees could be observed (with respect to entry 2).

Through the usual treatment under solvent-free conditions at room temperature, other electron-poor aldehydes were smoothly converted in the mixture of the corresponding vinylogous aldols and HDA adducts (entries 4 and 5) in a rather good yield and satisfactory ees. It is noteworthy that this organocatalytic procedure allowed the first synthetic approach to products of type **6**, whose unusual 2-alkoxy-pyrone moiety represents the main structural feature of Tridachiahydropyrone **7** (Fig. 2),[13] isolated in 1996 by Ortea and co-workers from the mollusc *Tridachia crispata*.

Furthermore, these preliminary results confirm the notable synthetic versatility of Brassard's and Chan's dienes, since different mechanistic pathways (leading to different classes of compounds) can be favoured by a marginal structural modification.

In conclusion, simple aromatic aldehydes, suitably hydrogen-bonding activated by the (*S*,*S*)-TADDOL derivative **5a** under solvent-free conditions, are shown to suffer a vinylogous aldol condensation by Chan's diene **1**, characterized by a complete γ-selectivity and



Scheme 4.

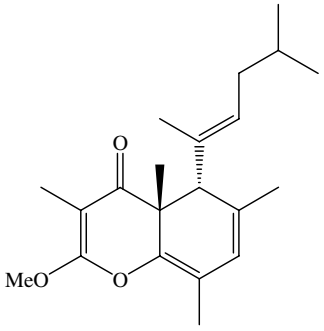


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Figure 2.

promising level of enantioselectivity. The electronic effects of the substituents on the aromatic nucleus played a determining role on the reactivity of the examined substrates, so that in the case of electron-poor aldehydes a competing asymmetric HDA reaction, leading to pyrone derivatives **6**, was found to take place in comparable (or higher) yields and ees with respect to the vinylogous aldol reaction. Further studies, in order to rationalize the product distribution in the case of electron-poor aldehydes as well as to enlarge the substrate generality of this reaction, are in progress.

Acknowledgement

We are grateful to MIUR for financial support.

References and notes

1. Chan, T. H.; Brownbridge, P. *J. Chem. Soc., Chem. Commun.* **1979**, 578–579.
2. Savard, J.; Brassard, P. *Tetrahedron Lett.* **1979**, *20*, 4911–4914.
3. (a) Midland, M. M.; Koops, R. W. *J. Org. Chem.* **1990**, *55*, 5058–5065; (b) Midland, M. M.; Koops, R. W. *J. Org. Chem.* **1990**, *55*, 4647–4650; (c) Midland, M. M.; Afonso, M. M. *J. Am. Chem. Soc.* **1989**, *111*, 4368–4371; (d) Midland, M. M.; Graham, R. S. *J. Am. Chem. Soc.* **1984**, *106*, 4294–4296.
4. (a) Fan, Q.; Lin, L.; Liu, J.; Huang, Y.; Feng, X. *Eur. J. Org. Chem.* **2005**, *16*, 3542–3552; (b) Fan, Q.; Lin, L.; Liu, J.; Huang, Y.; Feng, X.; Zhang, G. *Org. Lett.* **2004**, *6*, 2185–2188.
5. (a) Villano, R.; Acocella, M. R.; De Rosa, M.; Soriente, A.; Scettri, A. *Tetrahedron: Asymmetry* **2004**, *15*, 2421–2424; (b) Soriente, A.; De Rosa, M.; Villano, R.; Scettri, A. *Curr. Org. Chem.* **2004**, *8*, 993–1007; (c) Villano, R.; De Rosa, M.; Salerno, C.; Soriente, A.; Scettri, A. *Tetrahedron: Asymmetry* **2002**, *13*, 1949–1952; (d) Soriente, A.; De Rosa, M.; Stanzione, M.; Villano, R.; Scettri, A. *Tetrahedron: Asymmetry* **2001**, *12*, 959–963; (e) Soriente, A.; De Rosa, M.; Villano, R.; Scettri, A. *Tetrahedron: Asymmetry* **2000**, *11*, 2255–2258.
6. For recent references on organocatalysis, see: (a) Brandes, S.; Niess, B.; Bella, M.; Prieto, A.; Overgaard, J.; Jorgensen, K. A. *Chem. Eur. J.* **2006**, *12*, 6039–6052; (b) Bertelsen, S.; Marigo, M.; Brandes, S.; Diner, P.; Jorgensen, K. A. *J. Am. Chem. Soc.* **2006**, *128*, 12973–12980; (c) Notz, W., ; Tanaka, F.; Barbas, C. F., III. *Acc. Chem. Res.* **2004**, *37*, 580–591; (d) Armstrong, A. *Angew. Chem., Int. Ed.* **2004**, *43*, 1460–1462; (e) Dalko, P. I.; Moisan, L. *Angew. Chem., Int. Ed.* **2004**, *43*, 5138–5175; Special issue dedicated to organocatalysis: (f) Houk, K. N.; List, B. *Acc. Chem. Res.* **2004**, *37*.
7. (a) Connon, S. J. *Chem. Eur. J.* **2006**, *12*, 5418–5427; (b) Akiyama, T.; Itoh, J.; Fuchibe, K. *Adv. Synth. Catal.* **2006**, *348*, 999–1010; (c) Terada, M.; Machioka, K.; Sorimachi, K. *Angew. Chem., Int. Ed.* **2006**, *45*, 2254–2257; (d) Bolm, C.; Rantanen, T.; Schiffers, I.; Zani, L. *Angew. Chem., Int. Ed.* **2005**, *44*, 1758–1763; (e) Gondi, V. B.; Gravel, M.; Rawal, V. H. *Org. Lett.* **2005**, *7*, 5657–5660; (f) Unni, A. K.; Takenaka, N.; Yamamoto, H.; Rawal, V. H. *J. Am. Chem. Soc.* **2005**, *127*, 1336–1337; (g) Pihko, P. M. *Angew. Chem., Int. Ed.* **2004**, *43*, 2062–2064; (h) Huang, Y.; Unni, A. K.; Thadani, A. N.; Rawal, V. H. *Nature* **2003**, *424*, 146; (i) Domingo, L. R.; Andrés, J. *J. Org. Chem.* **2003**, *68*, 8662–8668; (j) Huang, Y.; Rawal, V. H. *J. Am. Chem. Soc.* **2002**, *124*, 9662–9663.
8. Du, H.; Zhao, D.; Ding, K. *Chem. Eur. J.* **2004**, *10*, 5964–5970.
9. McGilvra, J. D.; Unni, A. K.; Modi, K.; Rawal, V. H. *Angew. Chem., Int. Ed.* **2006**, *45*, 6130–6133.
10. *General procedure for the preparation of compounds* **3** *(Table 2)*: In a dry vial (*S*,*S*)-**5a** (0.05 mmol), aldehyde (0.5 mmol) and diene **1** (0.65 mmol) were added. The resulting mixture was stirred for 24 h at room temperature, then dry THF (2 ml) was added. This solution was cooled at −78 °C and TFA (0.2 ml) was added dropwise, then it was permitted to warm to room temperature and after completion of the desilylation reaction, it was neutralized by addition of saturated aq $NaHCO_3$. The reaction mixture was extracted with AcOEt and the combined organic phase was dried ($MgSO_4$) and concentrated. The residue was purified by non-flash chromatography ($CHCl_3/Et_2O$ 9/1) to give products **3**.
11. All new compounds were fully characterized on the basis of IR, ^1H NMR, ^{13}C NMR and mass spectroscopic data. Spectral data of selected compounds: Compound **3b**:[12] enantiomeric excess was determined by HPLC (Chiralpak AD), hexane–EtOH 95:5 + 0.1% TFA, 1 ml/min major enantiomer (*R*) $t_R = 23.3$, minor enantiomer (*S*) $t_R = 30.3$; Compound **3c**:[12] enantiomeric excess was determined by HPLC (Chiralpak AD), hexane–EtOH 95:5 + 0.1% TFA, 1 ml/min, major enantiomer (*R*) $t_R = 29.4$, minor enantiomer (*S*) $t_R = 42.3$; Compound **3e**:[14] enantiomeric excess was determined by HPLC (Chiralpak AD), hexane–EtOH 95:5 + 0.1% TFA, 1 ml/min minor enantiomer $t_R = 21.2$, major enantiomer $t_R = 23.5$; Compound **3g**:[12] enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 90:10, 0.8 ml/min, minor enantiomer (*S*) $t_R = 48.0$, major enantiomer (*R*) $t_R = 53.0$; Compound **6g**: yellow oil, *m*/*z*: 250 $[M+H]^+$, 272 $[M+Na]^+$; IR (KBr, neat) 2922, 1656, 1583, 1521, 1450, 1394, 1231; ^1H NMR ($CDCl_3$, 400 MHz): δ 8.28 (2H, d, $J = 8.6$ Hz), 7.59 (2H, d, $J = 8.6$ Hz), 5.61 (1H, dd, $J = 12.9$, 3.9 Hz), 4.98 (1H, s), 3.86 (3H, s), 2.77 (1H, dd, $J = 16.8$, 12.9 Hz), 2.68 (1H, dd, $J = 16.8$, 3.9 Hz); ^{13}C NMR ($CDCl_3$, 400 MHz): δ 190.6, 173.7, 148.0, 144.1, 126.6, 124.1, 82.8, 79.7, 56.2, 42.0; enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 90:10, 0.8 ml/min, minor enantiomer $t_R = 84.9$, major enantiomer $t_R = 113.6$; Compound **3h**: yellow oil, *m*/*z*: 290 $[M+Na]^+$; IR (KBr, neat) 3507, 2957, 1745, 1716, 1526, 1345–1077; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.96 (1H, d, $J = 8.2$ Hz), 7.89 (1H, d, $J = 7.8$ Hz), 7.67 (1H, m), 7.44 (1H, m), 5.70 (1H, dd, $J = 9.2$, 1.9 Hz), 3.75 (3H, s), 3.55 (2H, s), 3.22 (1H, dd, $J = 17.7$, 1.9 Hz), 2.87 (1H, dd, $J = 17.7$, 9.2 Hz); ^{13}C

NMR ($CDCl_3$, 400 MHz): δ 202.4, 167.1, 147.0, 138.0, 133.8, 128.4, 128.1, 124.4, 65.4, 52.5, 50.7, 49.2; enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 90:10, 0.8 ml/min, minor enantiomer $t_R = 28.0$, major enantiomer $t_R = 31.4$; Compound **6h**: yellow oil, *m*/*z*: 250 $[M+H]^+$, IR (KBr, neat) 2923, 2853, 1659, 1590, 1527, 1449, 1395–1054; ^1H NMR ($CDCl_3$, 400 MHz): δ 8.05 (1H, d, $J = 8.2$ Hz), 7.84 (1H, d, $J = 7.6$ Hz), 7.74 (1H, m), 7.56 (1H, m), 6.15 (1H, dd, $J =$ 13.4, 3.3 Hz), 4.99 (1H, s), 3.83 (3H, s), 2.94 (1H, dd, $J = 16.8$, 3.3 Hz), 2.71 (1H, dd, $J = 16.8$, 13.4 Hz); ^{13}C NMR ($CDCl_3$, 400 MHz): δ 190.9, 173.7, 147.3, 134.7, 134.0, 129.6, 127.9, 124.9, 83.0, 65.4, 56.1, 41.7; enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 90:10, 0.8 ml/min, minor enantiomer $t_R = 40.4$, major enantiomer $t_R = 44.0$; Compound **3i**:[15] enantiomeric excess was determined by HPLC (Chiralpak AD), hexane–EtOH 95:5 + 0.1% TFA, 1 ml/min, major enantiomer $t_R = 15.9$, minor enantiomer $t_R = 17.5$; Compound **6i**: yellow oil, *m*/*z*: 273 $[M+H]^+$, IR (KBr, neat) 2922, 2852, 1653, 1580, 1452, 1326, 1253–1124; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.69 (2H, d, $J = 8.0$ Hz), 7.53 (2H, d, $J = 8.0$ Hz), 5.56 (1H, dd, $J = 13.4$, 3.5 Hz), 4.97 (1H, s), 3.84 (3H, s), 2.79 (1H, dd, $J = 16.7$, 13.4 Hz), 2.65 (1H, dd, $J = 16.7$, 3.5 Hz); ^{13}C NMR ($CDCl_3$, 400 MHz): δ 191.1, 173.8, 145.0, 141.1, 126.2, 125.8, 108.2, 82.8, 80.3, 56.0, 42.0; enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 90:10, 0.8 ml/min, minor enantiomer $t_R = 22.8$, major enantiomer $t_R = 28.0$; Compound **3j**: yellow oil, *m*/*z*: 248 $[M+H]^+$, 270 $[M+Na]^+$; IR (KBr, neat) 3465, 2955, 2226, 1745, 1716, 1325–1065; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.65 (3H, m), 7.38 (1H, m), 5.52 (1H, dd, $J = 9.5$, 2.4 Hz), 3.74 (3H, s), 3.54 (2H, s), 3.08 (1H, dd, $J = 17.7$, 2.4 Hz), 2.94 (1H, dd, $J = 17.7$, 9.5 Hz); ^{13}C NMR ($CDCl_3$, 400 MHz): δ 202.2, 167.0, 145.8, 133.2, 132.8, 128.0, 126.6, 117.1, 109.6, 67.6, 52.5, 50.2, 49.3; enantiomeric excess was determined by HPLC (Chiralpak AD), hexane–*i*PrOH 80:20, 0.8 ml/min, major enantiomer $t_R = 11.6$, minor enantiomer $t_R = 14.3$; Compound **6j**: yellow oil, *m*/*z*: 230 $[M+H]^+$, 252 $[M+Na]^+$; IR (KBr, neat) 2923, 2853, 2226, 1658, 1586, 1449, 1254; ^1H NMR ($CDCl_3$,400 MHz): δ 7.69 (3H, m), 7.51 (1H, m), 5.83 (1H, dd, $J = 13.6$, 3.6 Hz), 5.00 (1H, s), 3.85 (3H, s), 2.84 (1H, dd, $J = 16.7$, 13.6 Hz), 2.70 (1H, dd, $J = 16.7$, 3.6 Hz); ^{13}C NMR ($CDCl_3$, 400 MHz): δ 190.5, 173.6, 140.4, 133.4, 129.5, 126.9, 116.5, 110.9, 83.0, 78.8, 56.1, 41.1; enantiomeric excess was determined by HPLC (Chiralcel OD), hexane–*i*PrOH 95:5, 0.8 ml/min, minor enantiomer $t_R = 97.0$, major enantiomer $t_R = 101.5$.

12. Xu, C.; Yuan, C. *Tetrahedron* **2005**, *61*, 2169–2186.
13. (a) Jeffery, D. W.; Perkins, M. V.; White, J. M. *Org. Lett.* **2005**, *7*, 407–409; (b) Gavagnin, M.; Mollo, E.; Cimino, G.; Ortea, J. *Tetrahedron Lett.* **1996**, *37*, 4259–4262.
14. Huckin, S. N.; Weiler, L. *Can. J. Chem.* **1974**, *52*, 2157–2164.
15. Soriente, A.; De Rosa, M.; Fruilo, M.; Lepore, L.; Gaeta, C.; Neri, P. *Adv. Synth. Catal.* **2005**, *347*, 816–824.