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Intermolecular C–H functionalization versus cyclopropanation of electron rich 1,1-disubstituted and trisubstituted alkenes

Dominic L. Ventura [b], Zhanjie Li [a], Michael G. Coleman [b], Huw M.L. Davies [a,*]

[a] Department of Chemistry, Emory University, Atwood Hall, 1515 Dickey Drive, Atlanta, GA 30322, United States
[b] Department of Chemistry, University at Buffalo, The State University of New York, Buffalo, NY 14260, United States

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ABSTRACT

Rhodium(II)-catalyzed reactions of aryldiazoacetates with electron rich 1,1-disubstituted and trisubstituted alkenes were systematically studied. The regio-, diastereo- and enantioselectivity of the chemistry was profoundly influenced by the nature of the substrates and the catalyst. Conditions were developed for either selective cyclopropanation or C–H insertion. Both reactions can be achieved with high diastereo- and enantioselectivity (for C–H insertion: >90% de, up to 96% ee, for cyclopropanation: >94% de, up to 95% ee). For the 1,1-disubstituted vinyl ethers, cyclopropanation occurs with variable diastereoselectivity but in optimized systems the cyclopropane is formed in >94% de and up to 98% ee.
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1. Introduction

Aryldiazoacetates are widely recognized as useful precursors to rhodium carbenoid intermediates.[1] The resulting donor/acceptor-substituted carbenoids are more stabilized than conventional carbenoids. Consequently, they are capable of a range of highly stereoselective reactions, including cyclopropanation,[2] cyclopropenation,[3] N–H,[4] O–H,[5] and C–H[6] insertions, and ylide transformations.[7] For some time we have explored the C–C bond-forming reactions of the donor/acceptor-substituted carbenoids with particular emphasis on intermolecular C–H insertion[6] and cyclopropanation.[2a–e] Substrates with an allylic moiety have two potentially competing pathways: cyclopropanation and allylic C–H insertion.[8] Thus, as the donor/acceptor carbenoids chemistry has evolved, a natural question has arisen: what controls the selectivity between these two reaction pathways (Fig. 1)? This study will illustrate how the catalyst and substrates can have a profound influence on which reaction pathway is preferred.

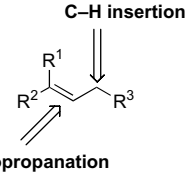

Figure 1. Two competing reaction pathways for carbenoid reactions at allylic systems.

The donor/acceptor carbenoids act as sterically demanding electrophiles. When they react with electron neutral alkenes, only monosubstituted, 1,1-disubstituted and, less favorably, *cis*-1,2-disubstituted alkenes can be cyclopropanated. More highly substituted alkenes will be susceptible to allylic C–H insertion, while competing cyclopropanation and C–H insertion often occurs in the reactions of *cis*-1,2-disubstituted alkenes. Recently, we discovered that electron rich *trans*-1,2-disubstituted alkenes can be stereoselectively cyclopropanated by aryldiazoacetates.[9] The competition between cyclopropanation and C–H insertion was controlled by a delicate balance between the substrates and the catalysts. This led to the current study, which explores the competition between C–H insertion to form **2** and cyclopropanation to form **3** of trisubstituted alkenes **1** (Scheme 1). The unexpected stereochemical outcome of cyclopropane **3** expanded the study to the cyclopropanation chemistry of 1,1-disubstituted alkenes (Scheme 2).

The synthetic chemistry of the donor/acceptor carbenoids has been greatly enriched by the availability of chiral dirhodium carboxylates capable of highly enantioselective reactions. The standard catalyst has been dirhodium tetraprolinate Rh_2(*S*-DOSP)$_4$, which has by now seen broad application in carbenoid reactions.[6] Another effective catalyst is the bridged prolinate catalyst, Rh_2(*S*-biTISP)$_2$,[10] while the most recent is Rh_2(*S*-PTAD)$_4$.[11] This study also gives a detailed analysis on how these highly effective catalysts can impact the outcome of this chemistry (Fig. 2).

* Corresponding author. Tel.: +1 404 727 6839; fax: +1 404 727 7766.
E-mail address: hmdavie@emory.edu (H.M.L. Davies).

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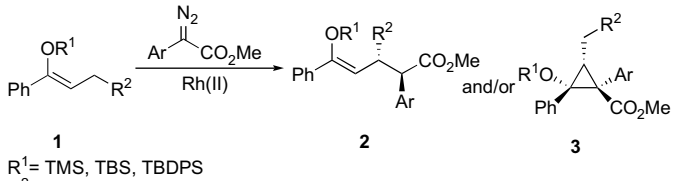
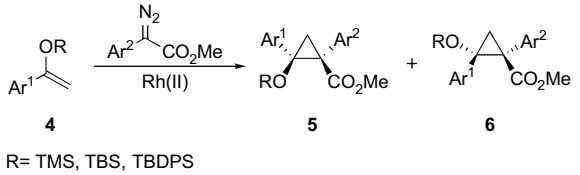


Scheme 1. Reaction of aryldiazoacetates with trisubstituted vinyl ethers.



Scheme 2. Reaction of aryldiazoacetates with 1,1-disubstituted vinyl ethers.

2. Results and discussion

The preliminary studies focused on the reaction of TMS-, TBS-, and TBDPS-protected silyl enol ethers **7a–c**. The standard reaction used *p*-bromophenyldiazoacetate **8** as the carbenoid precursor and 2,2-dimethylbutane (2,2-DMB) as solvent. When Rh_2(*S*-DOSP)$_4$ was used as catalyst, allylic C–H insertion and cyclopropanation occurred (Table 1, entries 1–3). Cyclopropane **10a** was favored by a 4:1 ratio with **7a**, containing the smallest silicon protecting group, (entry 1), while **7c** with the largest silyl group favored the C–H insertion product **9c** by a 2:1 ratio (entry 3). The C–H insertion products **9a–c** were formed with good diastereocontrol (82–88% de) and moderate enantiocontrol (54–73% ee) while the cyclopropanes **10a–c** were formed with excellent diastereocontrol (>94% de) and good enantiocontrol (78–91% ee). When the sterically more rigid catalyst, Rh_2(*S*-biTISP)$_2$, was used, the C–H insertion products **9a–c** were preferred over the cyclopropanes **10a–c** in ratios varying from 2:1 to 7:1 (Table 1, entries 4–6). The diastereoselectivity for **9a–c** (75–84% de) was similar to that observed with Rh_2(*S*-DOSP)$_4$, but the enantioselectivity was greatly improved (90–92% ee). Both series of compounds **9a–c** and **10a–c** were formed with opposite asymmetric induction to the reactions catalyzed by Rh_2(*S*-DOSP)$_4$. This switch in asymmetric induction between the two-prolinate catalysts is well established.[10]

The most impressive results were obtained in the reactions of **7a–c** catalyzed by Rh_2(*S*-PTAD)$_4$. This catalyst is gaining significance because it has been shown to be an effective catalyst in various reactions of donor/acceptor carbenoids.[11] Furthermore, in certain systems it can give superior diastereoselectivity and

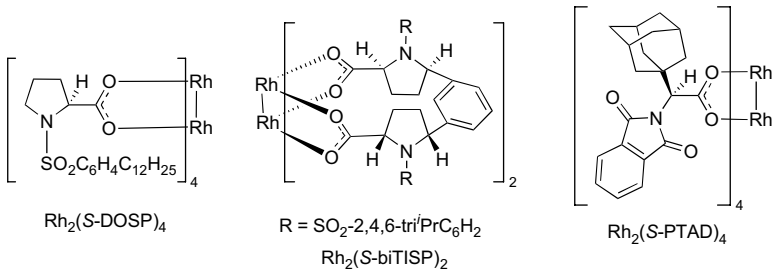
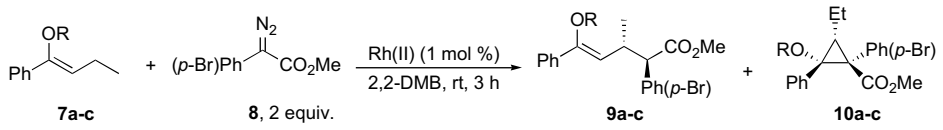


Figure 2. Chiral dirhodium catalysts.

Table 1
Optimization of the Rh(II) catalyzed reactions of **7a–c** with aryldiazoacetate



Entry	Substrate	Rh(II)	**9**/**10**[b]	**9**			**10**		
				Yield[c] (%)	de[b] (%)	ee[d,e] (%)	Yield[c] (%)	de[b] (%)	ee[d,e] (%)
1	**7a**	Rh_2(*S*-DOSP)$_4$	1/4	14	84	73	75	>94	91
2	**7b**	Rh_2(*S*-DOSP)$_4$	1/1	49	88	54	42	>94	80
3	**7c**	Rh_2(*S*-DOSP)$_4$	2/1	64	82	65	23	>94	78
4[a]	**7a**	Rh_2(*S*-biTISP)$_2$	2/1	40	75	−90	22	68	−60
5[a]	**7b**	Rh_2(*S*-biTISP)$_2$	7/1	66	82	−92	9	N.D.	−74
6[a]	**7c**	Rh_2(*S*-biTISP)$_2$	7/1	70	84	−91	9	N.D.	−77
7	**7a**	Rh_2(*S*-PTAD)$_4$	1/1	28	85	−83	35	90	34
8	**7b**	Rh_2(*S*-PTAD)$_4$	8/1	77	>94	−91	6	N.D.	47
9	**7c**	Rh_2(*S*-PTAD)$_4$	>15/1	89	92	−86	N.D.	N.D.	N.D.
10[f]	**7c**	Rh_2(*S*-PTAD)$_4$	>15/1	89	92	−93	N.D.	N.D.	N.D.

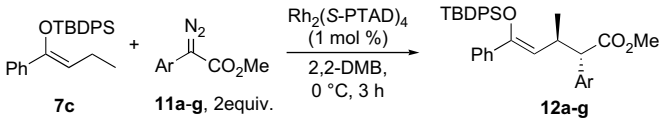
[a] CH_2Cl_2 was used as solvent.
[b] de was determined from the ^{1}H NMR of the crude reaction mixture.
[c] Reported yields are of isolated products.
[d] ee was determined by chiral HPLC.
[e] Negative value signifies the opposite enantiomeric series.
[f] Reaction was conducted at 0 °C.

enantioselectivity compared to the standard catalyst Rh_2(*S*-DOSP)$_4$. In the reactions of **7a–c** with Rh_2(*S*-PTAD)$_4$ the ratios of **9**/**10** were very sensitive to the size of the siloxy group (Table 1, entries 7–9). In the case of the TMS derivative **7a**, a 1:1 mixture of **9a** and **10a** was formed. Increasing the size of the siloxy group, increased the preference for the C–H insertion product **9**, and in the case of the TBDPS derivative **7c**, **9c** was the only product and was isolated in 89% yield with 92% de and 86% ee. The reaction of **7c** was also conducted at 0 °C, and under these conditions, the yield and diastereoselectivity of **9c** were retained while the enantioselectivity improved to 93% ee. Previous studies have shown that reactions catalyzed by Rh_2(*S*-PTAD)$_4$ can give either the same or the opposite enantioinduction to Rh_2(*S*-DOSP)$_4$.[11] Rh_2(*S*-PTAD)$_4$ and Rh_2(*S*-DOSP)$_4$ produced the C–H insertion products **9a–c** with opposite asymmetric induction. In contrast, the same absolute configuration of cyclopropanes **10a** and **10b** is obtained with both catalysts, although the enantioselectivity is quite low (34–47% ee) in the Rh_2(*S*-PTAD)$_4$-catalyzed reactions.

The Rh_2(*S*-PTAD)$_4$-catalyzed C–H insertion of the TBDPS derivative **7c** can be extended to a range of aryldiazoacetates **11a–f** with excellent results (Table 2). The C–H insertion products **12a–f** were cleanly formed with little evidence of the competing cyclopropanation pathway. Lower yields, however, were obtained with **11d** and **11e**, primarily because these diazo compounds were only partially soluble under the reaction conditions. No product was obtained in the reaction of **7c** with *p*-methoxyphenyldiazoacetate **11g**. This indicates that a reasonably reactive electrophilic carbenoid is required for an effective C–H insertion with this substrate.

The relative configurations of the C–H insertion products **9a–c** and **12a–f** are assigned on the basis of the distinctive shielding of the vinyl proton,[8b,c,12] while their absolute configurations are tentatively assigned by analogy to related established Rh_2(*S*-DOSP)$_4$-catalyzed C–H insertions[8b] and the predictive model that has been developed for Rh_2(*S*-DOSP)$_4$-catalyzed reactions.[6a] The initial assignment of the relative configuration of the cyclopropanes **10a–c** assumed that the cyclopropanation occurred with retention of the alkene geometry. The ^{1}H NMR of **10** showed a distinctive shielding of the methyl ester group to δ 3.2 ppm, which is diagnostic of a methyl ester cis to the C-2 phenyl. This stereochemical arrangement is opposite to that obtained in the cyclopropanation of less substituted styryl derivatives. Even the reaction of aryldiazoacetates with *trans*-1-aryl-1-propenes gives a single cyclopropane diastereomer, which has a trans arrangement between the C-2 aryl and the methyl ester.[2,9]

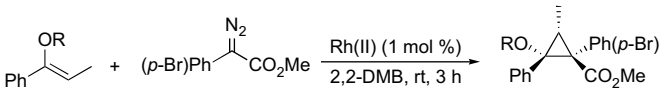
Table 2
Optimized conditions for C–H functionalization of **7c**



Entry	Substrate	Ar	**12**		
			Yield[a] (%)	de[b] (%)	ee[c] (%)
1	**11a**	*p*-ClPh	64	>90	90
2	**11b**	*p*-IPh	65	>90	96
3	**11c**	*p*-CF_3Ph	83	>90	93
4	**11d**	*p*-TfOPh	40	80	90
5	**11e**	3,4-diClPh	42	>90	84
6	**11f**	Ph	87	>90	72
7	**11g**	*p*-MeOPh		No reaction	

[a] Reported yields are of isolated products.
[b] de was determined from the ^{1}H NMR of the crude reaction mixture.
[c] ee was determined by chiral HPLC.

Table 3
Cyclopropanation of **14a–c** by aryldiazoacetate **8**



R: TMS (**13a**), TBS (**13b**), TBDPS (**13c**)

Entry	Substrate	Rh(II)	**14**		
			Yield[c] (%)	de[b] (%)	ee[d,e] (%)
1	**13a**	Rh_2(*S*-DOSP)$_4$	88[f]	>94	92
2	**13b**	Rh_2(*S*-DOSP)$_4$	70[f]	>94	89
3	**13c**	Rh_2(*S*-DOSP)$_4$	84[f]	>94	95
4[a]	**13a**	Rh_2(*S*-biTISP)$_2$	79[g]	72	−72
5[a]	**13b**	Rh_2(*S*-biTISP)$_2$	68[f]	>94	−88
6[a]	**13c**	Rh_2(*S*-biTISP)$_2$	61[h]	49	−69
7	**13a**	Rh_2(*S*-PTAD)$_4$	90[f]	90	−26
8	**13b**	Rh_2(*S*-PTAD)$_4$	86[f]	>94	−43
9	**13c**	Rh_2(*S*-PTAD)$_4$	67[i]	85	4

[a] CH_2Cl_2 was used as solvent.
[b] de was determined from the ^{1}H NMR of the crude reaction mixture.
[c] Reported yields are of isolated products.
[d] ee was determined by chiral HPLC.
[e] Negative value indicates the opposite enantiomeric series.
[f] Ratio of cyclopropane: C–H insertion product was >15:1.
[g] Ratio of cyclopropane: C–H insertion product was 11:1.
[h] Ratio of cyclopropane: C–H insertion product was 2:1.
[i] Ratio of cyclopropane: C–H insertion product was 3.7:1; the C–H insertion product was obtained in 20% isolated yield with 93% ee.

The stereoselective formation of pentasubstituted cyclopropanes broadens the synthetic range of donor/acceptor-substituted carbenoids. In order to optimize this reaction further, the propene derivatives **13a–c** were examined as substrates. It is well established that the C–H insertion by donor/acceptor carbenoids is controlled by a delicate balance of steric and electronic effects.[6a] In general methyl allylic sites are much harder to functionalize than methylene allylic sites. Substrates **13a–c** would be expected to be much more selective toward cyclopropanation than substrates **7a–c**, and this was indeed the case, as summarized in Table 3. The Rh_2(*S*-DOSP)$_4$-catalyzed reaction of **8** with

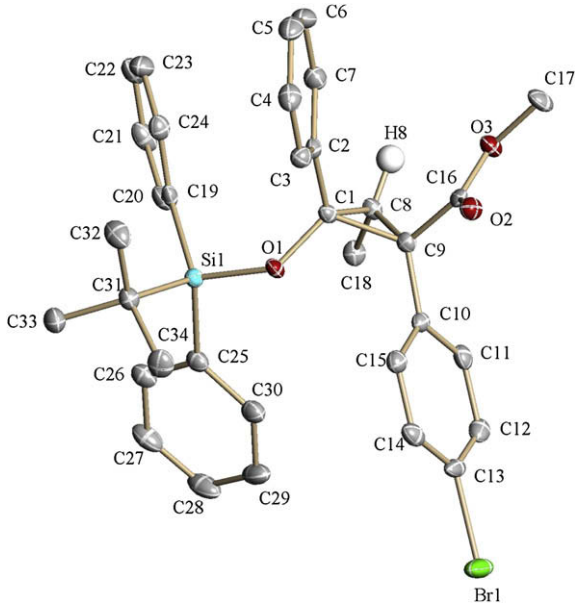
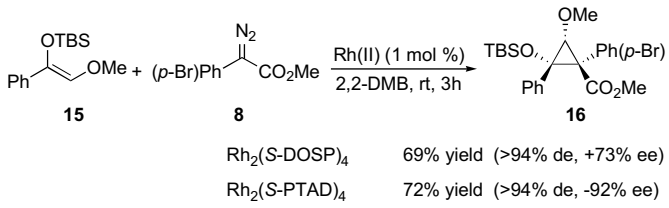
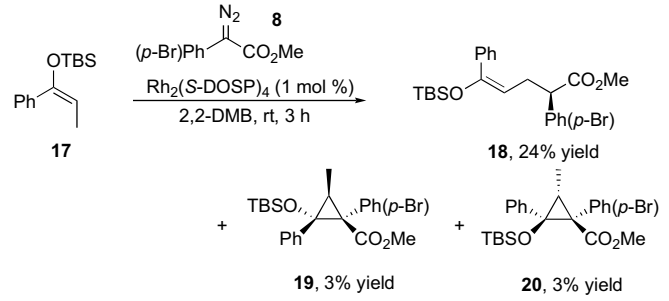


Figure 3. Crystallographic data of **14c**.



Scheme 3. Synthesis of cyclopropane **16**.



Scheme 4. Reaction of *E*-vinyl ether **17** with aryldiazoacetate **8**.

the vinyl ethers **13a–c** gave predominantly the cyclopropanes **14a–c** in high yield (70–88% yield) and with excellent stereocontrol (>94% de, 89–95% ee) (entries 1–3). Even the very bulky TBDPS derivative **13c** was capable of generating the cyclopropane **14c** in 84% isolated yield with >94% de and 95% ee. The other two catalysts, Rh_2(*S*-biTISP)$_2$ and Rh_2(*S*-PTAD)$_4$ were once again less selective toward the cyclopropanation, but in all cases the cyclopropanes **14a–c** were the dominant products. In the case of the TMS derivative **13a**, the cyclopropane **14a** was the exclusive product.

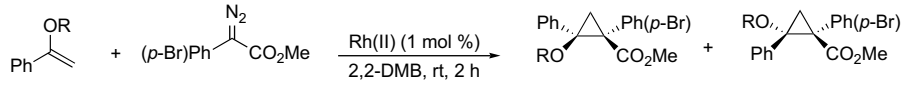
The unexpected relative configuration of the cyclopropanes prompted an effort to confirm the assignment by X-ray crystallography. The cyclopropane **14c** from the Rh_2(*S*-DOSP)$_4$-catalyzed reaction was isolated as a solid and one recrystallization from hexanes generated enantiomerically pure crystals (>99% ee). The results of the X-ray diffraction analysis are shown in Figure 3. This not only confirmed the assigned relative configuration, but also, gave an assignment of the absolute configuration.

Further studies were then conducted to expand the types of pentasubstituted cyclopropanes that could be formed. The reaction of the highly electron rich alkene **15** gave a highly diastereoselective cyclopropanation in both Rh_2(*S*-DOSP)$_4$ and Rh_2(*S*-PTAD)$_4$-catalyzed reactions. The two catalysts gave opposite asymmetric induction with Rh_2(*S*-PTAD)$_4$ giving the highest enantioselectivity (92% ee). The cis relationship between the C-2 phenyl and the methyl ester was again evident from the distinctive shielding of the methyl ester protons (Scheme 3).

Monosubstituted vinyl ethers and styrene undergo highly diastereoselective cyclopropanations with donor/acceptor carbenoids. Thus, it is not clear whether the unusual stereocontrol is due to the methyl group on the trisubstituted vinyl ether or the steric competition between the phenyl and the siloxy groups. Therefore, it became of interest to determine what would be the effect of changing the alkene geometry of the trisubstituted vinyl ether. The chemistry of the *E*-vinyl ether **17** was very different from the *Z*-vinyl ethers **13a–c**. The Rh_2(*S*-DOSP)$_4$-catalyzed reaction of **17** with **8** was not a high yielding process, resulting in only a 30% conversion (Scheme 4). The major product was the C–H insertion product **18**, while the two minor products were tentatively assigned as the cyclopropanes **19** and **20**. In this case, the cyclopropanation is not diastereoselective. The absolute configuration of **18–20** has not been unambiguously assigned, but are drawn assuming the predictive model for the asymmetric induction is still operational for this system.[6a,8b]

The profound difference between the reactions of *E*-vinyl ether **17** and *Z*-vinyl ethers **13a–c** indicate that the regio- and stereocontrol involve the subtle influences of all three substituents. In order to further understand these influences the reactions of 1-aryl vinyl ethers **21a–c** were examined. With these substrates only cyclopropanation can occur but the diastereoselectivity is still an issue as summarized in Table 4. The nature of the silyl group has very little influence on the diastereoselectivity as seen in entries 1–9. In contrast, the catalyst has a more significant influence. The Rh_2(*S*-DOSP)$_4$-catalyzed reaction favors the *E*-isomer **23** by about a 2:1 ratio (entries 1–3), while the Rh_2(*S*-PTAD)$_4$-catalyzed reaction favors the *Z*-isomer **22** by

Table 4
Effect of catalyst and silyl group on the cyclopropanation of aryl vinyl ethers

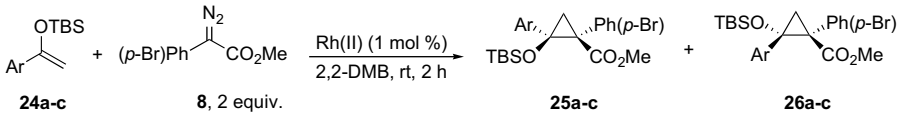


R: TMS (**21a**), TBS (**21b**), TBDPS (**21c**)

Entry	Substrate	Rh(II)	**22**/**23**[b]	**22**		**23**	
				Yield[c] (%)	ee[d] (%)	Yield[c] (%)	ee[d,e] (%)
1	**21a**	Rh_2(*S*-DOSP)$_4$	1/2	33	82	39	75
2	**21b**	Rh_2(*S*-DOSP)$_4$	1/2	25	69	46	83
3	**21c**	Rh_2(*S*-DOSP)$_4$	1/2	27	51	51	85
4[a]	**21a**	Rh_2(*S*-biTISP)$_2$	1/1	43	−92	46	−20
5[a]	**21b**	Rh_2(*S*-biTISP)$_2$	1/1	45	−90	46	−4
6[a]	**21c**	Rh_2(*S*-biTISP)$_2$	3/1	58	−91	23	−30
7	**21a**	Rh_2(*S*-PTAD)$_4$	3/1	63	−91	24	−64
8	**21b**	Rh_2(*S*-PTAD)$_4$	7/1	77	−90	10	−75
9	**21c**	Rh_2(*S*-PTAD)$_4$	4/1	73	−84	18	−83

[a] CH_2Cl_2 was used as solvent.
[b] de was determined from the ^{1}H NMR of the crude reaction mixture.
[c] Reported yields are of isolated products.
[d] ee was determined by chiral HPLC.
[e] Negative value indicates the opposite enantiomeric series.

Table 5
Effect of catalyst and substrate electronics on the cyclopropanation of aryl vinyl ethers

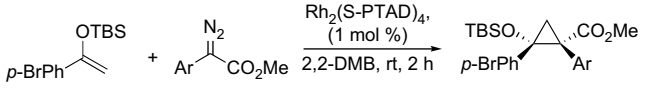


24a-c **8**, 2 equiv. **25a-c** **26a-c**

Entry	Substrate	Ar	Rh(II)	**25**/**26**[a]	**25**		**26**	
					Yield[b] (%)	ee[c,d] (%)	Yield[b] (%)	ee[c,d] (%)
1	**24a**	(*p*-MeO)Ph	Rh_2(*S*-DOSP)$_4$	2/1	61	74	27	73
2	**24a**	(*p*-MeO)Ph	Rh_2(*S*-PTAD)$_4$	7/1	67	−74	9	−90
3	**24b**	(*p*-Br)Ph	Rh_2(*S*-DOSP)$_4$	1/2	25	66	49	50
4	**24b**	(*p*-Br)Ph	Rh_2(*S*-PTAD)$_4$	>15/1	84	−94	N.D.	N.D.
5	**24c**	(*p*-CF_3)Ph	Rh_2(*S*-DOSP)$_4$	1/2	26	74	44	84
6	**24c**	(*p*-CF_3)Ph	Rh_2(*S*-PTAD)$_4$	>15/1	69	−97	N.D.	N.D.

[a] de was determined from the ^{1}H NMR of the crude reaction mixture.
[b] Reported yields are of isolated products.
[c] ee was determined by chiral HPLC.
[d] Negative value indicates the opposite enantiomeric series.

Table 6
Optimized conditions for the stereoselective cyclopropanation of 1-aryl vinyl ethers



24b **11**, 2 equiv. **27a-d**

Entry	Substrate	Ar	Product	**27**		
				Yield[a] (%)	de[b] (%)	ee[c] (%)
1	**11a**	*p*-ClPh	**27a**	92	>94	95
2	**11f**	Ph	**27b**	87	>94	95
3	**11g**	*p*-MeOPh	**27c**	89	>94	98
4	**11h**	*p*-MePh	**27d**	91	>94	95

[a] Reported yields are of isolated products.
[b] de was determined from the ^{1}H NMR of the crude reaction mixture.
[c] ee was determined by chiral HPLC.

a 3–7:1 ratio (entries 7–9). The diastereomers can be readily distinguished on the basis of the chemical shift in the ^{1}H NMR for the methyl ester protons. Further optimization of the diastereoselectivity was possible by adding an electron withdrawing group to the aryl vinyl ether (Table 5). The reaction of **24b** and **24c**, containing *p*-Br and *p*-CF_3 substituents greatly increased the formation of the *Z*-cyclopropane **25**. Indeed, the Rh_2(*S*-PTAD)$_4$-catalyzed reaction of **8** with **24c** generates essentially a single diastereomer of **25c** in 69% yield and 97% ee. The absolute configuration of the cyclopropanes is assigned using the predictive model that has been developed for Rh_2(*S*-DOSP)$_4$-catalyzed reactions.[6a] In Table 4, the Rh_2(*S*-DOSP)$_4$-catalyzed reactions give the opposite asymmetric induction to the Rh_2(*S*-PTAD)$_4$- and Rh_2(*S*-biTISP)$_2$-catalyzed reactions.

Once the optimized conditions were determined, highly enantioselective cyclopropanation of 1-aryl vinyl ethers can be predictably achieved (Table 6). Rh_2(*S*-PTAD)$_4$-catalyzed reaction of a range of aryldiazoacetates (**11a**, **11f**–**h**) with *p*-bromophenyl vinyl ether **24b** generated cyclopropanes **27a**-**d** in 87–92% yield, >94% de and 95–98% ee.

3. Conclusions

The reactions of electron rich trisubstituted alkenes and 1,1-disubstituted alkenes with aryldiazoacetates catalyzed by dirhodium carboxylate catalysts illustrate the subtle factors that control cyclopropanation versus C–H insertion chemistry. Electron rich trisubstituted alkenes can either undergo cyclopropanation to generate pentasubstituted cyclopropanes or C–H insertion. Both types of products can be obtained with excellent levels of diastereo- and enantiocontrol. A secondary allylic site is more favorable for C–H insertion compared to a primary allylic site. Rh_2(*S*-DOSP)$_4$ is the best catalyst to favor cyclopropanation while Rh_2(*S*-PTAD)$_4$ favors C–H insertion. The size of the silyl group is another important controlling feature with the TMS group favoring cyclopropanation and the bulky TBDPS group favoring C–H insertion. The nature of the catalyst and substrate also greatly influences the diastereoselectivity of the cyclopropanation of 1-aryl vinyl ethers, with Rh_2(*S*-PTAD)$_4$ and electron withdrawing groups on the aryl group strongly favoring the formation of the (*Z*)-tetrasubstituted cyclopropanes. These studies define some of the controlling influences of the reactivity of donor/acceptor carbenoids, which will help to guide their application in more elaborate systems.

4. Experimental

4.1. General

General methods for spectral and analytical procedures, the preparation of starting materials, and the X-ray crystallographic data for **14c** are described in Supplementary data.

4.2. General procedure for rhodium(II)-catalyzed decompositions of methyl aryldiazoacetates in the presence of alkenes

Methyl aryldiazoacetate (0.4–2.0 mmol, 1.5–2.0 equiv) in 6–12 mL of degassed 2,2-dimethylbutane (2,2-DMB) was added dropwise by syringe pump over 2–3 h to a solution of alkene (0.2–1.0 mmol, 1.0 equiv) and Rh(II) (0.01 equiv) in 3–6 mL of 2,2-DMB at rt under Ar. In the Rh_2(*S*-PTAD)$_4$-catalyzed reactions, trifluorotoluene (0.2 mL) was added to the 2,2-DMB to increase the solubility of the catalyst. After the addition is complete, the solution was stirred for an additional 16 h, then concentrated under vacuum. The crude product was purified by flash chromatography on silica using pentane/Et_2O as eluent to give the desired product.

*4.2.1. (2R,3S,Z)-Methyl 2-(4-bromophenyl)-3-methyl-5-phenyl-5-(trimethylsilyloxy)pent-4-enoate (**9a**) and (1S,2S,3R)-methyl 1-(4-bromophenyl)-3-ethyl-2-phenyl-2-(trimethylsilyloxy)-cyclopropanecarboxylate (**10a**)*

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1) enabled the separation of **9a** and **10a**. Compound **9a**: clear oil; R_f 0.50 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.39 (d, J=8.5 Hz, 2H), 7.27–7.23 (m, 7H), 4.75 (d, J=9.0 Hz, 1H), 3.69 (s, 3H), 3.44–3.39 (m, 2H), 1.15 (d, J=5.5 Hz, 3H), 0.07 (s, 9H);

^{13}C NMR (75 MHz, $CDCl_3$): 173.6 (C), 150.0 (C), 139.1 (C), 136.9 (C), 131.1 (CH), 130.4 (CH), 127.9 (CH), 127.6 (CH), 125.8 (CH), 121.1 (C), 113.2 (CH), 57.7 (CH), 51.9 (CH_3), 34.3 (CH), 19.6 (CH_3), 0.6 (CH_3); IR (neat) 1737, 1648, 1489, 1298, 1164, 1064, 846 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 469.0809; calcd ($C_{22}H_{27}O_3BrSiNa$): 469.0805; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 6.7 min (major), 10.9 min (minor), −90% ee with Rh_2(*S*-biTISP)$_4$; $[\alpha]_D^{23}$ +95.7 (*c* 1.0, $CHCl_3$). Compound **10a**: clear oil; R_f 0.41 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.51–7.48 (m, 4H), 7.38–7.30 (m, 5H), 3.23 (s, 3H), 2.60 (dd, *J*=8.0, 5.0 Hz, 1H), 1.59–1.51 (m, 1H), 1.29–1.22 (m, 1H), 1.19 (t, *J*=7.0 Hz, 3H), −0.18 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.2 (C), 138.9 (C), 134.1 (CH), 133.2 (C), 130.6 (CH), 129.6 (CH), 128.2 (CH), 128.0 (CH), 120.9 (C), 70.4 (C), 52.0 (CH_3), 42.0 (C), 34.2 (CH), 17.9 (CH_2), 13.7 (CH_3), 1.2 (CH_3); IR (neat) 1724, 1488, 1250, 1073, 890, 844 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 469.0808; calcd ($C_{22}H_{27}O_3BrSiNa$): 469.0805; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.9 min (major), 17.7 min (minor), 91% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +133.7 (*c* 1.0, $CHCl_3$).

4.2.2. (2R,3S,Z)-Methyl 2-(4-bromophenyl)-5-(tert-butyldimethylsilyloxy)-3-methyl-5-phenylpent-4-enoate (**9b**) and (1S,2S,3R)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-3-ethyl-2-phenylcyclopropanecarboxylate (**10b**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1 to 20:1) enabled the separation of **9b** and **10b**. Compound **9b**: clear oil; R_f 0.55 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.38 (d, *J*=8.5 Hz, 2H), 7.25–7.21 (m, 5H), 7.17–7.15 (m, 2H), 4.61 (d, *J*=10.0 Hz, 1H), 3.69 (s, 3H), 3.50–3.44 (m, 1H), 3.37 (d, *J*=10.5 Hz, 1H), 1.15 (d, *J*=6.5 Hz, 3H), 1.01 (s, 9H), −0.04 (s, 3H), −0.20 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.6 (C), 150.2 (C), 139.5 (C), 137.0 (C), 131.0 (CH), 130.4 (CH), 127.8 (CH), 127.6 (CH), 126.3 (CH), 121.0 (C), 113.9 (CH), 57.9 (CH), 51.9 (CH_3), 34.0 (CH), 25.8 (CH_3), 19.6 (CH_3), 18.2 (C), −3.9 (CH_3), −4.2 (CH_3); IR (neat) 1737, 1650, 1489, 1339, 1257, 1059 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 511.1264; calcd ($C_{25}H_{33}O_3BrSiNa$): 511.1275; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 7.4 min (major), 11.7 min (minor), −91% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +66.5 (*c* 1.1, $CHCl_3$). Compound **10b**: clear oil; R_f 0.43 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.50–7.48 (m, 4H), 7.37–7.31 (m, 5H), 3.24 (s, 3H), 2.58 (dd, *J*=8.0, 5.5 Hz, 1H), 1.61–1.56 (m, 1H), 1.41–1.35 (m, 1H), 1.21 (t, *J*=7.5 Hz, 3H), 0.61 (s, 9H), −0.25 (s, 3H), −0.34 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.3 (C), 138.9 (C), 134.5 (CH), 132.8 (C), 130.7 (CH), 130.2 (CH), 128.4 (CH), 128.1 (CH), 120.9 (C), 70.5 (C), 52.1 (CH_3), 42.0 (C), 34.9 (CH), 25.6 (CH_3), 18.3 (C), 17.9 (CH_3), 14.1 (CH_3), −3.0 (CH_3), −3.4 (CH_3); IR (neat) 1724, 1489, 1247, 1072, 886, 837 cm^{-1}; EI-HRMS: *m/z*, found: 488.1377; calcd ($C_{25}H_{33}O_3BrSi$): 488.1377; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 10.3 min (major), 31.8 min (minor), 80% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +94.3 (*c* 1.1, $CHCl_3$).

4.2.3. (2R,3S,Z)-Methyl 2-(4-bromophenyl)-5-(tert-butyldiphenylsilyloxy)-3-methyl-5-phenylpent-4-enoate (**9c**) and (1S,2S,3R)-methyl 1-(4-bromophenyl)-2-(tert-butyldiphenylsilyloxy)-3-ethyl-2-phenylcyclopropanecarboxylate (**10c**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1) enabled the separation of **9c** and **10c**. Compound **9c**: clear oil; R_f 0.48 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.52–7.50 (m, 4H), 7.42–7.26 (m, 8H), 7.10 (d, *J*=8.5 Hz, 2H), 7.02–6.99 (m, 1H), 6.95–6.89 (m, 4H), 4.51 (d, *J*=10.0 Hz, 1H), 3.68 (s, 3H), 3.46 (m, 1H), 3.31 (d, *J*=10.0 Hz, 1H), 1.08 (s, 9H), 0.96 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.4, 150.7, 138.9, 137.1, 135.7, 135.6, 133.4, 133.2, 131.1, 130.4, 129.5, 127.3, 127.2, 126.9, 120.9, 114.0, 57.8, 51.8, 34.5, 26.9, 19.8, 19.2; HPLC: (*R*,*R*)-whelk-01, 0.2% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 9.5 min (major), 23.0 min (minor), −93% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +38.4 (*c* 1.0, $CHCl_3$). Data are consistent with the reference.[8b] Compound **10c**: clear oil; R_f 0.38 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.57 (d, *J*=8.5 Hz, 2H), 7.44 (d, *J*=8.5 Hz, 2H), 7.38–7.31 (m, 4H), 7.24 (t, *J*=7.0 Hz, 2H), 7.18–7.12 (m, 5H), 7.06 (t, *J*=7.0 Hz, 4H), 3.17 (s, 3H), 2.48 (t, *J*=7.0 Hz, 1H), 1.54–1.41 (m, 2H), 1.02 (t, *J*=7.0 Hz, 3H), 0.76 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.2 (C), 138.2 (C), 136.5 (CH), 136.0 (CH), 134.9 (CH), 133.4 (C), 133.2 (C), 132.9 (C), 131.1 (CH), 130.6 (CH), 129.6 (CH), 129.3 (CH), 128.0 (CH), 127.4 (CH), 127.0 (CH), 126.9 (CH), 121.3 (C), 71.5 (C), 52.1 (CH_3), 42.5 (C), 35.4 (CH), 27.3 (CH_3), 19.6 (C), 18.2 (CH_2), 14.2 (CH_3); IR (neat) 1724, 1489, 1244, 1146, 1111, 1072, 699 cm^{-1}; EI-HRMS: *m/z*, found: 612.1671; calcd ($C_{35}H_{37}O_3BrSi$): 612.1690; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 10.4 min (major), 28.4 min (minor), 78% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +32.1 (*c* 1.3, $CHCl_3$).

4.2.4. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-2-(4-chlorophenyl)-3-methyl-5-phenylpent-4-enoate (**12a**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) to give **12a** as a clear oil. R_f 0.44 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.52 (t, *J*=6.0 Hz, 4H), 7.42–7.23 (m, 8H), 7.18–7.16 (d, *J*=8.0 Hz, 2H), 7.01 (t, *J*=7.5 Hz, 1H), 6.95–6.90 (m, 4H), 4.50 (d, *J*=10.0 Hz, 1H), 3.68 (s, 3H), 3.50–3.45 (m, 1H), 3.33 (d, *J*=10.0 Hz, 1H), 1.08 (s, 9H), 0.97 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.5 (C), 150.7 (C), 138.9 (C), 136.6 (C), 135.7 (CH), 135.6 (CH), 133.4 (C), 133.2 (C), 132.8 (C), 130.0 (CH), 129.5 (CH), 128.2 (CH), 127.3 (CH), 127.2 (CH), 126.9 (CH), 114.0 (CH), 57.7 (CH), 51.8 (CH_3), 34.6 (CH), 26.9 (CH_3), 19.8 (C), 19.2 (CH_3); IR (neat) 1737, 1652, 1491, 1428, 1337, 1113, 1073, 699 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 591.2075; calcd ($C_{35}H_{37}O_3ClSiNa$): 591.2093; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 8.3 min (major), 16.4 min (minor), 90% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +38.1 (*c* 1.0, $CHCl_3$).

4.2.5. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-2-(4-iodophenyl)-3-methyl-5-phenylpent-4-enoate (**12b**)

Purification by silica gel chromatography eluting with pentane/Et_2O (15:1) to give **12b** as a clear oil. R_f 0.47 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.58 (d, *J*=8.0 Hz, 2H), 7.52 (d, *J*=8.0 Hz, 4H), 7.42–7.26 (m, 6H), 7.03–6.90 (m, 7H), 4.50 (d, *J*=10.0 Hz, 1H), 3.67 (s, 3H), 3.49–3.44 (m, 1H), 3.30 (d, *J*=10.0 Hz, 1H), 1.08 (s, 9H), 0.96 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.3 (C), 150.7 (C), 138.9 (C), 137.8 (C), 137.1 (CH), 135.7 (CH), 135.6 (CH), 133.4 (C), 133.2 (C), 130.7 (CH), 129.5 (CH), 127.3 (CH), 127.2 (CH), 126.9 (CH), 114.0 (CH), 92.5 (C), 57.8 (CH), 51.8 (CH_3), 34.5 (CH), 26.9 (CH_3), 19.8 (C), 19.2 (CH_3); IR (neat) 1737, 1652, 1485, 1428, 1337, 1299, 1113, 1072, 699 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 683.1456; calcd ($C_{35}H_{37}O_3ISiNa$): 683.1449; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 9.3 min (major), 17.9 min (minor), 96% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +39.3 (*c* 1.0, $CHCl_3$).

4.2.6. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-3-methyl-5-phenyl-2-(4-(trifluoromethyl)phenyl)pent-4-enoate (**12c**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) to give **12c** as a clear oil. R_f 0.45 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.53–7.52 (m, 6H), 7.41–7.35 (m, 4H), 7.31–7.26 (m, 4H), 7.01 (t, *J*=7.0 Hz, 1H), 6.93 (t, *J*=7.5 Hz, 2H), 6.87 (d, *J*=7.0 Hz, 2H), 4.49 (d, *J*=10.0 Hz, 1H), 3.69 (s, 3H), 3.55–3.50 (m, 1H), 3.41 (d, *J*=10.0 Hz, 1H), 1.08 (s, 9H), 0.98 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.2 (C), 150.8 (C), 142.1 (C), 138.9 (C), 135.7 (CH), 135.6 (CH), 133.3 (C), 133.1 (C), 129.6 (CH), 129.0 (CH), 127.4 (CH), 127.3 (CH), 127.3 (CH), 126.9 (CH), 125.0 (CH), 124.9 (CH), 113.8 (CH), 58.2 (CH), 51.9 (CH_3), 34.7 (CH), 26.9 (CH_3), 19.8 (C), 19.1 (CH_3); ^{19}F NMR (376 MHz, $CDCl_3$): −62.2; IR (neat) 1737, 1653, 1326, 1166, 1115, 1069, 699 cm^{-1}; ESI-HRMS: (M+Na) *m/z*, found: 625.2356; calcd ($C_{35}H_{37}O_3F_3SiNa$): 625.2356; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 7.3 min (major),

10.3 min (minor), 93% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +15.2 (*c* 1.0, $CHCl_3$).

4.2.7. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-3-methyl-5-phenyl-2-(4-(trifluoromethylsulfonyloxy)phenyl)pent-4-enoate (**12d**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) to give **12d** as a clear oil. R_f 0.40 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.55 (d, *J*=7.0 Hz, 2H), 7.50 (d, *J*=7.0 Hz, 2H), 7.41–7.37 (m, 2H), 7.34–7.27 (m, 6H), 7.16 (d, *J*=8.5 Hz, 2H), 7.02 (t, *J*=7.0 Hz, 1H), 6.94 (t, *J*=7.5 Hz, 2H), 6.87 (d, *J*=7.5 Hz, 2H), 4.44 (d, *J*=10.0 Hz, 1H), 3.69 (s, 3H), 3.49–3.44 (m, 1H), 3.35 (d, *J*=10.0 Hz, 1H), 1.07 (s, 9H), 0.94 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.2 (C), 150.9 (C), 148.6 (C), 138.9 (C), 138.7 (C), 135.7 (CH), 135.6 (CH), 133.3 (C), 133.2 (C), 130.5 (CH), 129.6 (CH), 129.6 (CH), 127.4 (CH), 127.4 (CH), 127.3 (CH), 126.9 (CH), 120.8 (CH), 113.8 (CH), 57.8 (CH), 51.9 (CH_3), 34.8 (CH), 26.9 (CH_3), 19.8 (C), 19.1 (CH_3); IR (neat) 1737, 1653, 1426, 1214, 1141, 888, 700 cm^{-1}; APCI-HRMS: (M+H) *m*/*z*, found: 683.2107; calcd ($C_{36}H_{38}O_6F_3SSi$): 683.2110; HPLC: (*R*,*R*)-whelk-01, 0.6% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 9.2 min (major), 12.1 min (minor), 90% ee with Rh_2(*S*-PTAD)$_4$.

4.2.8. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-2-(3,4-dichlorophenyl)-3-methyl-5-phenylpent-4-enoate (**12e**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) to give **12e** as a clear oil. R_f 0.47 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.54 (d, *J*=8.0 Hz, 2H), 7.50 (d, *J*=8.0 Hz, 2H), 7.41 (d, *J*=2.0 Hz, 1H), 7.39–7.35 (m, 2H), 7.30–7.27 (m, 6H), 7.05–7.00 (m, 2H), 6.95–6.90 (m, 4H), 4.46 (d, *J*=10.0 Hz, 1H), 3.68 (s, 3H), 3.46–3.41 (m, 1H), 3.28 (d, *J*=10.0 Hz, 1H), 1.07 (s, 9H), 0.92 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.0 (C), 151.0 (C), 138.9 (C), 138.3 (C), 135.7 (CH), 135.6 (CH), 133.3 (C), 133.2 (C), 132.1 (C), 131.1 (C), 130.5 (CH), 129.9 (CH), 129.6 (CH), 129.5 (CH), 128.2 (CH), 127.4 (CH), 127.4 (CH), 127.3 (CH), 126.9 (CH), 113.7 (CH), 57.4 (CH), 51.9 (CH_3), 34.5 (CH), 26.9 (CH_3), 19.8 (C), 19.1 (CH_3); IR (neat) 1737, 1652, 1472, 1428, 1336, 1113, 1072, 699 cm^{-1}; EI-HRMS: *m*/*z*, found: 602.1796; calcd ($C_{35}H_{36}O_3Cl_2Si$): 602.1805; HPLC: (*R*,*R*)-whelk-01, 0.6% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 8.2 min (major), 17.2 min (minor), 84% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +28.7 (*c* 1.1, $CHCl_3$).

4.2.9. (2S,3R,Z)-Methyl 5-(tert-butyldiphenylsilyloxy)-3-methyl-2,5-diphenylpent-4-enoate (**12f**)

Purification by silica gel chromatography eluting with pentane/Et_2O/triethylamine (100:1:0.5) to give **12f** as a clear oil. R_f 0.51 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.55 (d, *J*=7.5 Hz, 2H), 7.50 (d, *J*=7.0 Hz, 2H), 7.38–7.35 (m, 2H), 7.27 (t, *J*=7.5 Hz, 9H), 6.97 (t, *J*=7.0 Hz, 1H), 6.91–6.85 (m, 4H), 4.52 (d, *J*=9.5 Hz, 1H), 3.67 (s, 3H), 3.56–3.51 (m, 1H), 3.38 (d, *J*=10.0 Hz, 1H), 1.08 (s, 9H), 0.98 (d, *J*=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.8, 150.4, 139.1, 138.0, 135.7, 135.6, 133.5, 133.4, 129.5, 129.4, 128.7, 128.1, 127.3, 127.2, 127.1, 127.0, 126.9, 114.4, 58.4, 51.7, 34.4, 26.9, 19.8, 19.2; IR (neat) 1736, 1653, 1429, 1113, 1071, 698 cm^{-1}; EI-HRMS: *m*/*z*, found: 534.2585; calcd ($C_{35}H_{38}O_3Si$): 534.2585; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 8.6 min (major), 16.0 min (minor), 72% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +15.5 (*c* 1.2, $CHCl_3$).

4.2.10. (1S,2S,3R)-Methyl 1-(4-bromophenyl)-3-methyl-2-phenyl-2-(trimethylsilyloxy)cyclopropanecarboxylate (**14a**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1 to 15:1) enabled the separation of the two diastereomer of **14a**. Major diastereomer: white solid; R_f 0.38 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.50–7.48 (m, 4H), 7.35 (t, *J*=8.0 Hz, 2H), 7.31–7.28 (m, 3H), 3.20 (s, 3H), 2.80 (q, *J*=6.0 Hz, 1H), 1.08 (d, *J*=7.0 Hz, 3H), −0.20 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.2 (C), 139.1 (C), 134.3 (CH), 132.8 (C), 130.7 (CH), 129.4 (CH), 128.1 (CH), 128.0 (CH), 121.0 (C), 70.3 (C), 52.0 (CH_3), 41.9 (C), 26.5 (CH), 10.4 (CH_3), 0.9 (CH_3); IR (neat) 1724, 1248, 1057, 1012, 874, 842 cm^{-1}; ESI-HRMS: (M+H) *m*/*z*, found: 433.0826; calcd ($C_{21}H_{26}O_3BrSi$): 433.0829; HPLC: (*R*,*R*)-whelk-01, 0.7% ^{i}PrOH/hexane, 0.6 mL min^{-1}, UV 254 nm, t_R: 12.6 min (major), 24.4 min (minor), 92% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +138.5 (*c* 1.0, $CHCl_3$). Minor diastereomer: clear oil; R_f 0.48 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.23 (d, *J*=7.0 Hz, 2H), 7.18–7.12 (m, 5H), 7.05 (d, *J*=8.5 Hz, 2H), 3.69 (s, 3H), 2.27 (q, *J*=6.5 Hz, 1H), 1.62 (d, *J*=6.5 Hz, 3H), −0.03 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.1 (C), 138.9 (C), 136.9 (C), 131.9 (CH), 130.6 (CH), 128.4 (CH), 127.8 (CH), 127.7 (CH), 120.6 (C), 68.7 (C), 51.7 (CH_3), 43.5 (C), 26.2 (CH), 10.4 (CH_3), 1.1 (CH_3); IR (neat) 1734, 1490, 1448, 1433, 1308, 1251, 1213, 1025, 1010, 876, 844 cm^{-1}; ESI-HRMS: (M+Na) *m*/*z*, found: 455.0651; calcd ($C_{21}H_{25}O_3BrSiNa$): 455.0649.

4.2.11. (1S,2S,3R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-3-methyl-2-phenylcyclopropanecarboxylate (**14b**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) enabled the separation of **14b** as a clear oil. R_f 0.36 (pentane/Et_2O 5:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.72–7.69 (m, 4H), 7.58–7.52 (m, 5H), 3.42 (s, 3H), 3.01 (q, *J*=6.3 Hz, 1H), 1.35 (d, *J*=6.3 Hz, 3H), 0.84 (s, 9H), 0.13 (s, 3H), −0.37 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.2, 139.2, 134.7, 132.4, 130.7, 129.7, 128.2, 128.1, 121.0, 70.2, 52.0, 41.7, 26.9, 25.6, 18.2, 10.5, −3.9, −4.2; IR (neat) 1725, 1489, 1462, 1448, 1434, 1250, 1132, 1058, 1013, 863, 839, 777, 701 cm^{-1}; EI-HRMS: *m*/*z*, found: 475.1281; calcd ($C_{24}H_{32}O_3BrSi$): 475.1299; HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 7.3 min (major), 16.4 min (minor), 89% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +85.3 (*c* 1.1, $CHCl_3$).

4.2.12. (1S,2S,3R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldiphenylsilyloxy)-3-methyl-2-phenylcyclopropanecarboxylate (**14c**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1 to 20:1) enabled the separation of the two diastereomers of **14c**. Major diastereomer: clear oil; R_f 0.32 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.65 (d, *J*=8.5 Hz, 2H), 7.48 (d, *J*=8.0 Hz, 2H), 7.43–7.34 (m, 4H), 7.27 (t, *J*=7.5 Hz, 2H), 7.22–7.12 (m, 7H), 7.06 (d, *J*=7.0 Hz, 2H), 3.21 (s, 3H), 2.67 (q, *J*=6.5 Hz, 1H), 1.05 (d, *J*=6.5 Hz, 3H), 0.81 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 171.0 (C), 138.4 (C), 136.5 (CH), 135.9 (CH), 135.1 (CH), 133.6 (C), 132.8 (C), 132.7 (C), 131.1 (CH), 130.4 (CH), 129.7 (CH), 129.3 (CH), 127.9 (CH), 127.4 (CH), 127.0 (CH), 121.3 (C), 71.4 (C), 52.0 (CH_3), 42.1 (C), 27.7 (CH), 27.1 (CH_3), 19.6 (C), 11.3 (CH_3); IR (neat) 1724, 1489, 1428, 1247, 1133, 1112, 1058, 1013, 911, 853, 735, 700 cm^{-1}; EI-HRMS: *m*/*z*, found: 598.1540; calcd ($C_{34}H_{35}O_3BrSi$): 598.1533; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 10.5 min (major), 42.1 min (minor), 95% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +40.2 (*c* 1.0, $CHCl_3$). Minor diastereomer: clear oil; R_f 0.52 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64 (d, *J*=6.5 Hz, 2H), 7.42–7.38 (m, 3H), 7.35–7.31 (m, 3H), 7.23 (t, *J*=7.5 Hz, 2H), 7.13 (d, *J*=8.5 Hz, 2H), 7.08 (d, *J*=8.5 Hz, 2H), 6.86–6.81 (m, 3H), 6.69 (t, *J*=7.5 Hz, 2H), 3.83 (s, 3H), 2.07 (q, *J*=7.0 Hz, 1H), 1.58 (d, *J*=6.5 Hz, 3H), 0.95 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.2 (C), 136.8 (C), 136.7 (C), 136.2 (CH), 135.8 (CH), 134.3 (C), 133.8 (C), 131.3 (CH), 130.7 (CH), 130.5 (CH), 129.3 (CH), 129.2 (CH), 127.4 (CH), 127.1 (CH), 127.0 (CH), 126.9 (CH), 120.6 (C), 69.7 (C), 51.9 (CH_3), 43.2 (C), 27.2 (CH_3), 26.7 (CH), 19.8 (C), 10.4 (CH_3); IR (neat) 1733, 1489, 1429, 1308, 1209, 1112, 1010, 737, 699 cm^{-1}; ESI-HRMS: (M+Na) *m*/*z*, found: 621.1457; calcd ($C_{34}H_{35}O_3BrSiNa$): 621.1431. *C–H insertion product*: clear oil; R_f 0.44 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.65–7.61 (m, 4H), 7.43–7.27 (m, 10H), 7.17–7.13 (m 3H), 6.92 (d, *J*=9.0 Hz, 2H), 4.75 (t, *J*=7.0 Hz, 1H), 3.58 (s, 3H), 3.22 (t, *J*=8.0 Hz, 1H), 2.65–2.62 (m, 1H), 2.38–2.33 (m, 1H), 1.02 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.4 (C), 151.4 (C), 139.0 (C), 137.6 (C), 135.6 (CH), 135.5 (CH), 133.3 (C), 133.2 (C), 131.4 (CH), 129.7 (CH), 129.6 (CH), 127.7 (CH), 127.6 (CH), 127.4 (CH), 126.5 (CH), 121.0 (C), 106.9

(CH), 51.9 (CH_3), 50.6 (CH), 30.1 (CH_2), 26.8 (CH_3), 19.8 (C); IR (neat) 1737, 1652, 1488, 1428, 1113, 1074, 700 cm^{-1}; ESI-HRMS: (M+Na) *m*/*z*, found: 621.1420; calcd ($C_{34}H_{35}O_3BrSiNa$): 621.1431; HPLC: (*R*,*R*)-whelk-01, 0.5% ^{i}PrOH/hexane, 0.8 mL min^{-1}, UV 254 nm, t_R: 17.4 min (major), 21.2 min (minor), 93% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ +43.8 (*c* 1.0, $CHCl_3$).

4.2.13. (1R,2S,3R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-3-methoxy-2-phenylcyclopropanecarboxylate (**16**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) to give **16** as a white solid. Mp 117–119 °C; R_f 0.35 (20% Et_2O/pentane); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.48–7.44 (m, 4H), 7.36–7.26 (m, 5H), 5.44 (s, 1H), 3.70 (s, 3H), 3.23 (s, 3H), 0.54 (s, 9H), −0.29 (s, 3H), −0.31 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.0, 138.1, 134.9, 131.0, 130.5, 128.9, 128.2, 128.1, 121.1, 68.9, 68.7, 59.3, 52.0, 42.8, 25.4, 18.1, −3.9, −4.2; IR (neat) 1721, 1489, 1448, 1247, 1205, 1089, 1072, 1013, 962, 891, 839, 777, 723, 699 cm^{-1}. Anal. Calcd for $C_{24}H_{31}O_4BrSi$: C, 58.65; H, 6.36. Found: C, 58.67; H, 6.42. EI-HRMS: *m*/*z*, found: 490.1182; calcd ($C_{24}H_{31}O_4BrSi$): 490.1170; HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 6.3 min (major), 15.0 min (minor), 73% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +45.9 (*c* 1.0, $CHCl_3$).

4.2.14. (R,E)-Methyl 2-(4-bromophenyl)-5-(tert-butyldimethylsilyloxy)-5-phenylpent-4-enoate (**18**), (1S,2S,3S)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-3-methyl-2-phenylcyclopropanecarboxylate (**19**), and (1S,2R,3R)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-3-methyl-2-phenylcyclopropanecarboxylate (**20**)

Purification by silica gel chromatography eluting with pentane/diethyl ether (100:1 to 50:1) enabled the separation of **18**, **19**, and **20**. Compound **18**: clear oil; R_f 0.50 (pentane/Et_2O 5:1); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.41 (d, *J*=8.0 Hz, 2H), 7.34–7.28 (m, 5H), 7.11 (d, *J*=8.0 Hz, 2H), 4.84 (t, *J*=7.5 Hz, 1H), 3.65 (s, 3H), 3.55 (t, *J*=8.0 Hz, 1H), 2.85–2.80 (m, 1H), 2.61–2.55 (m, 1H), 0.88 (s, 9H), −0.01 (s, 3H), −0.03 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 173.5 (C), 151.8 (C), 137.4 (C), 137.3 (C), 131.6 (CH), 129.8 (CH), 128.2 (CH), 127.9 (C), 127.8 (CH), 121.2 (C), 106.3 (CH), 52.0 (CH), 51.9 (CH_3), 31.5 (CH_2), 25.6 (CH_3), 18.1 (C), −4.6 (CH_3), −4.7 (CH_3); IR (neat) 1738, 1649, 1489, 1252, 1161, 1074, 1012 cm^{-1}; EI-HRMS: *m*/*z*, found: 474.1205; calcd ($C_{24}H_{31}O_3BrSi$): 474.1220; $[\alpha]_D^{23}$ −17.6 (*c* 1.0, $CHCl_3$). Compound **19**: clear oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.48–7.45 (m, 4H), 7.38–7.31 (m, 5H), 3.36 (s, 3H), 2.07 (q, *J*=7.2 Hz, 1H), 1.70 (d, *J*=8.5 Hz, 3H), 0.43 (s, 9H), −0.14 (s, 3H), −0.52 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.2 (C), 137.6 (C), 137.4 (C), 133.5 (CH), 130.6 (CH), 129.9 (CH), 128.1 (CH), 127.9 (CH), 120.6 (C), 69.6 (C), 51.6 (CH_3), 42.7 (C), 35.7 (CH), 24.9 (CH_3), 17.4 (C), 12.2 (CH_3), −4.6 (CH_3), −4.6 (CH_3); APCI-HRMS: (M+H) *m*/*z*, found: 475.1301; calcd ($C_{24}H_{32}O_3BrSi$): 475.1304. Compound **20**: clear oil; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.53–7.51 (m, 2H), 7.30–7.21 (m, 5H), 6.99–6.97 (m, 2H), 3.68 (s, 3H), 2.56 (q, *J*=7.0 Hz, 1H), 1.34 (d, *J*=7.0 Hz, 3H), 0.81 (s, 9H), 0.10 (s, 3H), −0.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.6 (C), 138.4 (C), 133.3 (CH), 133.1 (C), 130.8 (CH), 130.1 (CH), 127.9 (CH), 127.9 (CH), 121.1 (C), 66.7 (C), 52.4 (CH_3), 43.7 (C), 30.2 (CH), 25.4 (CH_3), 17.8 (C), 13.9 (CH_3), −4.2 (CH_3), −4.3 (CH_3); APCI-HRMS: (M+H) *m*/*z*, found: 475.1310; calcd ($C_{24}H_{32}O_3BrSi$): 475.1304.

4.2.15. (1S,2R)-Methyl 1-(4-bromophenyl)-2-phenyl-2-(trimethylsilyloxy)cyclopropanecarboxylate (**22a**) and (1S,2S)-methyl 1-(4-bromophenyl)-2-phenyl-2-(trimethylsilyloxy)-cyclopropanecarboxylate (**23a**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1) enabled the separation of **22a** and **23a**. Compound **22a**: clear oil; R_f 0.46 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.17 (d, *J*=8.5 Hz, 2H), 7.11 (t, *J*=8.5 Hz, 3H), 7.08 (t, *J*=8.5 Hz, 2H), 6.99 (d, *J*=8.5 Hz, 2H), 3.70 (s, 3H), 2.48 (d, *J*=7.0 Hz, 1H), 2.12 (d, *J*=6.5 Hz, 1H), 0.05 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.5 (C), 138.7 (C), 134.8 (C), 132.9 (CH), 130.6 (CH), 127.7 (CH), 127.2 (CH), 126.6 (CH), 121.0 (C), 66.5 (CH_3), 52.4 (C), 42.9 (CH_2), 22.2 (C), 0.7 (CH_3); IR (neat) 1731, 1490, 1449, 1434, 1327, 1251, 1240, 1214, 1126, 1076, 1056, 1011, 977, 931, 846, 846, 756, 714, 698, 669 cm^{-1}; EI-HRMS: *m*/*z*, found: 419.0665; calcd ($C_{20}H_{24}O_3BrSi$): 419.0673. Anal. Calcd for $C_{20}H_{24}O_3BrSi$: C, 57.28; H, 5.53. Found: C, 57.18; H, 5.52. HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 6.1 min (major), 10.3 min (minor), 82% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +36.0 (*c* 1.0, $CHCl_3$). Compound **23a**: clear oil; R_f 0.37 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.51–7.49 (m, 4H), 7.41 (d, *J*=8.5 Hz, 2H), 7.36 (t, *J*=7.5 Hz, 2H), 7.30 (t, *J*=7.5 Hz, 1H), 3.23 (s, 3H), 2.71 (d, *J*=6.0 Hz, 1H), 1.70 (d, *J*=6.5 Hz, 1H), −0.22 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.2 (C), 138.8 (C), 135.3 (C), 133.5 (CH), 130.6 (CH), 128.3 (CH), 127.9 (CH), 127.8 (CH), 121.0 (C), 67.0 (C), 52.0 (CH_3), 41.4 (C), 24.0 (CH_2), 0.4 ($3CH_3$); IR (neat) 1726, 1489, 1448, 1435, 1294, 1252, 1225, 1117, 1086, 1010, 936, 846, 787, 754, 715, 698 cm^{-1}; EI-HRMS: *m*/*z*, found: 419.0683; calcd ($C_{20}H_{24}O_3BrSi$): 419.0673. Anal. Calcd for $C_{20}H_{24}O_3BrSi$: C, 57.28; H, 5.53. Found: C, 56.46; H, 5.43. HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 6.0 min (major), 11.0 min (minor), 75% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +79.4 (*c* 1.0, $CHCl_3$).

4.2.16. (1S,2R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-phenylcyclopropanecarboxylate (**22b**) and (1S,2S)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-phenylcyclopropanecarboxylate (**23b**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) gave **22b**. White solid; mp 86–88 °C; R_f 0.48 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.14–7.09 (m, 7H), 7.01 (d, *J*=10.5 Hz, 2H), 3.69 (s, 3H), 2.40 (d, *J*=8.5 Hz, 1H), 2.11 (d, *J*=8.5 Hz, 1H), 0.87 (s, 9H), 0.09 (s, 3H), −0.26 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.4 (C), 138.4 (C), 134.9 (C), 132.7 (CH), 130.5 (CH), 127.7 (CH), 127.4 (CH), 127.2 (CH), 120.9 (C), 66.5 (C), 52.4 (CH_3), 42.6 (C), 25.5 ($3CH_3$), 21.3 (CH_2), 17.8 (C), −3.9 (CH_3), −4.2 (CH_3); IR (neat) 1732, 1490, 1449, 1434, 1394, 1316, 1239, 1213, 1126, 1077, 1055, 1011, 977, 931, 871, 834, 779, 713, 699 cm^{-1}; EI-HRMS: *m*/*z*, found: 460.1067; calcd ($C_{23}H_{29}O_3BrSi$): 460.1064. Anal. Calcd for $C_{23}H_{29}O_3BrSi$: C, 59.86; H, 6.33. Found: C, 59.96; H, 6.34. HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 5.2 min (major), 10.1 min (minor), 69% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +18.2 (*c* 1.0, $CHCl_3$). Compound **23b**: white solid; mp 69–71 °C; R_f 0.48 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.52–7.50 (m, 4H), 7.43 (d, *J*=11.0 Hz, 2H), 7.39 (t, *J*=8.5 Hz, 2H), 7.32 (t, *J*=9.0 Hz, 1H), 3.25 (s, 3H), 2.74 (d, *J*=8.0 Hz, 1H), 1.69 (d, *J*=8.0 Hz, 1H), 0.54 (s, 9H), −0.14 (s, 3H), −0.37 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.1 (C), 138.5 (C), 135.1 (C), 133.7 (CH), 130.6 (CH), 128.5 (CH), 127.9 (CH), 127.8 (CH), 121.0 (C), 67.0 (C), 51.9 (CH_3), 41.2 (C), 25.0 ($3CH_3$), 23.9 (CH_2), 17.9 (C), −4.3 (CH_3), −4.6 (CH_3); IR (neat) 1727, 1489, 1472, 1462, 1448, 1435, 1394, 1294, 1257, 1226, 1117, 1086, 1071, 1010, 936, 833, 814, 778, 716, 698 cm^{-1}; EI-HRMS: *m*/*z*, found: 460.1070; calcd ($C_{23}H_{29}O_3BrSi$): 460.1064. Anal. Calcd for $C_{23}H_{29}O_3BrSi$: C, 59.86; H, 6.33. Found: C, 59.87; H, 6.21. HPLC: (*R*,*R*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 5.9 min (major), 16.2 min (minor), 83% ee with Rh_2(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +107.0 (*c* 1.0, $CHCl_3$).

4.2.17. (1S,2R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldiphenylsilyloxy)-2-phenylcyclopropanecarboxylate (**22c**) and (1S,2S)-methyl 1-(4-bromophenyl)-2-(tert-butyldiphenylsilyloxy)-2-phenylcyclopropanecarboxylate (**23c**)

Purification by silica gel chromatography eluting with pentane/Et_2O (25:1) gave **22c**. White solid; mp 54–56 °C; R_f 0.53 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.53 (d, *J*=10.0 Hz, 2H), 7.48

(d, J=10.0 Hz, 2H), 7.37 (t, J=9.0 Hz, 1H), 7.27 (t, J=10.0 Hz, 3H), 7.19 (t, J=10.0 Hz, 2H), 7.09 (d, J=10.0 Hz, 2H), 7.01 (d, J=10.0 Hz, 2H), 6.90–6.80 (m, 5H), 3.76 (s, 3H), 2.33 (d, J=9.5 Hz, 1H), 1.88 (d, J 9.5 Hz, 1H), 1.00 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.6 (C), 137.6 (C), 136.2 (CH), 136.0 (CH), 135.0 (C), 133.6 (C), 133.5 (C), 132.5 (CH), 130.4 (CH), 129.5 (CH), 129.3 (CH), 127.7 (CH), 127.7 (CH), 127.3 (CH), 127.2 (CH), 127.1 (CH), 120.9 (C), 67.7 (C), 52.5 (CH_3), 42.6 (C), 26.9 ($3CH_3$), 21.5 (CH_2), 19.3 (C); IR (neat) 1731, 1489, 1428, 1393, 1313, 1240, 1212, 1112, 1079, 1054, 1011, 977, 931, 910, 822, 787, 736, 698 cm^{-1}; ESI-HRMS: (M+Na) m/z, found: 607.1285; calcd ($C_{33}H_{33}O_3BrNaSi$): 607.1275. Anal. Calcd for $C_{33}H_{33}O_3BrSi$: C, 67.68; H, 5.68. Found: C, 67.37; H, 5.61. HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 6.6 min (minor), 14.8 min (major), 51% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +1.8 (*c* 0.25, $CHCl_3$). Compound **23c**: white solid; mp 100–102 °C; R_f 0.43 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.56 (d, J=10.5 Hz, 2H), 7.47 (d, J=10.5 Hz, 2H), 7.34–7.28 (m, 4H), 7.21–7.09 (m, 9H), 6.86 (d, J=9.5 Hz, 2H), 3.11 (s, 3H), 2.36 (d, J=8.5 Hz, 1H), 1.58 (d, J=8.5 Hz, 1H), 0.74 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.0 (C), 138.0 (C), 136.3 (C), 135.7 (CH), 135.1 (C), 134.2 (CH), 133.6 (C), 132.6 (C), 131.0 (CH), 129.6 (CH), 129.4 (CH), 128.8 (CH), 127.5 (CH), 127.4 (CH), 127.2 (CH), 127.1 (CH), 121.4 (CH), 67.7 (C), 51.9 (CH_3), 41.3 (C), 26.6 ($3CH_3$), 24.0 (CH_2), 18.8 (C); IR (neat) 1727, 1589, 1488, 1428, 1293, 1255, 1113, 1086, 1010, 935, 822, 801, 737, 699, 670 cm^{-1}; ESI-HRMS: (M+Na) m/z, found: 607.1258; calcd ($C_{37}H_{31}BrNaSi$): 607.1250. Anal. Calcd for $C_{33}H_{33}O_3BrSi$: C, 67.68; H, 5.68. Found: C, 67.14; H, 5.70. HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 8.7 min (minor), 40.3 min (major), 85% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +47.5 (*c* 0.25, $CHCl_3$).

4.2.18. (1S,2R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-(4-methoxyphenyl)cyclopropanecarboxylate (**25a**) and (1S,2S)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-(4-methoxyphenyl)cyclopropanecarboxylate (**26a**)

Purification by silica gel chromatography eluting with pentane/Et_2O (25:1) gave **25a**. White solid; mp 104–106 °C; R_f 0.60 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.16 (d, J=8.5 Hz, 2H), 7.06 (d, J=9.0 Hz, 2H), 7.04 (d, J=8.5 Hz, 2H), 6.65 (d, J=9.0 Hz, 2H), 3.73 (s, 3H), 3.69 (s, 3H), 2.36 (d, J=6.5 Hz, 1H), 2.04 (s, J=6.5 Hz, 1H), 0.86 (s, 9H), 0.07 (s, 3H), −0.27 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.5, 158.8, 135.1, 132.7, 130.5, 128.6, 120.8, 113.0, 66.4, 55.0, 52.3, 42.5, 25.5, 21.5, 17.8, −3.9, −4.2; IR (neat) 1735, 1670, 1608, 1512, 1489, 1463, 1293, 1251, 1208, 1173, 1127, 1110, 1074, 1032, 1010, 838, 779 cm^{-1}; ESI-HRMS: (M+Na) m/z, found: 513.1055; calcd ($C_{24}H_{31}O_4BrNaSi$): 513.1045; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 14.2 min (minor), 33.8 min (major), 74% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +25.8 (*c* 1.0, $CHCl_3$). Compound **26a**: white solid; mp 75–77 °C; R_f 0.60 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.47 (d, J=8.5 Hz, 2H), 7.38 (d, J=8.0 Hz, 4H), 6.85 (d, J=8.5 Hz, 2H), 3.81 (s, 3H), 3.42 (s, 3H), 2.65 (d, J=6.5 Hz, 1H), 1.61 (d, J=6.5 Hz, 1H), 0.48 (s, 9H), −0.19 (s, 3H), −0.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.2, 159.1, 135.3, 133.8, 130.8, 130.6, 129.8, 120.9, 113.2, 66.6, 55.1, 52.0, 41.4, 25.0, 24.2, 17.4, −4.2, −4.6; IR (neat) 1726, 1611, 1515, 1489, 1462, 1435, 1304, 1252, 1174, 1117, 1085, 1072, 1035, 1010, 933, 841, 778, 669, 619 cm^{-1}; ESI-HRMS: (M+Na) m/z, found: 513.1058; calcd ($C_{24}H_{31}O_4BrNaSi$): 513.1067; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 16.6 min (minor), 81.0 min (major), 73% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +54.0 (*c* 0.93, $CHCl_3$).

4.2.19. (1S,2R)-Methyl 1,2-bis(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)cyclopropanecarboxylate (**25b**) and (1S,2S)-methyl 1,2-bis(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)cyclopropanecarboxylate (**26b**)

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) gave **25b**. White solid; mp 114–116 °C; R_f 0.66 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.26 (d, J=7.5 Hz, 2H), 7.18 (d, J=7.5 Hz, 2H), 7.01 (d, J=8.0 Hz, 4H), 3.69 (s, 3H), 2.41 (d, J=7.0 Hz, 1H), 2.06 (d, J=7.0 Hz, 1H), 0.87 (s, 9H), 0.09 (s. 3H), −0.24 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.0, 137.8, 134.4, 123.6, 130.8, 130.7, 128.7, 121.4, 121.2, 65.9, 52.4, 42.7, 25.5, 21.4, 17.8, −3.8, −4.1; IR (neat) 1732, 1490, 1472, 1434, 1395, 1331, 1239, 1213, 1103, 1075, 1056, 1010, 977, 931, 871, 835, 779, 717, 669 cm^{-1}; EI-HRMS: m/z, found: 538.0165; calcd ($C_{23}H_{28}O_3Br_2Si$): 538.0169; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 10.2 min (minor), 26.9 min (major), 66% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +26.1 (*c* 1.0, $CHCl_3$). Compound **26b**: white solid; mp 62–64 °C; R_f 0.61 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.47 (m, 4H), 7.35 (m, 4H), 3.25 (s, 3H), 2.65 (d, J=6.5 Hz, 1H), 1.66 (d, J=6.5 Hz, 1H), 0.49 (s, 9H), −0.21 (s, 3H), −0.38 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 170.5, 138.3, 135.3, 134.2, 131.6, 131.3, 130.7, 122.5, 121.8, 66.9, 52.7, 42.1, 25.5, 24.5, 18.0, −3.5, −4.0; IR (neat) 1729, 1489, 1472, 1463, 1434, 1394, 1281, 1253, 1215, 1117, 1102, 1074, 1057, 1010, 977, 933, 870, 838, 779, 720 cm^{-1}; EI-HRMS: m/z, found: 538.0154; calcd ($C_{23}H_{28}O_3Br_2Si$): 538.0169; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 12.0 min (minor), 43.7 min (major), 80% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +79.5 (*c* 1.0, $CHCl_3$).

4.2.20. (1S,2R)-Methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-(4-(trifluoromethyl)phenyl)cyclopropanecarboxylate (**25c**) and (1S,2S)-methyl 1-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-2-(4-(trifluoromethyl)phenyl)-cyclopropanecarboxylate (**25c**)

Purification by silica gel chromatography eluting with pentane/Et_2O (30:1) gave **25c**. Clear oil; R_f 0.43 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.40 (d, J=8.5 Hz, 2H), 7.24 (d, J=7.5 Hz, 2H), 7.17 (d, J=8.0 Hz, 2H), 6.99 (d, J=8.5 Hz, 2H), 3.70 (s, 3H), 2.49 (d, J=7.0 Hz, 1H), 2.15 (d, J=7.0 Hz, 1H), 0.89 (s, 9H), 0.11 (s, 3H), −0.25 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 168.9, 142.9, 134.2, 136.6, 130.8, 129.5 (q, J=32.0 Hz), 127.3, 124.7 (q, J=4.0 Hz), 123.9 (q, J=270.0 Hz), 121.3, 65.8, 52.5, 43.1, 25.5, 21.6, 17.9, −3.8, −4.1; IR (neat) 1728, 1325, 1258, 1167, 1110, 1072, 1011, 934, 833, 780 cm^{-1}; EI-HRMS: m/z, found: 528.0941; calcd ($C_{24}H_{28}O_3BrF_3Si$): 528.0938; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.0 min (minor), 20.5 min (major), 74% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +48.2 (*c* 1.4, $CHCl_3$). Compound **26c**: clear oil; R_f 0.39 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.60 (s, 4H), 7.49 (d, J=8.0 Hz, 2H), 7.37 (d, J=8.5 Hz, 2H), 3.22 (s, 3H), 2.72 (d, J=6.5 Hz, 1H), 1.72 (d, J=6.5 Hz, 1H), 0.50 (s, 9H), −0.21 (s, 3H), −0.39 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.8, 142.7, 134.6, 133.6, 130.8, 130.1 (q, J=32.0 Hz), 128.7, 124.9 (q, J=4.0 Hz), 124.0 (q, J=270.0 Hz), 121.4, 66.3, 52.2, 41.8, 25.0, 24.0, 17.5, −4.1, −4.5; IR (neat) 1732, 1491, 1435, 1325, 1242, 1216, 1167, 1127, 1110, 1072, 1013, 977, 931, 836, 810, 780 cm^{-1}; EI-HRMS: m/z, found: 528.0931; calcd ($C_{24}H_{28}O_3BrF_3Si$): 528.0938; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.7 min (minor), 21.5 min (major), 84% ee with Rh$_2$(*S*-DOSP)$_4$; $[\alpha]_D^{23}$ +110.3 (*c* 0.71, $CHCl_3$).

4.2.21. (1R,2S)-Methyl 2-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-1-(4-chlorophenyl)cyclopropanecarboxylate (**27a**)

Purification by silica gel chromatography eluting with pentane/Et_2O (15:1) gave **27a**. White solid; mp 114–116 °C; R_f 0.54 (20% Et_2O/pentane); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.25 (m, 2H), 7.08–7.00 (m, 6H), 3.70 (s, 3H), 2.42 (d, J=7.0 Hz, 1H), 2.07 (d, J=7.0 Hz, 1H), 0.87 (s, 9H), 0.09 (s, 3H), −0.24 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.0, 137.8, 133.9, 132.9, 132.2, 130.8, 128.7, 127.7, 121.3, 65.9, 52.3, 42.6, 25.5, 21.4, 17.8, −3.8, −4.2; IR (neat) 1732, 1493, 1434, 1331, 1240, 1213, 1127, 1092, 1075, 1060, 1009, 977, 931, 835, 779 cm^{-1}; EI-HRMS: m/z, found: 495.0741; calcd ($C_{23}H_{29}O_3BrClSi$): 495.0747; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.4 min (major), 19.4 min (minor), 95% ee with Rh$_2$(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ −57.3 (*c* 0.96, $CHCl_3$).

*4.2.22. (1R,2S)-Methyl 2-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-1-phenylcyclopropanecarboxylate (**27b**)*

Purification by silica gel chromatography eluting with pentane/Et_2O (20:1) gave **27b**. Clear oil; R_f 0.58 (20% Et_2O/pentane); ^1H NMR (500 MHz, $CDCl_3$): δ 7.22 (d, J=8.0 Hz, 2H), 7.14 (m, 3H), 7.05 (m, 2H), 7.01 (d, J=8.0 Hz, 2H), 3.70 (s, 3H), 2.41 (d, J=6.5 Hz, 1H), 2.10 (d, J=6.5 Hz, 1H), 0.88 (s, 9H), 0.10 (s, 3H), −0.23 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.5, 138.2, 135.3, 131.0, 130.6, 128.8, 127.5, 126.9, 121.1, 65.7, 52.3, 43.4, 25.6, 21.4, 17.8, −3.7, −4.1; IR (neat) 1731, 1240, 1213, 1064, 1009, 977, 931, 834, 778, 752, 699 cm^{-1}; EI-HRMS: m/z, found: 483.0980; calcd ($C_{25}H_{28}O_3BrSi$): 483.0986; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.1 min (major), 13.6 min (minor), 95% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ −54.8 (*c* 1.12, $CHCl_3$).

*4.2.23. (1R,2S)-Methyl 2-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-1-(4-methoxyphenyl)cyclopropanecarboxylate (**27c**)*

Purification by silica gel chromatography eluting with pentane/Et_2O (15:1) gave **27c**. White solid; mp 87–89 °C; R_f 0.32 (20% Et_2O/pentane); ^1H NMR (500 MHz, $CDCl_3$): δ 7.24 (d, J=8.5 Hz, 2H), 7.04 (d, J=8.5 Hz, 2H), 7.01 (d, J=8.5 Hz, 2H), 6.58 (d, J=8.5 Hz), 3.69 (s, 3H), 2.37 (d, J=6.5 Hz, 1H), 2.04 (d, J=7.0 Hz, 1H), 0.88 (s, 9H), 0.09 (s, 3H), −0.24 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.8, 158.3, 138.3, 132.0, 130.6, 128.8, 127.3, 121.0, 112.9, 66.4, 55.5, 52.9, 43.2, 26.2, 22.1, 18.4, −3.2, −3.5; IR (neat) 1731, 1514, 1463, 1434, 1295, 1250, 1213, 1177, 1126, 1066, 1033, 1009, 978, 931, 836, 800, 779, 749 cm^{-1}; EI-HRMS: m/z, found: 513.1082; calcd ($C_{26}H_{30}O_4BrSi$): 513.1091; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 13.0 min (major), 54.0 min (minor), 98% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ −63.0 (*c* 0.79, $CHCl_3$).

*4.2.24. (1R,2S)-Methyl 2-(4-bromophenyl)-2-(tert-butyldimethylsilyloxy)-1-p-tolylcyclopropanecarboxylate (**27d**)*

Purification by silica gel chromatography eluting with pentane/Et_2O (5:1) gave **27d**. White solid; mp 53–55 °C; R_f 0.54 (20% Et_2O/pentane); ^1H NMR (500 MHz, $CDCl_3$): δ 7.24 (d, J=8.0 Hz, 2H), 7.02 (m, 4H), 6.85 (d, J=8.0 Hz, 2H), 3.68 (s, 3H), 2.37 (d, J=6.5 Hz, 1H), 2.19 (s, 3H), 2.05 (d, J=7.0 Hz, 1H), 0.87 (s, 9H), 0.09 (s, 3H), −0.24 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 169.7, 138.3, 136.5, 132.2, 130.7, 130.6, 128.9, 128.3, 121.0, 65.8, 52.3, 43.0, 25.5, 21.4, 21.0, 17.8, −3.8, −4.1; IR (neat) 1732, 1434, 1332, 1240, 1218, 1208, 1183, 1126, 1103, 1062, 1009, 978, 931, 836, 779, 746 cm^{-1}; EI-HRMS: m/z, found: 474.1212; calcd ($C_{24}H_{31}O_3BrSi$): 474.1220; HPLC: (*S*,*S*)-whelk-01, 2.0% ^{i}PrOH/hexane, 1.0 mL min^{-1}, UV 254 nm, t_R: 7.3 min (major), 15.9 min (minor), 95% ee with Rh_2(*S*-PTAD)$_4$; $[\alpha]_D^{23}$ −70.0 (*c* 0.94, $CHCl_3$).

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Supplementary data

Detailed experimental for the compounds described in this paper. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2008.11.059.

References and notes

1. Doyle, M. P.; McKervey, M.; Ye, T. *Modern Catalytic Methods for Organic Synthesis with Diazo Compounds: From Cyclopropanes to Ylides*; John Wiley & Sons: New York, NY, 1998.
2. (a) Davies, H. M. L.; Bruzinski, P. R.; Fall, M. J. *Tetrahedron Lett.* **1996**, *37*, 4133; (b) Davies, H. M. L.; Panaro, S. A. *Tetrahedron* **2000**, *56*, 4871; (c) Davies, H. M. L.; Nagashima, T.; Klino, J. L., III. *Org. Lett.* **2000**, *2*, 823; (d) Ni, A.; France, J. E.; Davies, H. M. L. *J. Org. Chem.* **2006**, *71*, 5594; (e) Hedley, S. J.; Ventura, D. L.; Dominiak, P. M.; Nygren, C. L.; Davies, H. M. L. *J. Org. Chem.* **2006**, *71*, 5349; (f) Xu, Z.-H.; Zhu, S.-N.; Sun, X.-L.; Tang, Y.; Dai, L.-X. *Chem. Commun.* **2007**, 1960; (g) Thompson, J. L.; Davies, H. M. L. *J. Am. Chem. Soc.* **2007**, *129*, 6090.
3. Davies, H. M. L.; Lee, G. H. *Org. Lett.* **2004**, *6*, 1233.
4. (a) Liu, B.; Zhu, S.; Zhang, W.; Chen, C.; Zhou, Q. *J. Am. Chem. Soc.* **2007**, *129*, 5834; (b) Lee, E. C.; Fu, G. C. *J. Am. Chem. Soc.* **2007**, *129*, 12066; (c) Moody, C. J. *Angew. Chem., Int. Ed.* **2007**, *45*, 91482; (d) Deng, Q.; Xu, H.; Yuen, A. W.; Xu, Z.; Che, C. *Org. Lett.* **2008**, *10*, 1529.
5. (a) Maier, T. C.; Fu, G. C. *J. Am. Chem. Soc.* **2006**, *128*, 4594; (b) Chen, C.; Zhu, S.; Liu, B.; Wang, L.; Zhou, Q. *J. Am. Chem. Soc.* **2007**, *129*, 12616; (c) Zhu, S.; Chen, C.; Cai, Y.; Zhou, Q. *Angew. Chem., Int. Ed.* **2008**, *47*, 932.
6. (a) Davies, H. M. L.; Beckwith, E. *J. Chem. Rev.* **2003**, *103*, 2861; (b) Davies, H. M. L.; Loe, Ø. *Synthesis* **2004**, *16*, 2595; (c) Davies, H. M. L.; Manning, J. R. *Nature* **2008**, *451*, 417.
7. (a) Hodgson, D. M.; Pierard, F. Y. T. M.; Stupple, P. A. *Chem. Soc. Rev.* **2001**, *30*, 50; (b) Doyle, M. P.; Hu, W.; Timmons, D. J. *Org. Lett.* **2001**, *3*, 933; (c) Lu, C.; Liu, H.; Chen, Z.; Hu, W.; Mi, A. *Org. Lett.* **2005**, *7*, 83; (d) Guo, Z.; Huang, H.; Fu, Q.; Hu, W. *Synlett* **2006**, 2486.
8. (a) Davies, H. M. L.; Antoulinakis, E. G.; Hansen, T. *Org. Lett.* **1999**, *1*, 383; (b) Davies, H. M. L.; Ren, P. *J. Am. Chem. Soc.* **2001**, *123*, 2070; (c) Davies, H. M. L.; Ren, P.; Jin, Q. *Org. Lett.* **2001**, *3*, 3587.
9. Davies, H. M. L.; Coleman, M. G.; Ventura, D. L. *Org. Lett.* **2007**, *9*, 4971.
10. (a) Davies, H. M. L.; Panaro, S. A. *Tetrahedron Lett.* **1999**, *40*, 5287; (b) Davies, H. M. L.; Hansen, T.; Hopper, D. W.; Panaro, S. A. *J. Am. Chem. Soc.* **1999**, *121*, 6509; (c) Davies, H. M. L.; Venkataramani, C. *Org. Lett.* **2003**, *5*, 1403; (d) Davies, H. M. L.; Lee, G. H. *Org. Lett.* **2004**, *6*, 2117.
11. (a) Reddy, R. P.; Lee, G. H.; Davies, H. M. L. *Org. Lett.* **2006**, *8*, 3437; (b) Reddy, R. P.; Davies, H. M. L. *Org. Lett.* **2006**, *8*, 5013; (c) Denton, J. R.; Sukumaran, D.; Davies, H. M. L. *Org. Lett.* **2007**, *9*, 262; (d) Reddy, R. P.; Davies, H. M. L. *J. Am. Chem. Soc.* **2007**, *129*, 10312; (e) Denton, J. R.; Cheng, K.; Davies, H. M. L. *Chem. Commun.* **2008**, 1238.
12. Davies, H. M. L.; Ren, P. *Tetrahedron Lett.* **2001**, *42*, 3149.