DOI: 10.1002/ejoc.200800598

# Enantioselective Binaphthophosphepine-Promoted [3+2] Annulations of *N*-Ts- and *N*-DPP-Imines with Allenoates and 2-Butynoates

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**Keywords:** Phosphanes / Asymmetric catalysis / [3+2] Cyclisations / Allenes / Imines

The use of binaphthophosphepine **1a** as a catalyst for the [3+2] cyclisation between allenoates or 2-butynoates and imines was investigated. The effects of the imine protecting group on both the catalytic activity and enantioselectivity were determined by comparing the behaviour of *N*-tosyl- and *N*-DPP-imines. The *N*-DPP-imines displayed lower reactivity, but afforded the desired pyrrolines in higher enantiomeric excess (73–92% *ee*). The DPP protecting group was removed from the final pyrrolines under mild conditions to afford the corresponding secondary amines.


## Introduction

The binaphthophosphepines **1** initially described by Gladiali et al.[1] have been developed as efficient chiral ligands in enantioselective organometallic catalysis.[2] Recently, their suitability as chiral nucleophilic promoters for organocatalytic processes has been pointed out by Fu through investigations on the [4+2] annulations of imines with allenes (*ee* = 75–98%),[3a] as well as on the [3+2] cyclisations of allenes with enones (*ee* = 75–90%).[3b] Our group also has been involved in studies on the use of **1** as an organocatalyst, in which the enantioselective [3+2] annulation of various *N*-tosyl-arylimines with 2,3-butadienoates[4a] or allenylphosphonates,[4b] leading to functionalised pyrrolines, have been considered. Additional investigations on these reactions are reported here. The aim of this study is to disclose the effects of the imine protecting group on the enantioselectivity of the [3+2] annulations promoted by **1a** by comparing *N*-Ts- and *N*-DPP-imines, as well as to outline suitable *N*-deprotection procedures for the final pyrrolines. The stereochemical outcome of these cyclisations is also discussed.

## Results and Discussion

The phosphane-promoted [3+2] annulation of allenoates (or 2-butynoates) with imines disclosed by Lu[5] represents a useful strategy for the synthesis of functionalised 3-pyrrolines,[6] including biologically active compounds[7] and relevant synthetic intermediates.[8] Suitable substrates are imines activated toward nucleophilic additions by electron-withdrawing nitrogen substituents. Thus, besides the *N*-Ts-imines initially investigated, also *N*-*p*-nitrobenzenesulfonyl- and *N*-β-(trimethylsilyl)ethanesulfonyl-benzaldimines had been considered. The use of alternative protecting groups was expected to expand the synthetic utility of these cyclisations, because such groups can usually be removed easier than the *N*-Ts substituent. However, none of the protecting groups could be removed from the [3+2] annulation products to afford the corresponding secondary 3-pyrrolines. Not only did Ts deprotection with sodium methoxide fail, but the removal of the Ts or SES group by fluoride ions, under mild conditions, also unexpectedly led to concomitant aromatization and isolation of the corresponding, undesired pyrroles.[5b,6b] The use of DPP as the removable *N*-protecting group had not been considered in depth.[9]

In this context, after our initial studies on the enantioselective [3+2] cyclisations of *N*-Ts-imines[4a,10] promoted notably by phosphanes **1**, we decided to check the suitability of *N*-DPP-imines as starting materials in the same cyclisations. Parallel work from Jacobsen describes the use of DPP-imines in analogous enantioselective [3+2] cyclisations promoted by a phosphinothiourea catalyst.[11]

The *N*-DPP-imines **2a**–**f** were prepared according to literature methods.[12] Their [3+2] cyclisations with both allenoates and 2-butynoates were investigated in the presence of achiral catalysts ($PBu_3$ or $PPh_3$) and the chiral binaphthophosphepine (*S*)-**1a**, according to Scheme 1.

Imines **2** were converted into the corresponding racemic *N*-DPP-pyrrolines **3** or **4** by their reaction with ethyl or cyclohexyl 2-butynoate, respectively, in toluene, in the presence of 10 mol-% of $PBu_3$ (Table 1, Entries 1, 3, 5 and 6). Alternatively, we used ethyl 2,3-butadienoate as a suitable starting material for these [3+2] cyclisations, with either $PPh_3$ or $PBu_3$ as the catalyst (Table 1, Entries 2, 4 and 7–9). Reagents and conditions are given in Table 1. Isolated yields of 40–80% were obtained for reactions performed on a 0.3–3 mmol scale.

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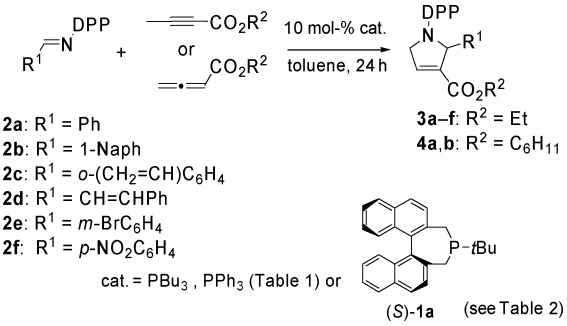



Scheme 1. [3+2] annulation reactions of *N*-DPP-imines.

Table 1. [3+2] Cyclisations of *N*-DPP-imines **2a**–**f** promoted by achiral catalysts (Scheme 1).

| Entry | Prod. | $R^1$ | $R^2$ | Catalyst | *T* [°C] | Yield |
|---|---|---|---|---|---|---|
| 1 | **3a**[a] | Ph | Et | $PBu_3$ | 110 | 72 %[c] |
| 2 | **3a**[b] | Ph | Et | $PPh_3$ | 110 | 81 % |
| 3 | **4a**[a] | Ph | Cy[d] | $PBu_3$ | 110 | 74 % |
| 4 | **3b**[b] | 1-Naph | Et | $PPh_3$ | 50 | 70 % |
| 5 | **4b**[a] | 1-Naph | Cy | $PBu_3$ | 50 | 36 % |
| 6 | **3c**[a] | *o*-vinyl-$C_6H_4$ | Et | $PBu_3$ | 110 | 45 % |
| 7 | **3d**[b] | CH=CH–Ph | Et | $PPh_3$ | 50 | 45 %[c] |
| 8 | **3e**[b] | *m*-Br-$C_6H_4$ | Et | $PBu_3$ | 110 | 46 % |
| 9 | **3f**[b] | *p*-$NO_2$-Ph | Et | $PBu_3$ | 110 | 60 % |

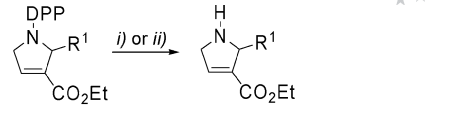
[a] From 2-butynoates. [b] From ethyl 2,3-butadienoate. [c] On 3-mmol scale. [d] Cy = $C_6H_{11}$.

Although good conversion rates were attained in these reactions, it must be mentioned here that the isolation of the *N*-DPP-pyrrolines **3** and **4** by column chromatography occasionally suffered from partial decomposition, leading to lower isolated yields. We were unable to identify the origin of this randomly observed decomposition process. Thus, it is recommend that pyrrolines be purified by flash chromatography shortly after their synthesis and be stored at low temperature.[13]

With respect to the Ts group, the DPP protecting group offers the major advantage of being easily removed.[14] Thus, pyrrolines **3a**–**d**,**f** were converted into the corresponding secondary amines by treatment with $BF_3{\cdot}OEt_2$[15] (for the synthesis of **5a** and **5b**) or aqueous HCl (for **5c**,**d**,**f**), at r.t. Under such mild conditions, aromatization into pyrroles was suitably prevented. Pyrrolines **5** were isolated after aqueous workup and extraction from the aqueous phases at pH ≈ 10 (Scheme 2). Occasionally, purification by column chromatography provided a suitable alternative to these workup conditions. Yields were moderate for reactions performed on a 0.2–0.5 mmol scale (compounds **5b**–**d**,**f**), while **5a** could be prepared in 95% yield on a 3 mmol scale.

In a second series of experiments, the [3+2] cyclisations described above were performed in the presence of phosphepine (*S*)-**1a**. The results are reported in Table 2. For comparison purposes, the enantiomeric excesses obtained previously[4a] in the analogous cyclisations of *N*-Ts-imines are recalled in the table.

2-Butynoates proved to be the most suitable reactants, giving clean conversions into the desired pyrrolines **3** and **4**, whereas the formation of unidentified side-products was




Conditions: *i)* $BF_3{\cdot}Et_2O$, $MeOH/CH_2Cl_2$, 0 °C to r.t.; *ii)* $HCl_{aq}$, MeOH, r.t. overnight. [a] Reaction performed on 2-mmol scale.

Scheme 2. Removal of the DPP protecting group from pyrrolines **3a**–**d**,**f**.

Table 2. Enantioselective [3+2] cyclisations of *N*-DPP-imines **2** with 2-butynoates promoted by binaphthophosphepine (*S*)-**1a** (Scheme 1).

| | *N*-DPP-Pyrroline | | | | | *N*-Ts-Pyrroline[a] | |
|---|---|---|---|---|---|---|---|
| Entry | Prod. | Solvent | *T* | Yield | *ee*[c] | Yield | *ee* |
| 1 | **3a** | toluene | r.t. | <20 % | 75 | | |
| 2 | **3a** | $CH_2Cl_2$ | r.t. | 50 % | 85 | 64 % | 71 |
| 3 | **3a** | $CH_2Cl_2$ | 0 °C[b] | <20 % | 92 | | |
| 4 | **4a** | $CH_2Cl_2$ | r.t. | 45 % | 88 | 86 % | 62 |
| 5 | **3b** | $CH_2Cl_2$ | r.t. | 36 % | 84 | 70 % | 54 |
| 6 | **4b** | $CH_2Cl_2$ | r.t. | 74 % | 85 | 88 % | 41 |
| 7 | **3c** | $CH_2Cl_2$ | r.t. | 40 % | 77 | | |
| 8 | **3e** | $CH_2Cl_2$ | r.t. | 25 % | 73 | | |

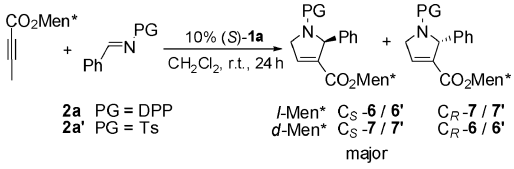
[a] From ref.[4a]; *N*-Ts-pyrrolines were obtained from the corresponding allenoates. [b] 72 h. [c] Enantiomeric excesses were measured by chiral HPLC. Absolute configurations were assumed to be (*S*) (see below).

observed when starting from the corresponding allenoates. These reactions were routinely performed in $CH_2Cl_2$[16] at r.t. for 24 h to give isolated yields of 25–74% and enantiomeric excesses of 73–88%. Conversion rates increased at a higher temperature, but the enantioselectivity decreased concomitantly. For instance, for substrate **3a**, the reaction in refluxing $CH_2Cl_2$ provided an 81% conversion and a 77% *ee*, while the same reaction at room temperature provided a 50% conversion and an 85% *ee*. Imines **2d** and **2f** failed to react in the presence of phosphane **1a** either at room temperature or at 50 °C.

As a general trend, the use of the DPP protecting group decreased the reactivity of the imine relative to the previously reported *N*-Ts-imines, as a result of a combination of steric effects and a lower electrophilicity of the imine carbon.[5b] However, the DPP group induces higher levels of asymmetric induction.[17] We found additional evidence for this trend from experiments on the diastereoselective annulations between *l*-menthyl or *d*-menthyl 2-butynoates and *N*-DPP- or *N*-Ts-benzaldimines (**2a** and **2a′**, respectively). In these annulation reactions, mixtures of the epimeric pyrrolines **6** (or **6′**) and **7** (or **7′**) were formed (Scheme 3).

With achiral catalysts [e.g. P(*i*Bu)$_3$], 1:1 mixtures of the expected epimeric pyrrolines were obtained (Scheme 3, Entries 1 and 4), showing that the menthyl group had a minor effect on the stereoselectivity of these reactions. With the chiral phosphane **1a**, starting from *N*-DPP-imines and menthyl butynoates, high diastereomeric excesses were obtained




| | PG | | Men* | Conv. | Products | Ratio[a] |
|---|---|---|---|---|---|---|
| 1 | DPP | P($i$Bu)$_3$ | *l*-menthyl | 50 % | **6 / 7** | 49/51 |
| 2 | DPP | (*S*)-**1a** | *l*-menthyl | 58 % | $C_S$-**6** / $C_R$-**7** | **91**/9 |
| 3 | DPP | (*S*)-**1a** | *d*-menthyl | 43 % | $C_S$-**7** / $C_R$-**6** | **95**/5 |
| 4 | Ts | P($i$Bu)$_3$ | *l*-menthyl | 83 % | **6' / 7'** | 54/46 |
| 5 | Ts | (*S*)-**1a** | *l*-menthyl | 84 % | $C_S$-**6'** / $C_R$-**7'** | 67/33 |
| 6 | Ts | (*S*)-**1a** | *d*-menthyl | 64 % | $C_S$-**7'** / $C_R$-**6'** | 78/22 |

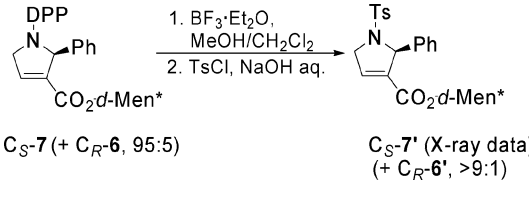
[a] From $^1$H NMR analysis of the crude reaction mixtures.

Scheme 3. Diastereoselective [3+2] annulation reactions of menthyl 2-butynoates with benzaldimines **2a** and **2a′**.

and a small variation in the product ratios (**6**/**7**) was noticed for chiral menthyl units with opposite configurations; the diastereomeric excesses were 82% and >90% for the *l*-menthyl and *d*-menthyl esters, respectively (Scheme 3, Entries 2 and 3). The chiral catalyst definitely controls the stereochemical outcome of these cyclisations, with only small match-mismatch effects observed between the chiral catalyst and the chiral substrate. We observed lower diastereoselectivities and a more pronounced match-mismatch effect when analogous experiments were performed on the *N*-Ts-benzaldimine **2a′** (Scheme 3, Entries 5, 6); with (*S*)-**1a** as the catalyst, mixtures of the epimeric pyrrolines **6′** and **7′** were obtained in 34% and 56% *de* from *l*-menthyl and *d*-menthyl 2-butynoate, respectively. *N*-Ts-imines give higher conversion rates than did the corresponding *N*-DPP-imines.

In order to determine the direction of chiral induction from phosphane (*S*)-**1a**, we previously performed an X-ray analysis on crystals of the major epimer, **7′**, obtained from *d*-menthyl 2-butynoate and *N*-Ts-imine **2a′**.[4a] This allowed for the assignment of the α carbon of this pyrroline as (*S*)-configured. The configurations of the other *N*-Ts-pyrrolines **6′** and **7′** could be inferred from this assignment. The same (*S*) configuration was thus assigned to the major epimer, **6′**, obtained from *l*-menthyl 2-butynoate and imine **2a′**.

The stereochemical course of reactions involving *N*-DPP-imine **2a** and menthyl butynoates was established by chemical correlation between the final product **6** and the *N*-Ts-pyrroline $C_S$-**7′** of known configuration, as follows (Scheme 4).




Scheme 4. Assignment of the α carbon configuration of pyrroline **7** by chemical correlation to **7′**.

We treated the 95:5 mixture of epimeric pyrrolines **7** and **6**, obtained from *d*-menthyl 2-butynoate, imine **2a** and (*S*)-**1a** as the catalyst, with $BF_3{\cdot}OEt_2$ to remove the DPP protecting group. The subsequent tosylation of the crude mixture of epimeric pyrrolines with tosyl chloride in aqueous $NaOH/CH_2Cl_2$ afforded the *N*-Ts-imines **7′** and **6′** in a >9:1 ratio. The $^1$H NMR spectroscopic data of **7′** from this reaction fit with those of the pyrroline $C_S$-**7′**, whose configuration was determined from X-ray crystal data. Importantly, it must be noted that, under the reaction conditions of Scheme 4, only a very small change in the initial ratio of epimers was observed, which showed that the stereochemical integrity of pyrroline **7** was essentially retained through the deprotection/tosylation process.

These experiments demonstrated that phosphane (*S*)-**1a** induced the same direction of asymmetric induction [i.e., (*S*) configuration of the α carbon], in the annulation reactions of both *N*-DPP-imine **2a** and *N*-Ts-imine **2a′** with menthyl butynoates. Based on these results, we tentatively assumed that (*S*)-configured pyrrolines are always produced from *N*-Ts-imines and *N*-DPP-imines in the presence of (*S*)-**1a**. This assignment was applied in Table 2.

Altogether, this work emphasizes the potential utility of the asymmetric [3+2] annulations of *N*-DPP-imines promoted by phosphepine **1a**, which combine fairly high levels of asymmetric induction with synthetically valuable methods for the removal of the nitrogen protecting group.

## Experimental Section

**General:** Imines **2a**–**f**[12,18] were prepared from the corresponding aldehydes and diphenylphosphinamide in the presence of $TiCl_4$, according to the reported method.[12] Characterization data for the new imine **2c**: $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 5.49 (d, $^3J$ = 11.0 Hz, 1 H, =$CH_2$), 5.66 (d, $^3J$ = 18.0 Hz, 1 H, $CH_2$), 7.4–7.5 (10 H), 7.9 (4 H), 8.18 (d, $J$ = 8.0 Hz, 1 H), 9.66 (d, $^3J_{H,P}$ = 32.0 Hz, 1 H, N=CH) ppm. HRMS: calcd. for $C_{21}H_{18}NNaOP$ 354.1024; found 354.1015. Menthyl butynoates were prepared from butynoic acid and (–)- or (+)-menthol by esterification with DCC/DMAP, according to the reported procedure.[19]

**Phosphane-Catalysed Annulations of Imines 2 with 2-Butynoate. General Procedure A:** $PBu_3$ (33 μL, 1 M in toluene) was added to a solution of 2-butynoate (0.39 mmol) and imine **2** (0.33 mmol) in degassed toluene (1 mL) under argon. The mixture was refluxed for 24 h. The solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel to afford **3**.

**General Procedure B:** A solution containing 2-butynoate (42 μL, 0.36 mmol), imine **2** (0.30 mmol) and phosphane **1a** (11 mg, 0.03 mmol) in degassed $CH_2Cl_2$ (1 mL) was stirred under argon at r.t. for 24 h. The solvent was removed under reduced pressure, and the residue was purified by column chromatography.

**Ethyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-phenylpyrrole-3-carboxylate (3a):**[5b] The purification of **3a** was performed by column chromatography on silica gel with heptane/EtOAc (4:6) as the eluent ($R_f$ = 0.2). Colourless oil. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 1.09 (t, $J$ = 7.2 Hz, 3 H, Me), 3.91–4.09 (m, 2 H, $OCH_2$), 4.31 (dtd, $J$ = 17.1, 6.0, 1.8 Hz, 1 H, $NCH_2$), 4.42 (ddt, $J$ = 17.1, 10.8, 2.4 Hz 1 H, $NCH_2$), 5.51 (m, 1 H, NCH), 6.87 (3 H), 7.1–7.3 (5 H), 7.5–7.7 (4 H), 7.8 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.9 (Me), 54.7 (d, $^2J_{C,P}$ = 2.8 Hz, $NCH_2$), 60.5 ($OCH_2$), 68.3 (d, $^2J_{C,P}$ = 3.5 Hz, NCH), 127.2, 127.4, 127.8, 128.0, 128.2, 128.5, 128.7,

130.2 (d, $^1J_{C,P}$ = 79 Hz, C-P), 131.6 (d, $J_{C,P}$ = 2.7 Hz, CH), 131.9 (d, $J_{C,P}$ = 2.6 Hz, CH), 132.4, 132.5, 137.0 (d, $^3J_{C,P}$ = 5.1 Hz, $NCH_2CH$=), 137.6 (d, $J_{C,P}$ = 5.4 Hz, C), 142.4 (d, $J_{C,P}$ = 2.6 Hz, C), 162.2 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 26 ppm. MS (ESI): *m*/*z* = 440 [M + Na]$^+$. HPLC: Chiracel AD, heptane/*i*PrOH (80:20), 1 mL/min, $t_R$ = 7.5 min for the (*R*) enantiomer, $t_R$ = 8.5 min for the (*S*) enantiomer. $[\alpha]_D^{20}$ = +126 (*c* = 1, $CHCl_3$, 75% *ee*).

Pyrroline **3a** slowly converted into the corresponding pyrrole when stored at r.t. An authentic sample of ethyl 1-(diphenylphosphinoyl)-2-phenylpyrrole-3-carboxylate was obtained by the DDQ oxidation[20] of **3a**: $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 0.94 (t, *J* = 7.2 Hz, 3 H, Me), 3.96 (q, *J* = 7.2 Hz, 2 H, $OCH_2$), 6.49 (t, $J_{H,H} \approx J_{H,P}$ = 3.6 Hz, 1 H), 6.64 (t, $J_{H,H} \approx J_{H,P}$ = 3.0 Hz, 1 H), 6.9–7.1 (5 H), 7.3–7.4 (4 H), 7.4–7.5 (6 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.9 (Me), 59.7 ($OCH_2$), 111.9 (d, $J_{C,P}$ = 7.4 Hz, CH), 119.4 (d, $J_{C,P}$ = 6.3 Hz, C), 124.6 (d, $J_{C,P}$ = 5.9 Hz, CH), 126.7, 128.0, 128.5, 128.7, 128.9 (C), 129.0 (C), 130.7 (C), 131.7, 131.96, 132.10, 132.80, 132.83, 142.6 (d, $J_{C,P}$ = 7.4 Hz, C), 164.1 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 25 ppm. MS (ESI): *m*/*z* = 438 [M + Na]$^+$.

**Cyclohexyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-phenylpyrrole-3-carboxylate (4a):** The purification of **4a** was performed by column chromatography with a heptane/EtOAc gradient (40:60 to 0:100) as the eluent ($R_f$ = 0.2, EtOAc). Colourless oil. $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 1.1–1.7 (10 H), 4.29 (dt, *J* = 17.5, 4.5 Hz, 1 H, $NCH_2$), 4.39 (dd, *J* = 17.5, 11.0 Hz, 1 H, $NCH_2$), 4.61 (m, 1 H, OCH), 5.52 (m, 1 H, NCH), 6.85 (3 H), 7.108 (3 H), 7.19 (2 H), 7.3–7.5 (4 H), 7.55 (2 H), 7.81 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 23.3 ($CH_2$), 23.5 ($CH_2$), 25.2 ($CH_2$), 31.0 ($CH_2$), 31.4 ($CH_2$), 54.7 (d, $^2J_{C,P}$ = 2.9 Hz, $NCH_2$), 68.2 (d, $^2J_{C,P}$ = 3.3 Hz, NCH), 73.0 (OCH), 126.7, 127.1, 127.4, 127.8, 128.0, 128.1, 128.5, 130.2 (d, $^1J_{C,P}$ = 81 Hz, C-P), 131.5 (d, $J_{C,P}$ = 2.6 Hz, CH), 131.9 (d, $J_{C,P}$ = 2.5 Hz, CH), 132.35, 132.40, 132.47, 132.53, 137.0 (d, $^3J_{C,P}$ = 5.1 Hz, $NCH_2CH$=),138.0 (d, $J_{C,P}$ = 5.6 Hz, C), 142.4 (d, $J_{C,P}$ = 2.4 Hz, C), 161.7 ($CO_2$Cy) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 27 ppm. HPLC: Chiracel AD, heptane/*i*PrOH (80:20), 1 mL/min, $t_R$ = 6.6 min for the (R) enantiomer, $t_R$ = 8.8 min for the (*S*) enantiomer.

Pyrroline **4a** slowly dehydrogenated into the corresponding pyrrole. An authentic sample of cyclohexyl 1-(diphenylphosphinoyl)-2-phenylpyrrole-3-carboxylate was obtained by the DDQ oxidation of **4a**: $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 1.0–1.6 (10 H), 4.66 (OCH), 6.55 (t, *J* = 3.5 Hz, 1 H, CH), 6.72 (t, *J* = 3.0 Hz, 1 H, CH), 6.98–7.05 (4 H), 7.1 (1 H), 7.4 (4 H), 7.5–7.6 (6 H) ppm. $^{13}$C NMR ($CDCl_3$, 125 MHz): $\delta$ = 23.2 ($CH_2$), 25.3 ($CH_2$), 31.2 ($CH_2$), 71.9 (OCH), 112.0 (d, $^2J_{C,P}$ = 7.4 Hz, NCH), 120.0 (d, $^2J_{C,P}$ = 6.0 Hz, C), 124.5 (d, $^3J_{C,P}$ = 5.7 Hz, CH), 126.7, 128.0, 128.6, 128.7, 129.4 (C), 130.4 (C), 131.2 (C), 131.7, 132.0, 132.1, 132.8, 142.2 (d, $J_{C,P}$ = 4.3 Hz, C), 163.7 ($CO_2$Cy) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 22 ppm.

**Ethyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-(1-naphthyl)pyrrole-3-carboxylate (3b):** Purification of **3b** was performed by column chromatography on silica gel with heptanes/EtOAc (3:7) as the eluent ($R_f$ = 0.2). Colourless oil. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 0.81 (t, *J* = 7.2 Hz, 3 H, Me), 3.82 (q, *J* = 7.2 Hz, 2 H, $OCH_2$), 4.40 (dm, *J* = 17.1 Hz, 1 H, $NCH_2$), 4.47 (m, 1 H, $NCH_2$), 6.42 (br., 1 H, NCH), 6.7 (2 H), 6.9 (2 H), 7.1 (1 H), 7.2–7.4 (8 H), 7.6 (3 H), 7.7 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.6 (Me), 54.8 ($NCH_2$), 60.5 ($OCH_2$), 123.16, 124.95, 125.07, 125.44, 127.50, 127.67, 128.02, 128.49, 128.66, 131.2 (d, $J_{C,P}$ = 2 Hz, CH), 131.8 (d, $J_{C,P}$ = 2 Hz, CH), 132.10, 132.22, 132.34, 136.8 (d, $^3J_{C,P}$ = 5.0 Hz, $NCH_2CH$=), 162.3 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 26 ppm. MS (ESI): *m*/*z* = 490 [M + Na]$^+$. HPLC: Chiracel AD heptane/*i*PrOH (80:20), 1 mL/min, $t_R$ = 11.0 min for the (*R*) enantiomer, $t_R$ = 16.8 min for the (*S*) enantiomer.

**Cyclohexyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-(1-naphthyl)pyrrole-3-carboxylate (4b):** Purification of **4b** was performed by column chromatography with heptanes/EtOAc (3:7) as the eluent ($R_f$ = 0.2). Colourless oil. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 0.6–1.6 (10 H), 4.2–4.5 (m, 2 H, $NCH_2$), 6.37 (br., 1 H, NCH), 6.7 (2 H), 6.8 (2 H), 7.1 (1 H), 7.2–7.3 (8 H), 7.5 (3 H), 7.7 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 23.4 ($CH_2$), 23.5 ($CH_2$), 25.0 ($CH_2$), 30.7 ($CH_2$), 31.2 ($CH_2$), 54.9 ($NCH_2$), 73.0 (OCH), 123.2, 124.9, 125.0, 125.5, 127.4, 127.6, 128.0, 128.5, 128.7, 131.1 (d), 131.8 (d), 132.2, 132.3, 136.7 (d, $^3J_{C,P}$ = 4.6 Hz, $NCH_2CH$=), 161.8 ($CO_2$Cy) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 27 ppm. MS (ESI): *m*/*z* = 544 [M + Na]$^+$. HPLC: Chiracel AD, heptane/*i*PrOH (85:15), 1 mL/min, $t_R$ = 10.4 min for the (*R*) enantiomer, $t_R$ = 13.6 min for the (*S*) enantiomer.

**Ethyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-(2-vinylphenyl)pyrrole-3-carboxylate (3c):** Compound **3c** was purified by chromatography on TLC plates (silica gel) with heptanes/EtOAc (3:7) as the eluent. $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 1.07 (t, *J* = 7.0 Hz, 3 H, Me), 3.97 (m, 2 H, $OCH_2$), 4.29 (dt, $^2J$ = 17.0, 5.5 Hz, 1 H, $NCH_2$), 4.43 (br. dd, $^2J \approx$ 17 Hz, 1 H, $NCH_2$), 4.96 (d, $^3J$ = 11.0 Hz, 1 H, =$CH_2$), 5.19 (d, $^3J$ = 17.5 Hz, 1 H, =$CH_2$), 5.99 (m, 1 H, NCH), 6.60 (dd, $^3J$ = 17.5, 11.0 Hz, 1 H, =CHAr), 6.89 (s, 1 H, $NCH_2CH$=), 7.1–7.5 (12 H), 7.8 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.9 (Me), 55.1 (d, $^2J_{C,P}$ = 2.6 Hz, $NCH_2$), 60.5 ($OCH_2$), 63.6 (NCH), 115.7 (=$CH_2$), 125.7, 127.4, 127.7, 127.9, 128.1, 128.6, 128.7, 129.1 (C), 130.8 (C), 131.1 (C), 131.6 (d, $J_{C,P}$ = 2.6 Hz, CH), 131.9 (d, $J_{C,P}$ = 2.6 Hz, CH), 132.1, 132.3, 132.5, 132.6, 132.8 (C), 133.9 (=*CH*Ph), 136.9 (C), 137.2 (d, $^3J_{C,P}$ = 4.8 Hz, $NCH_2CH$=), 137.8 (C), 137.9 (C), 139.9 (C), 162.2 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 27 ppm. HRMS: calcd. for $C_{27}H_{26}NNaO_3P$ 466.1548; found 466.1553. HPLC: Chiracel AD, heptane/*i*PrOH (80:20), 1 mL/min, $t_R$ = 6.7 min for the major (*R*) enantiomer, $t_R$ = 9.7 min for the (*S*) enantiomer.

**Ethyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-(2-styryl)pyrrole-3-carboxylate (3d):** Purification of **3d** was performed by column chromatography on alumina with heptanes/EtOAc (1:1) as the eluent. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 1.14 (t, *J* = 7.2 Hz, 3 H, Me), 4.0–4.2 (m, 4 H, $OCH_2$ + $NCH_2$), 5.04 (m, 1 H, NCH), 5.78 (d, $^3J_{A,B}$ = 15.6 Hz, 1 H, =CHPh), 5.91 (dd, $^3J$ = 15.6, 7.8 Hz, 1 H, C*H*=CHPh), 6.74 (s, 1 H, $NCH_2CH$=), 7.0–7.9 (Ph) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 14.1 (Me), 53.6 ($NCH_2$), 60.4 ($OCH_2$), 66.9 (NCH), 126.6, 127.5, 128.1–128.7, 131.6, 131.9–132.1, 132.5, 132.6, 132.7, 136.0 (d, $J_{C,P}$ = 5.6 Hz, C), 136.6 (C), 137.9 (d, $^3J_{C,P}$ = 5.6 Hz, $NCH_2CH$=), 162.4 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 26 ppm. HRMS: calcd. for $C_{27}H_{26}NNaO_3P$ 466.1548; found 466.1539.

**Ethyl 2-(3-Bromophenyl)-1-(diphenylphosphinoyl)-2,5-dihydropyrrole-3-carboxylate (3e):** Purification of **3e** was performed by column chromatography on silica gel with EtOAc as the eluent. $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 1.11 (t, *J* = 7.0 Hz, 3 H, Me), 3.9–4.1 (m, 2 H, $OCH_2$), 4.31 (dm, $^2J$ = 17.1, *J* = 7, 5, 1.9 Hz, 1 H, $NCH_2$), 4.42 (dm, $^2J$ = 17, *J* = 11 Hz, 1 H, $NCH_2$), 5.47 (m, 1 H, NCH), 6.84 (t, *J* = 1.5 Hz, 1 H), 6.87 (d, *J* = 8.0 Hz, 1 H), 6.91 (s, 1 H), 7.0 (t, *J* = 7.5 Hz, 1 H), 7.2–7.3 (3 H), 7.4–7.5 (3 H), 7.5–7.6 (3 H), 7.8 (2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.9 (Me), 54.7 ($NCH_2$), 60.9 ($OCH_2$), 68.1 (NCH), 122.0 (C), 126.1, 128.1, 128.3, 128.6, 128.8, 129.5, 130.3, 130.6, 131.9–132.5, 136.8 (C), 137.7 (d, $^3J_{C,P}$ = 4.7 Hz, $NCH_2CH$=), 144.7 (C), 162.2 ($CO_2$Et)

ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 27 ppm. HRMS: calcd. for $C_{25}H_{23}BrNNaO_3P$ 518.0497; found 518.0489. HPLC: Chiracel AD, heptane/*i*PrOH (80:20), 1 mL/min, $t_R$ = 7.9 min for the major (*R*) enantiomer, $t_R$ = 8.9 min for the (*S*) enantiomer.

**Ethyl 1-(Diphenylphosphinoyl)-2,5-dihydro-2-(4-nitrophenyl)pyrrole-3-carboxylate (3f):** Purification of **3f** was performed by column chromatography on silica gel with EtOAc as the eluent. $^1$H NMR ($CDCl_3$, 500 MHz): $\delta$ = 1.12 (t, *J* = 7.0 Hz, 3 H, Me), 3.9–4.1 (m, 2 H, $OCH_2$), 4.3–4.4 (m, 2 H, $NCH_2$), 5.65 (br., 1 H, NCH), 6.94 (s, 1 H, HC=), 7.06 (d, *J* = 8.5 Hz, 2 H), 7.23 (m, 2 H), 7.4–7.5 (m, 3 H), 7.5–7.6 (m, 3 H), 7.8 (2 H), 7.96 (d, *J* = 8.3 Hz, 2 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 13.9 (Me), 55.0 ($NCH_2$), 60.9 ($OCH_2$), 67.8 (NCH), 123.2, 128.3, 128.4, 128.7, 128.8, 129.5 (C), 129.8 (C), 131.2 (C), 131.6 (C), 132.0, 132.1, 132.3, 136.4 (d, $J_{C,P}$ = 4.9 Hz, C) 138.3 (d, $J_{C,P}$ = 5.0 Hz, $NCH_2CH$=), 146.9 (C), 149.8 (C), 161.7 ($CO_2$Et) ppm. $^{31}$P NMR ($CDCl_3$, 121 MHz): $\delta$ = 26 ppm. HRMS: calcd. for $C_{25}H_{23}N_2NaO_5P$ 485.1242; found 485.1241.

**Removal of the DPP Protecting Group from Pyrrolines 3**

**Ethyl 2,5-Dihydro-2-phenyl-1*H*-pyrrole-3-carboxylate (5a):** To a solution of pyrroline **3a** (1.0 g, 2.4 mmol) in $CH_2Cl_2$ (25 mL) at 0 °C were added successively MeOH and $BF_3{\cdot}OEt_2$ (3 mL, 24 mmol). The mixture was stirred at 0 °C for 30 min and then at r.t. for 4 h. After hydrolysis, the aqueous layer was separated, treated with $K_2CO_3$ until pH ≈ 10 and extracted with $CH_2Cl_2$. The evaporation of the solvent afforded pyrroline **5a** as a pale yellow oil. Yield 0.49 g (95%). $^1$H NMR ($D_2O$, 300 MHz): $\delta$ = 1.04 (t, *J* = 7.2 Hz, 3 H, Me), 4.04 (q, *J* = 7.2 Hz, 2 H, $OCH_2$), 4.29 (dt, *J* = 17.4, *J* ≈ 1.8 Hz, 1 H, $NCH_2$), 4.37 (dt, *J* = 17.4, *J* ≈ 2.5 Hz, 1 H, $NCH_2$), 5.74 (t, *J* ≈ 1.5 Hz, 1 H, NCH), 7.12 (q, *J* ≈ 2.0 Hz, 1 H, $NCH_2CH$=), 7.4–7.5 (5 H, Ph) ppm. $^{13}$C NMR ($D_2O$, 75 MHz): $\delta$ = 13.0 (Me), 51.4 ($NCH_2$), 62.4 ($OCH_2$), 67.5 (NCH), 128.0 (CH), 129.5 (CH), 130.3 (CH), 132.95 (C), 133.07 (C), 138.2 ($NCH_2CH$=), 163.1 ($CO_2$Et) ppm. MS (ESI): *m*/*z* = 218 [M + H]$^+$.

**Ethyl 2,5-Dihydro-2-(1-naphthyl)-1*H*-pyrrole-3-carboxylate (5b):** The method described above for the deprotection of **3a** was applied to the synthesis of **5b** from **3b** on a 0.5 mmol scale. Compound **5b** was obtained in 42% isolated yield (55 mg) as a pale yellow oil. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 0.97 (t, *J* = 7.2 Hz, 3 H, Me), 3.85 (dm, *J* = 17.5 Hz, 1 H, $NCH_2$), 3.9–4.0 (3 H, $OCH_2$ + $NCH_2$), 5.92 (br., 1 H, NCH), 7.05 (q, *J* ≈ 2.0 Hz, 1 H, $NCH_2CH$=), 7.17 (dd, *J* = 7.2, 1.2 Hz, 1 H), 7.31 (t, *J* = 7.7 Hz, 1 H), 7.39 (t, *J* = 7.5 Hz, 1 H), 7.45 (t, *J* = 7.0 Hz, 1 H), 7.67 (d, *J* = 8.5 Hz, 1 H), 7.76 (d, *J* = 8.0 Hz, 1 H), 8.18 (d, *J* = 8.5 Hz, 1 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 14.0 (Me), 53.6 ($NCH_2$), 60.3 ($OCH_2$), 63.8 (NCH), 123.5, 123.7, 125.4, 125.7, 126.3, 128.1, 128.7 (CH), 131.6 (C), 134.1 (C), 137.1 (C), 138.7 (C), 142.3 ($NCH_2CH$=), 163.6 ($CO_2$Et) ppm. MS (ESI): *m*/*z* = 290 [M + Na]$^+$ (30%), 268 [M + H]$^+$ (100%).

**Ethyl 2,5-Dihydro-2-(2-vinylphenyl)-1*H*-pyrrole-3-carboxylate (5c):** A solution of pyrroline **3c** (108 mg, 0.24 mmol) in MeOH (3 mL) was treated with aqueous HCl (0.5 mL, 12 N) at r.t. The mixture was stirred overnight, the volatiles were removed, and the crude reaction mixture was purified by column chromatography with EtOAc as the eluent. Compound **5c** ($R_f$ = 0.3) was obtained in 55% isolated yield (33 mg) as a colourless oil. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 1.03 (t, *J* = 7.2 Hz, 3 H, Me), 3.1 (br., 1 H, NH), 4.0–4.1 (4 H, $NCH_2$ + $OCH_2$), 5.29 (dd, $^3J$ = 11.1, $^2J$ = 1.5 Hz, 1 H, C$H_2$=CHAr), 5.50 (br., 1 H, NCH), 5.58 (dd, $^3J$ = 17.4, $^2J$ = 1.5 Hz, 1 H, C$H_2$=CHAr), 6.97 (1 H, $NCH_2CH$=), 7.0–7.4 (5 H) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 14.0 (Me), 53.4 ($NCH_2$), 60.4 ($OCH_2$), 63.8 (NCH), 116.9 ($CH_2$=CHAr), 126.4 (CH), 126.6 (CH), 127.8 (CH), 128.1 (CH), 134.5 (CH), 137.1 (C), 139.5 (C), 141.3 ($NCH_2CH$=), 163.2 ($CO_2$Et) ppm. HRMS: calcd. for $C_{15}H_{18}NO_2$ 244.1338; found 244.1331.

**Ethyl 2,5-Dihydro-2-(2-styryl)-1*H*-pyrrole-3-carboxylate (5d):** A solution of pyrroline **3d** (0.22 g, 0.5 mmol) in MeOH (4 mL) was treated with aqueous HCl (1 mL, 12 N). The mixture was stirred overnight, the solvent was evaporated, and the residue was diluted with aqueous HCl. The aqueous mixture was extracted with EtOAc and then treated with NaOH until pH ≈ 10. The aqueous layer was extracted with EtOAc, and evaporation of the solvent afforded pure **5d** (51 mg, 41%). $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 1.18 (t, *J* = 7.2 Hz, 3 H, Me), 3.83 (br. d, *J* = 17.1 Hz, 1 H, $NCH_2$), 3.9 (br. d, 1 H, $NCH_2$), 4.1–4.2 (2 H, $OCH_2$), 4.78 (br., 1 H, NCH), 6.16 (dd, $^3J$ = 15.9, 7.5 Hz, 1 H, C*H*=CHPh), 6.55 (d, $^3J$ = 15.9 Hz, 1 H, CH=C*H*Ph), 6.81 (1 H, $NCH_2CH$=), 7.1–7.3 (5 H, Ph) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 14.2 (Me), 53.3 ($NCH_2$), 60.4 ($OCH_2$), 65.8 (NCH), 126.5 (CH), 127.2 (CH), 128.5 (CH), 129.7 (*C*H=CHPh), 130.7 (CH=*C*HPh), 136.9 (C), 140.9 ($NCH_2CH$=), 163.5 ($CO_2$Et) ppm. MS (ESI): *m*/*z* = 244 [M + H]$^+$ (100%).

**Ethyl 2,5-Dihydro-2-(4-nitrophenyl)-1*H*-pyrrole-3-carboxylate (5f):** A solution of pyrroline **3f** (0.20 g, 0.43 mmol) in MeOH (6 mL) was treated with aqueous HCl (1 mL, 12 N). The mixture was stirred overnight, the solvent was evaporated, and the residue was taken up in $CH_2Cl_2$/$Et_3N$. The volatiles were evaporated, and the residue was purified by column chromatography with EtOAc as the eluent. Yield 45 mg (40%). $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ = 1.16 (t, *J* = 7.2 Hz, 3 H, Me), 4.0–4.2 (4 H, $NCH_2$ + $OCH_2$), 5.38 (br., 1 H, NCH), 7.04 (1 H, $NCH_2CH$=), 7.51 (d, $^3J$ = 8.7 Hz, 2 H, Ar), 8.18 (d, $^3J$ = 8.7 Hz, 2 H, Ar) ppm. $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ = 14.2 (Me), 53.3 ($NCH_2$), 60.8 ($OCH_2$), 67.4 (NCH), 123.9 (CH), 128.4 (CH), 137.0 (C), 141.6 ($NCH_2CH$=), 147.5 (C), 151.1 (C), 163.0 ($CO_2$Et) ppm. HRMS: calcd. for $C_{13}H_{15}N_2O_4$ 263.1032; found 263.1026.

**Studies on the Diastereoselective [3+2] Cyclisation Reactions Between Menthyl 2-Butynoate and Imines:** Scheme 3. All reactions were performed in $CH_2Cl_2$ at r.t., according to the General Procedure B, with either P(*i*Bu)$_3$ or phosphepine (*S*)-**1a** as the catalyst. Reactions of *N*-DPP-imine **2a** with *d*- or *l*-menthyl butynoate (Entries 2 and 3 in Scheme 3) were performed on a 0.3 mmol scale. The crude reaction mixtures were analyzed by $^1$H NMR to determine the diastereomeric ratios. The filtration of the reaction mixture on a short silica gel column (heptanes/EtOAc, 30:70, as the eluent, $R_f$ = 0.2) afforded samples of pyrrolines **6** (or **7**), which contained variable amounts of the starting imine **2a**. These samples allowed for the characterisation of pyrrolines $C_S$-**6** and $C_S$-**7** by $^1$H NMR spectroscopy. MS (ESI) *m*/*z* 550 [M + Na]. Diastereomeric ratios were measured from the integration of the menthyl OCH signals.

Pyrroline $C_S$-**6** was obtained as the major epimer of the 91:9 mixture from the reaction of *l*-menthyl 2-butynoate with **2a** promoted by (*S*)-**1a**. $^1$H NMR (500 MHz, $CDCl_3$, selected data): $\delta$ = 0.61 (d, $^3J$ = 7.0 Hz, 3 H, CH*Me*$_2$), 0.80 (d, $^3J$ = 6.5 Hz, 3 H, CH*Me*$_2$), 0.83 (d, $^3J$ = 7.0 Hz, 3 H, CH*Me*), 0.8–1.7 (9 H), 4.28–4.35 (m, 1 H, $NCH_2$), 4.40–4.46 (m, 1 H, $NCH_2$), 4.52 (td, *J* = 11.0, 4.0 Hz, 1 H, OCH), 5.55 (1 H, NCH), 6.82 (2 H), 7.0–7.6 (12 H), 7.8 (2 H) ppm.

Pyrroline $C_S$-**7** was obtained as the major epimer of the >95:5 mixture from the reaction of *d*-menthyl 2-butynoate with **2a** promoted by (*S*)-**1a**. $^1$H NMR (500 MHz, $CDCl_3$, selected data): $\delta$ = 0.47 (d, $^3J$ = 6.5 Hz, 3 H, CH*Me*$_2$), 0.57 (d, $^3J$ = 7.0 Hz, 3 H, CH*Me*$_2$), 0.87 (d, $^3J$ = 6.5 Hz, 3 H, CH*Me*), 0.8–1.4 (6 H), 1.5–1.6 (2 H),

1.84 (1 H), 4.24–4.42 (m, 2 H, $NCH_2$), 4.60 (td, $J$ = 10.5, 4.0 Hz, 1 H, OCH), 5.55 (1 H, NCH), 6.8 (m, 2 H), 6.9–7.9 (14 H) ppm.

The configuration of pyrroline $C_S$-**7** was assigned as follows. The crude mixture of pyrrolines obtained from *d*-menthyl butynoate and imine **2a** was submitted to the *N*-deprotection procedure with $BF_3{\cdot}OEt_2$, according to the procedure described for the deprotection of **3a** above. The crude secondary pyrroline thus obtained was reacted with excess tosyl chloride in aqueous $NaOH/CH_2Cl_2$, with $BnEt_3NCl$ as the catalyst, at r.t. for 4 h. The organic phase was separated, washed with water, dried with $MgSO_4$, and the solvents were evaporated. $^1$H NMR analysis showed the presence of the known pyrrolines $C_S$-**7** and $C_R$-**6** (see below) in a 9:1 ratio.

The reactions of the *N*-Ts-imine **2a**′ with *d*- or *l*-menthyl butynoate (Scheme 3) were performed on a 0.3 mmol scale with a 1:1 alkyne/imine ratio, in $CH_2Cl_2$ (1 mL), at r.t.

Starting from *l*-menthyl 2-butynoate, imine **2a**′ and P(*i*Bu)$_3$ as the catalyst (10 mol-%), a 54:46 mixture of **6**′ and **7**′ was obtained (Scheme 3, Entry 4). The mixture was purified by column chromatography on silica gel with heptane/EtOAc (7:3, $R_f$ = 0.4).

Starting from *l*-menthyl 2-butynoate, imine **2a**′ and phosphane (*S*)-**1a** as the catalyst (10 mol-%), a 33:67 mixture of **7**′ and **6**′ was obtained (Scheme 3, Entry 5).

Starting from *d*-menthyl 2-butynoate, imine **2a**′ and phosphane (*S*)-**1a** as the catalyst (10 mol-%), a 78:22 mixture of **7**′ and **6**′ was obtained (Scheme 3, Entry 6).

**D-Menthyl 2,5-Dihydro-2-phenyl-1-tosylpyrrole-3-carboxylate ($C_S$-7′):** Compound $C_S$-**7**′ was isolated in diastereomerically pure form by crystallization of the enriched mixtures obtained from *d*-menthyl 2-butynoate. The NMR spectroscopic data for $C_S$-**7**′ have been reported previously. Selected, representative $^1$H NMR spectroscopic data: (300 MHz, $CDCl_3$): $\delta$ = 0.43 (d, $^3J$ = 7.0 Hz, 3 H, CH$Me_2$), 0.56 (d, $^3J$ = 6.8 Hz, 3 H, CH$Me_2$), 6.89 (1 H, $NCH_2CH$=) ppm. $C_{28}H_{35}NO_4S$ (481.65): calcd. C 69.82, H 7.32; found C 69.63, H 7.15.

**D-Menthyl 2,5-Dihydro-2-phenyl-1-tosylpyrrole-3-carboxylate ($C_R$-6′):** Compound $C_R$-**6**′ was isolated from a 9:1 mixture with $C_S$-**7**′. This sample was isolated by crystallization of the epimeric mixture obtained from *d*-menthyl 2-butynoate and P(*i*Bu)$_3$ as the catalyst. $^1$H NMR (500 MHz, $CDCl_3$): $\delta$ = 0.64 (d, $^3J$ = 6.9 Hz, 3 H, CH$Me_2$), 0.79 (d, $^3J$ = 6.7 Hz, 3 H, CH$Me_2$), 0.86 (d, $^3J$ = 7.4 Hz, 3 H, CH$Me$), 0.8–1.3 (4 H), 1.6–1.7 (5 H), 2.38 (s, 3 H, Me), 4.37 (ddd, $^2J_{A,B}$ = 16.9, $^3J$ = 5.8, $^4J$ = 1.7 Hz, 1 H, $NCH_2$), 4.5–4.6 (2 H, $NCH_2$ + OCH), 5.75 (1 H, NCH), 6.76 (1 H, $NCH_2CH$=), 7.14 (d, $J$ = 8.1 Hz, 2 H, Ts), 7.2–7.3 (5 H, Ph), 7.42 (d, $J$ = 8.1 Hz, 2 H, Ts) ppm. $^{13}$C NMR ($CDCl_3$): $\delta$ = 16.4 (Me), 20.6 (Me), 21.4 (Me), 21.9 (Me), 23.6 ($CH_2$), 26.5 ($C$HMe$_2$), 31.2 ($C$HMe), 34.0 ($CH_2$), 40.1 ($CH_2$), 46.9 (CH), 54.9 ($NCH_2$), 69.1 (NCH), 75.0 (OCH), 127.1, 127.8, 128.1, 129.4, 134.8 ($NCH_2C$H=), 135.7 (C), 136.5 (C), 139.4 (C), 143.2 (C), 161.5 ($CO_2$Men) ppm. MS (ESI): $m/z$ = 504 [M + Na]$^+$. HRMS: calcd. for $C_{28}H_{35}NNaO_4S$ 504.2185; found 504.2184.

## Acknowledgments

We are grateful to Dr. Thomas Riermeier and Dr. Renat Kadyrov (Evonik Degussa GmbH, Hanau, Germany) for a generous gift of the chiral phosphane **1a**. This work was performed within the CP2D program, 2007, of the Agence Nationale de la Recherche (ANR).

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Received: June 20, 2008
Published Online: November 25, 2008

  