Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tetrahedron: Asymmetry
Tetrahedron: *Asymmetry* 16 (2005) 761–771

Synthesis of chiral sultams and their application as chiral auxiliaries in an asymmetric Diels–Alder reaction

Hong-Kui Zhang,[a] Wing-Hong Chan,[b,*] Albert W. M. Lee,[b] Wai-Yeung Wong[b] and Ping-Fang Xia[b]

[a]*Department of Chemistry, Xiamen University, Xiamen, China*
[b]*Department of Chemistry and Central Laboratory of the Institute of Molecular Technology for Drug Discovery and Synthesis, Hong Kong Baptist University, Kowloon Tong, Kowloon, Hong Kong*

Received 1 September 2004; revised 13 December 2004; accepted 17 December 2004

Abstract—A number of bicyclic chiral sultams were synthesized based on 1,3-dipolar cycloaddition reactions of nitrile oxides and nitrones with prop-1-ene-1,3-sultone. The corresponding *N*-enoyl sultams were prepared by acylation. Their relative effectiveness as new chiral auxiliaries in asymmetric synthesis was evaluated for the asymmetric Diels–Alder reactions with cyclopentadiene. Good chemical yield and excellent *endo* selectivity were observed. The relationship between the structure and their effectiveness in promoting asymmetric induction of the synthetic chiral sultams was investigated.
© 2005 Elsevier Ltd. All rights reserved.

1. Introduction

The introduction of chirality through the use of chiral auxiliaries has been demonstrated as an effectual means for preparing homochiral materials.[1,2] Most chiral auxiliaries reported in the literature have been derived from naturally occurring compounds such as alkaloids,[3,4] α-amino acids,[5] terpenes[6,7] and carbohydrates.[8,9] In particular, the importance of Evan's et al. 1,3-oxazolidin-2-ones and Oppolzer chiral sultams for asymmetric carbon–carbon bond formation has been well documented.[10,11] On the other hand, chiral auxiliaries prepared by rational synthetic design have received intense attention from numerous research groups.[12] Diastereofacial discrimination exhibited by the substrates as the result of incorporating a chiral auxiliary is the key feature in such approaches, which has been widely exploited in asymmetric synthesis. Conceivably, minor variations in the structure of an auxiliary may exert great influence on the effectiveness of the asymmetric induction in a chemical transformation. In this regard, chiral auxiliaries derived from rational chemical design in contrast to those from natural products may provide greater flexibility for improvement through structural variations. To investigate extensively the relationship between the structures of synthetic chiral auxiliaries and their effectiveness in asymmetric synthesis, we have synthesized a number of bicyclic structurally demanding chiral sultams. Subsequently, their relative effectiveness in asymmetric synthesis was evaluated for the asymmetric Diels–Alder reaction with cyclopentadiene.

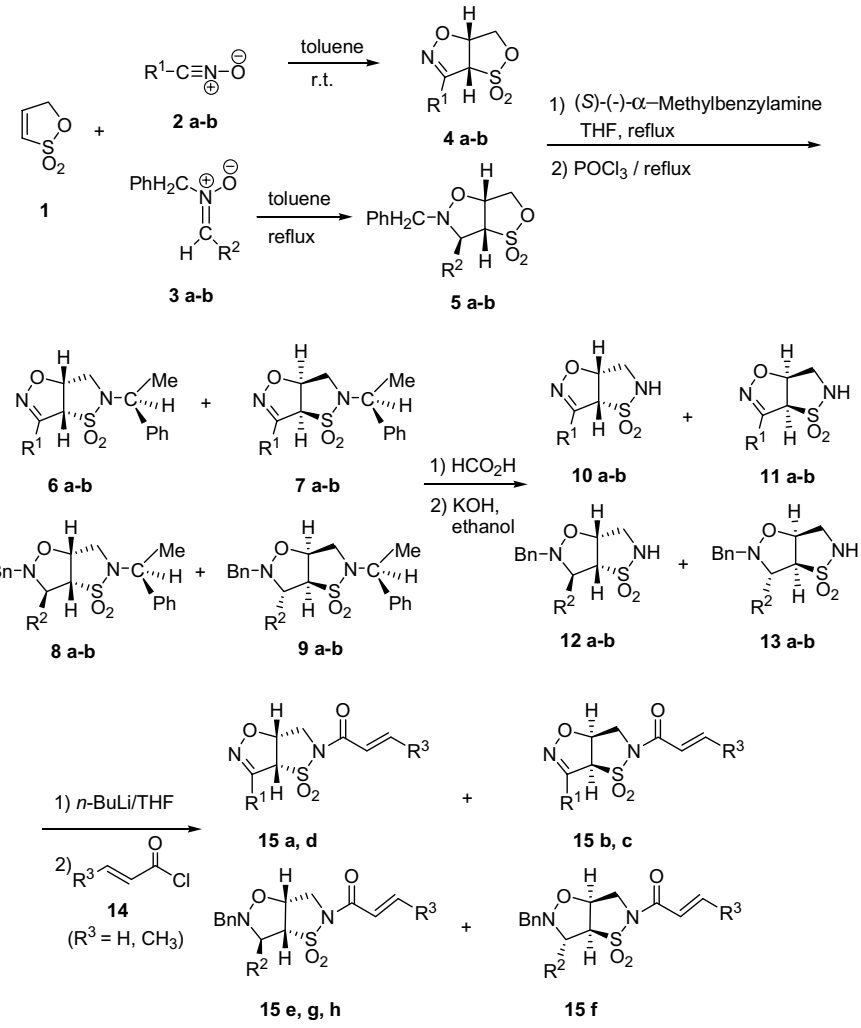
2. Results and discussion

As revealed from numerous examples in the literature,[12,13] sterically demanded chiral auxiliaries could be built on bicyclic or polycyclic ring systems. In our previous findings, tricyclic chiral sultams assembled from prop-1-ene-1,3-sultone **1** and cyclopentadiene has demonstrated to be effective chiral auxiliaries.[14]

Furthermore, based on the 1,3-dipolar cycloaddition of **1** with nitrile oxides or nitrones, a series of structurally related bicyclic sultams comprising an isoxazoline or isoxazolidine moiety were synthesized under an expeditious synthetic route described in Scheme 1. Via a five-step protocol developed in our laboratory,[14c] chiral sultams **10**–**13** were obtained in optically active form. Specifically, nucleophilic ring opening of racemic sultone adducts **4a**,**b** obtained from 1,3-dipolar cycloaddition of **1** and nitrile oxides **2a**,**b** by (*S*)-(−)-α-methylbenzylamine in ethanol at 70 °C for about 10 h afforded a

* Corresponding author. Tel.: +852 2339 7063; fax: +852 2339 7348; e-mail: whchan@hkbu.edu.hk

0957-4166/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetasy.2004.12.026



	2a-13a	2b-13b
R^1	Ph	*t*-Bu
R^2	Ph	*t*-Bu

	15a	15b	15c	15d	15e	15f	15g	15h
R^1	Ph	Ph	Ph	*t*-Bu				
R^2					Ph	Ph	Ph	
R^3	CH_3	CH_3	H	CH_3	CH_3	CH_3	H	CH_3

Scheme 1. Preparation of bicyclic chiral sultams.

diastereomeric mixture of internal ammonium sulfonate salts. $POCl_3$ mediated cyclization of the internal salts furnished a 1:1 diastereomeric mixture of **6** and **7**. The mixture can be easily separated by column chromatography to give homochiral materials **6a**, **7a** and **6b**, **7b**. The structure of **6a** was established unambiguously by X-ray crystallographic analysis. Treatment of **6** and **7** with concentrated formic acid at 70–80 °C for 5 h followed by base hydrolysis afforded **10** and **11**, respectively. In a representative trial, starting from **1**, the total yield of **10a**, **11a** and **10b**, **11b** over the five-step reaction sequence can reach 52% and 35%, respectively. Using a similar approach, column chromatographically separable homochiral diastereomeric **8a**, **9a** and **8b**, **9b** were obtained. Debenzylation of **8** and **9** gave chiral sultams **12** and **13** in a total yield about 25% over five steps. Again, the structures of the adducts were established firmly by NMR spectroscopic methods and X-ray crystallographic analysis as exemplified by **8b** (Fig. 1). Apparently, due to the higher reactivity of nitrile oxides in contrast to nitrones towards **1** in the corresponding dipolar cycloaddition reaction, the yield of the corresponding sultam isoxazolines is higher than those of the isoxazolidines. On the other hand, as outlined in Scheme 2, a more convergent synthesis of **10** and **11** can be achieved by using the chiral sultam **14** as the starting material.[15] For instance, overall yields of 52% and 35% over a three-step sequence were obtained for the preparation of **10a** and **11a**, **10b** and **11b**, respectively. It is noteworthy that structurally demanded *t*-butyl and pyrenyl group were introduced in **10b**, **11b** and **12b**, **13b**, respectively. With this chiral set of synthetic

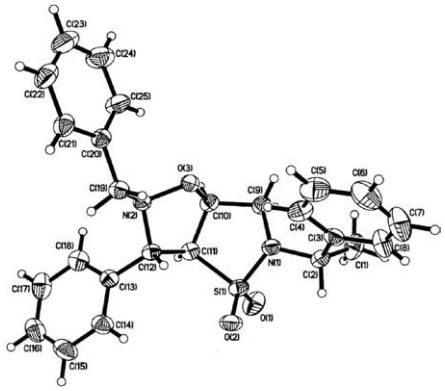
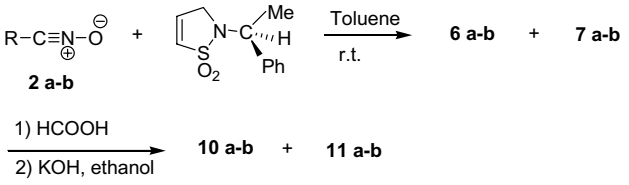


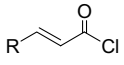
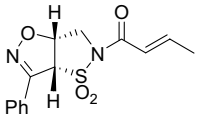
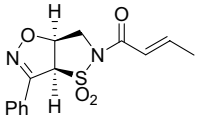
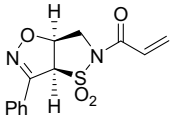
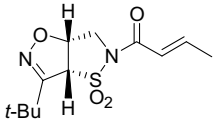
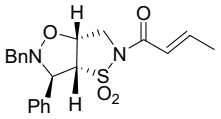
Figure 1. X-ray structure of **8b**.



Scheme 2. Alternative route in making chiral sultams.

sultams at our disposal, we could embark on an investigation to assess their suitability as chiral auxiliaries in promoting asymmetric reactions. The Diels–Alder reaction, allowing the formation of two sigma bonds in a stereo- and regioselective manner, has been often utilized by synthetic chemists as an indispensable synthetic tool for building up complex molecules. To look for a versatile chiral auxiliary in asymmetric synthesis from the chiral pool of synthetic sultams, Diels–Alder reaction was thus chosen as the 'test reaction' for fishing out the best candidate among all structural related chiral sultams. Accordingly, dienophiles incorporating the various chiral auxiliary were prepared by making the corresponding *N*-enoyl sultams. Thus, *N*-acylation of chiral sultams by successive treatment with *n*-butyllithium and acid chlorides afforded the corresponding *N*-acryloyl sultams **15c**,**g** and *N*-crotonyl sultams **15a**,**b**,**d**,**e**,**f**,**h** as shown in Table 1. The results revealed that crotonoylation proceeded well and gave high yields of products while a much lower yield of about 35% of *N*-acryloyl sultams resulted. Modification of the reaction conditions and the adoption of Thom's procedure[16] did not alleviate the problem of low yield. Nevertheless, with the array of chiral dienophiles in hand, we have set the stage for conducting asymmetric Diels–Alder reactions

Table 1. Acylation of chiral bicyclic sultams

Entry	Sultam	 R=	*N*-Enoyl sultam AuxH	Yield (%)
1	**10a**	CH_3	 **15a**	85
2	**11a**	CH_3	 **15b**	82
3	**11a**	H	 **15c**	37
4	**10b**	CH_3	 **15d**	80
5	**12a**	CH_3	 **15e**	85

(*continued on next page*)

Table 1 (*continued*)

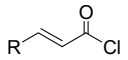
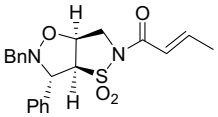
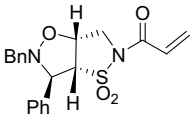
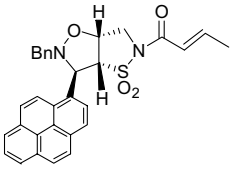
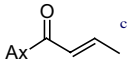
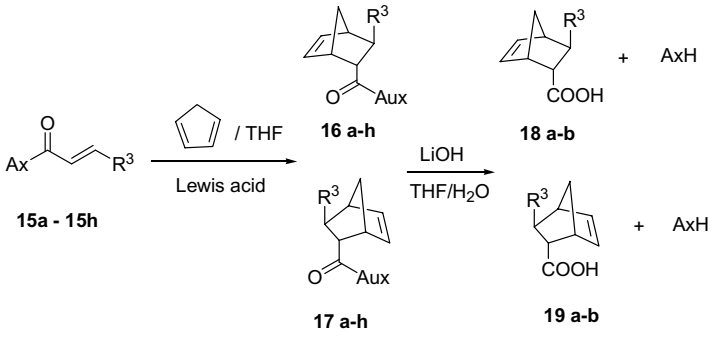
Entry	Sultam	 R=	*N*-Enoyl sultam AuxH	Yield (%)
6	**13a**	CH_3	 **15f**	80
7	**12a**	H	 **15g**	33
8	**12b**	CH_3	 **15h**	85

Table 2. Asymmetric Diels–Alder reaction of **15** with cyclopentadiene

Entry	*N*-Enoyl sultam	Temp, °C (time, h)	Diastereomeric products: dr[b]	De	Yield (%)	Carboxylic acid (from adduct, %)	$[\alpha]_D^{22}$ of the acid
1	**15a**	−50 (6)	**16a**/**17a** = 70/30	40	80	**18a** (**16a**, 78)	−138
2	**15a**	−78 (12)	**16a**/**17a** = 90/10	80	78		
3	**15a**[a]	−78 (12)	**16a**/**17a** = 91/9	82	80		
4	**15b**	−78 (12)	**16b**/**17b** = 13/87	74	86	**19a** (**17b**, 72)	+141
5	**15c**	−78 (5)	**16c**/**17c** = 28/72	44	86	**19b** (**17c**, 75)	+135
6	**15d**	−78 (12)	**16d**/**17d** = 80/20	60	72	**18a** (**16d**, 83)	−139
7	**15e**	−50 (6)	**16e**/**17e** = 90/10	80	90	**18a** (**16e**, 80)	−138
8	**15e**	−78 (12)	**16e**/**17e** = 96/4	92	87		
9	**15f**	−78 (12)	**16f**/**17f** = 4/96	92	92	**19a** (**17f**, 78)	+140
10	**15g**	−78 (6)	**16g**/**17g** = 78/22	56	83	**18b** (**16g**, 73)	−136
11	**15h**	−78 (8)	**16h**/**17h** = 99/1	98	80	**18a** (**16h**, 72)	−139
12	 [c]	−78 (1)	**16a**/**17a** = 96/4	98	98		

[a] 0.5 equiv of $SnCl_4$ was used while $TiCl_4$ was used in other entries.
[b] Ratios determined by ^1H NMR.
[c] Aux = oxazolidinone, also see Ref. 10.

to find the best auxiliary within the synthetic chiral pool. In the presence of $TiCl_4$, chiral dienophiles **15a**–**h** bearing structurally related sultam moieties were allowed to react with excess cyclopentadiene at low temperature. The results of the cycloaddition are summarized in Table 2. In general, the reactions proceeded smoothly to afford cycloadducts with excellent chemical yield and very high *endo* selectivity. The diastereoselectivities of the cycloaddition were established by ^1H NMR methods. The stereochemistry of the major products was determined from the stereochemical correlations of their hydrolyzed carboxylic acids **18a**,**b** and **19a**,**b** with known



	a	b	c	d	e	f	g	h
16	CH_3	CH_3	H	CH_3	CH_3	CH_3	H	CH_3
17	CH_3	CH_3	H	CH_3	CH_3	CH_3	H	CH_3
18	CH_3	H						
19	CH_3	H						

Scheme 3. Characterization of cycloadducts and regeneration of the auxiliaries.

compounds[17] (Scheme 3). Non-destructive removal of the chiral auxiliary was readily accomplished by saponification under standard conditions.[17a] Up to 80% yield of the chiral sultam auxiliaries was recovered, which can be repeatedly used after purification by column chromatography. The stereochemical structure of the cycloadducts was also unambiguously confirmed by the X-ray crystallographic analysis as exemplified by the adduct **17c** (Fig. 2).

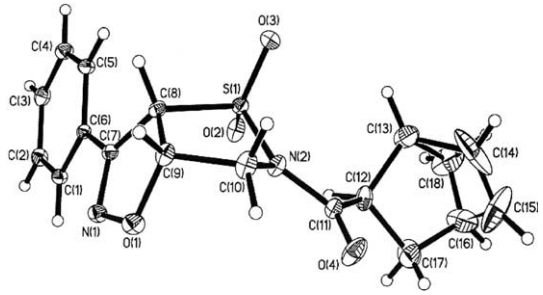
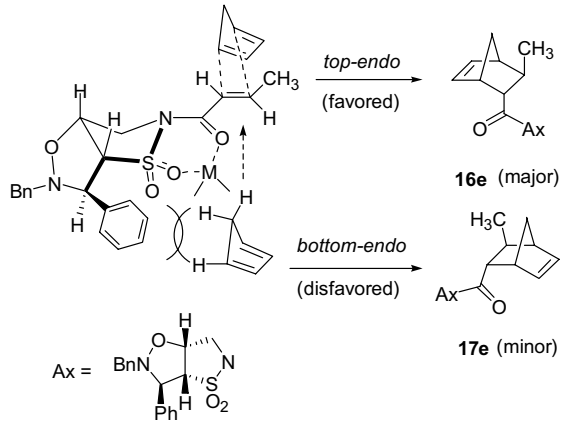


Figure 2. X-ray structure of **17c**.

Most of the reactions were conducted at −78 °C and 0.5 equiv of $TiCl_4$ was chosen as the catalyst for promoting the asymmetric reaction. By increasing the reaction temperature from −78 to −50 °C, both *N*-enoyl sultams **15a** and **15e** reacted in a faster rate with cyclopentadiene but at the expense of the diastereoselectivity (Table 2, entries 1 vs 2 and 7 vs 8). On the other hand, one of the key issues to be addressed in this study is the effect of chiral auxiliaries on the extent of asymmetric induction of the Diels–Alder reaction as exemplified by the reaction of cyclopentadiene to *N*-enoyl sultams **15a**–**h**. From the product distribution of the cycloadducts, it was apparent that the fine structure of a chiral auxiliary exerts a significant effect on the asymmetric induction of the Diels–Alder reaction under comparable conditions.

A closer examination of the experimental results in Table 2 revealed that minor variation in the structure of an auxiliary may have great influence on the effectiveness of the asymmetric induction in a chemical transformation. Comparing results in entries 2 and 7; 5 and 10 in Table 2, it is evident that chiral auxiliaries containing the isoxazolidine moiety are superior to those of the isoxazoline derivatives in terms of chiral induction. For instance, cyclopentadiene, in reaction with **15e** could achieve the same level of dr as that of **15a**, but at a higher temperature. Conceivably, the more planar nature of the bicyclic isoxazolidine moiety in **15a** renders the attack of cyclopentadiene from both sides of the dienophile equally accessible. The diastereoselectivity of the substrate can be improved by introducing a more sterically demanding *tert*-butyl group in replacing the phenyl group. Thus, higher diastereoselectivity was observed for **15d** (Table 2, entry 6). To substantiate further our strategy to develop an auxiliary with improved performance via rational design, a pyrenyl group was incorporated into the synthetic chiral sultam **12b**. Presumably, the bulky pyrenyl substituent may completely shield one face of the dienophile **15h**, according to the HPLC chromatogram of the crude products, the major diastereomer was formed in 99%. Apparently, the effectiveness of **15h** in promoting asymmetric Diels–Alder reaction is as good as Evan's oxazolidinone but not better in terms of chemical yield (Table 2, entries 11 vs 12).

The stereochemical outcome of the products we obtained in the cycloaddition may be rationalized by inspection of proposed transition state model in Scheme 4.[14b] Under the influence of a Lewis acid, the major product may arise from the top-*endo* transition state in a preferred conformation of **15e** in cycloaddition of **15e** with cyclopentadiene. This transition state is stabilized by the secondary molecular orbital interactions between the carbonyl carbon of *N*-crotonoyl sultam and cyclopentadiene, and the top-*endo* attack alleviates a ste-



Scheme 4. Preferred conformation of **15e** in *endo* transition state.

ric encumbrance between the incoming diene and aromatic ring of the dienophile.

In conclusion, we have demonstrated the possibility to improve the effectiveness of synthetic chiral auxiliaries by minor variations on their structures.

3. Experimental

3.1. General information

Unless otherwise noted, solvents and starting materials were obtained from commercial suppliers. All chemicals were reagent grade and used without further purification. Melting points were taken on a MEL-TEMP melting point apparatus, and were reported uncorrected in °C. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian INOVA Unity (400 MHz for ^{1}H, and 100.6 MHz for ^{13}C) or on a JOEL JNM-EX 270 (270 MHz for ^{1}H, and 67.8 MHz for ^{13}C) in $CDCl_3$. Chemical shifts were recorded in ppm (δ) relative to TMS. Optical rotations were taken on a JASCO DIP-1000 digital polarimeter. IR was recorded on a Nicolet Magna 550 spectrometer. Electron impact (EI, 70 eV, positive mode) or fast atomic bombardment (FAB, positive mode) mass spectra were recorded on a Finnigan MAT SSQ-710 spectrometer. High resolution mass spectra (HRMS *m*/*z*) were recorded on a QSTAR Pulsar/LC/MS/MS System, ESI-QTOF instrument (Applied Biosystem, Canada). Elemental analyses were preformed on a Perkin Elmer 240B microanalyzer in Chengdu Institute of Organic Chemistry, Sichuan, China. All glass equipment were dried in an oven at 120 °C prior to use.

Single-crystal X-ray diffraction experiments were carried out at room temperature on a Bruker Axs SMART 1000 CCD area-detector diffractometer using graphite-monochromated Mo-K_α radiation (λ = 0.71073 A). Crystallographic data (comprising hydrogen atom coordinates, thermal parameters and full tables of bond lengths and angles) for the structural analysis has been deposited with the Cambridge Crystallographic Centre (CCDC-261644 for **8b** and CCDC-261645 for **17c**). Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK (Fax: +44-1223-336-033; e-mail: deposit@ccdc.cam.ac.uk or www: http://www.ccdc.cam.ac.uk).

3.2. Preparation of 2-isoxazolines 4a/4b

To a solution of chlorosuccinimide (NCS) (3.0 mmol) and 0.08 mL of pyridine in 5 mL dry dichloromethane was added aldoximes (3.0 mmol) in one portion with stirring. The mixture was stirred under nitrogen at 40 °C for 20 min, and then continued stirring at room temperature for 0.5 h until the NCS was completely dissolved. The solution then turned to a green-blue colour. A solution of 1-propene-1,3-sultone (1.0 mmol) in 10 mL of dry toluene was added. Then, Et_3N (5.0 mmol) in 5 mL of dry toluene was added over 3 h by a syringe pump at room temperature. The mixture was stirred at room temperature for 24 h. The reaction was quenched by adding 10 mL of saturated ammonium chloride solution. Organic phase was separated. The aqueous layer was extracted with dichloromethane (3×10 mL). The combined organic phase was dried over magnesium sulfate, and evaporated under reduced pressure to yield the crude product, which was purified by column chromatography on silica gel (ethyl acetate/petroleum ether, 1:3, v/v) to give products **4a** and **4b**.

3.2.1. 3-Phenyl-4,5-oxathiain-4,4-dioxide[3,4-*d*]-2-isoxazoline 4a. Yield 82%; mp 151–153 °C; ^{1}H NMR (270 MHz, $CDCl_3$): δ 4.64 (dd, J = 3.6, 10.8 Hz, 1H), 4.81 (d, J = 10.8 Hz, 1H), 5.19 (dd, J = 8.8 Hz, 1H), 5.78 (dd, J = 3.6, 8.8 Hz, 1H), 7.48 (m, 3H), 7.75 (m, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 66.7, 71.0, 85.0, 126.4, 127.3, 129.1, 131.3, 150.9; IR (KBr): 3069, 2976, 1447,1376, 1349, 1208, 1158, 1014, 952, 863 cm^{-1}; MS (EI) *m*/*z*: 239 (M^+), 144, 117, 77; $C_{10}H_9NO_4S$ requires 239. Anal. Calcd for $C_{10}H_9NO_4S$: C, 50.19; H, 3.80; N, 5.86; S, 13.40. Found: C, 50.14; H, 3.85; N, 6.01; S, 13.36.

3.2.2. 3-*t*-Butyl-4,5-oxathiain-4,4-dioxide[3,4-*d*]-2-isoxazoline 4b. Yield 60%; mp 113–115 °C; ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.35 (s, 9H), 4.59 (dd, J = 3.6, 4.0 Hz, 1H), 4.70 (d, J = 8.8 Hz, 1H), 4.72 (d, J = 10.8 Hz, 1H), 5.56 (dd, J = 3.6, 8.8 Hz, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 29.2, 33.8, 67.9, 70.5, 85.1, 160.5; IR (KBr): 2983, 1478, 1346, 1250, 1238, 1018, 948 cm^{-1}; MS (EI) *m*/*z*: 219 (M^+), 173, 117, 57; $C_8H_{13}NO_4S$ requires 219; HRMS (ESI) *m*/*z* $C_8H_{13}NO_4S$ (M^+). Calcd: 219.0566. Found: 219.0560.

3.3. Preparation of isoxazolidines 5a/5b

A mixture of nitrone (3.0 mmol) and 1-propene-1,3-sultone (1.0 mmol) in 15 mL of dry toluene was stirred under nitrogen at 120 °C for 24 h.[18] The reaction mixture was cooled to room temperature and added saturated ammonium chloride (15 mL). Organic layer was separated, and aqueous layer was extracted with ethyl acetate (3×15 mL). The combined organic phase was dried over anhydrous magnesium sulfate. After removal

of solvent, the crude products were purified by flash column chromatography on silica gel (ethyl acetate/petroleum ether = 1:2) to give pure adducts **5a** and **5b**.

3.3.1. 2-Benzyl-4,5-oxathiain-4,4-dioxide-3-phenyl[3,4-*d*]-isoxazolidine 5a. Yield 86%; mp 165–167 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.77 (d, J = 14.8 Hz, 1H), 3.96 (d, J = 14.4 Hz, 1H), 4.06 (dd, J = 7.2, 14.4 Hz, 1H), 4.22 (d, J = 7.2 Hz, 1H), 4.33 (dd, J = 3.5, 11.2 Hz, 1H), 4.46 (d, J = 11.2 Hz, 1H), 5.14 (dd, J = 3.2, 7.2 Hz, 1H), 7.30–7.51 (m, 10H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 59.3, 69.2, 69.8, 73.8, 79.6, 127.5, 127.9, 128.2, 128.4, 129.1, 129.2, 134.8, 136.5; IR (KBr): 3038, 2883, 1648, 1499, 1456, 1369, 1355, 1156, 948, 849, 701 cm^{-1}; MS (EI) *m/z*: 331 (M^+), 254, 236, 181, 115, 91, 77; $C_{17}H_{17}NO_4S$ requires 331. Anal. Calcd for $C_{17}H_{17}NO_4S$: C, 61.60; H, 5.18; N, 4.23; S, 9.68. Found: C, 61.36; H, 5.11; N, 4.13; S, 9.48.

3.3.2. 2-Benzyl-4,5-oxathiain-4,4-dioxide-3-1′-pyrenyl-[3,4-*d*]isoxazolidine 5b. Yield 86%; mp 240–242 °C; ^{1}H NMR (270 MHz, $CDCl_3$): δ 3.91 (s, 2H), 4.44 (dd, J = 3.6, 11.2 Hz, 1H), 4.46 (s, 1H), 4.59 (d, J = 10.8 Hz, 1H), 5.42 (dd, J = 3.6, 4.8 Hz, 1H), 7.22–7.27 (m, 5H), 8.05–8.32 (m, 8H), 8.75 (d, J = 9.5 Hz, 1H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 59.5, 69.1, 70.0, 70.1, 80.4, 122.6, 124.6, 125.2, 125.3, 125.7, 125.8, 126.3, 127.2, 127.6, 128.3, 128.4, 128.7, 129.6, 130.6, 131.3, 132.0, 136.5; IR (KBr): 2948, 2876, 1602, 1503, 1467, 1363, 1223, 1156, 954, 850, 772 cm^{-1}; HRMS (ESI) *m/z* $C_{27}H_{22}NO_4S$ $(M+H)^+$. Calcd: 456.1269. Found: 456.1290; Anal. Calcd for $C_{27}H_{21}NO_4S$: C, 71.19; H, 4.65; N, 3.07. Found: C, 71.11; H, 4.58; N, 3.00.

3.4. General procedure for the preparation of chiral bicyclic sultams

3.4.1. Preparation of *N*-alkyl bicyclic sultams. To a solution of isoxazoline **4a** or **4b** (2.0 mmol) in dry THF (20 mL) was added (*S*)-(α)-methyl-benzylamine (3.6 mmol). The mixture was refluxed under nitrogen for about 24 h. The course of the reaction was monitored by TLC. When isoxazolidine was completely consumed, the reaction mixture was cooled down to room temperature. Phosphorus oxychloride (7.2 mmol) was added, and the mixture was refluxed for 12 h. Dimethylamino pyridine (0.36 mmol) and triethylamine (6 mL) was added at room temperature. The mixture was then refluxed under nitrogen for 36 h. Water (2 mL) was carefully added to destroy the excess phosphorus oxychloride. The mixture was concentrated under reduced pressure. Water (15 mL) was added, and extracted with dichloromethane (4 × 20 mL). The combined organic phase was dried over anhydrous $MgSO_4$. After the removal of solvent, the residue was subjected to column chromatography on silica gel (ethyl acetate/petroleum ether = 1:5, v/v) to give pure **6a/7a** and **6b/7b**.

Following the above procedure, pure **8a/9a** and **8b/9b** were obtained in 85% yield from isoxazolidines **5a** and **5b**.

3.4.1.1. (3a*R*,6a*R*)-3-Phenyl-5-(*S*)-α-phenylethyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]-2-isoxazoline 6a. Yield 48%; mp 164–166 °C; $[\alpha]_D^{21} = +126.2$ (c 0.9, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.60 (d, J = 6.8 Hz, 3H), 3.26 (dd, J = 4.0, 12.4 Hz, 1H), 3.49 (d, J = 12 Hz, 1H), 4.74 (q, J = 7.2 Hz, 1H), 5.04 (d, J = 9.6, 1H), 5.38 (dd, J = 3.2, 10.0 Hz, 1H), 7.27–7.38 (m, 5H), 7.77–7.89 (m, 4H), 8.17 (d, J = 7.6 Hz, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 19.1, 47.8, 54.6, 69.5, 81.1, 127.2, 127.4, 127.5, 128.2, 128.7, 128.8, 128.9, 130.0, 130.9, 132.8, 134.3, 139.7, 151.5; IR (KBr): 2919, 2857, 1497, 1460, 1446, 1320, 1212, 1140, 1106, 953, 922, 841 cm^{-1}. Anal. Calcd for $C_{18}H_{18}N_2O_3S$: C, 63.14; H, 5.30; N, 8.18. Found: C, 63.00; H, 5.50; N, 7.90. MS (FAB): *m/z* 343 $(M+1)^+$; $C_{18}H_{18}N_2O_3S$ requires 342.

3.4.1.2. (3a*S*,6a*S*)-3-Phenyl-5-(*S*)-α-phenylethyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]-2-isoxazoline 7a. Yield 36%; mp 164–166 °C; $[\alpha]_D^{21} = -148.0$ (c 0.5, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.70 (d, J = 6.4 Hz, 3H), 3.37 (d, J = 11.6 Hz, 1H), 3.53 (dd, J = 4.0, 11.6 Hz, 1H), 4.97 (q, J = 6.4 Hz, 1H), 5.07 (d, J = 9.2 Hz, 1H), 5.49 (dd, J = 3.6, 9.2 Hz, 1H), 7.26–7.39 (m, 5H), 7.46–7.49 (m, 3H), 7.80–7.82 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 17.4, 45.1, 51.3, 68.9, 80.8, 127.0, 127.2, 127.7, 128.2, 128.3, 128.6, 128.9, 129.2, 130.6, 130.8, 131.1, 139.0, 151.4; IR (KBr): 2923, 2855, 1736, 1446, 1358, 1306, 1218, 1135, 1056, 996, 928, 837, 773 cm^{-1}; HRMS (ESI) *m/z* $C_{18}H_{18}N_2O_3NaS$ $(M+Na)^+$. Calcd: 365.0936. Found: 365.0941.

3.4.1.3. (3a*R*,6a*R*)-3-*t*-Butyl-5-(*S*)-α-phenylethyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]-2-isoxazoline 6b. Yield 72%; $[\alpha]_D^{20} = +10.5$ (c 1.4, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.36 (s, 9H), 1.63 (d, J = 7.2 Hz, 1H), 3.22 (dd, J = 4.8, 12.0 Hz, 1H), 3.46 (dd, J = 1.2, 12.0 Hz, 1H), 4.57 (d, J = 9.2 Hz, 1H), 4.83 (q, J = 6.8 Hz, 1H), 5.17 (m, 1H), 7.30–7.38 (m, 5H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 18.41, 29.14, 33.47, 46.41, 53.84, 70.49, 80.96, 127.18, 128.05, 128.70, 139.51, 161.02; IR (KBr): 3461, 2979, 1479, 1457, 1379, 1293, 1159, 1131, 896, 776 cm^{-1}; MS (FAB) *m/z* 323 $(M+1)^+$, 149, 105, 77, 57; $C_{16}H_{22}N_2O_3S$ requires 322; HRMS (ESI) *m/z* $C_{16}H_{22}N_2NaO_3S$ $(M+Na)^+$. Calcd: 345.1249. Found: 345.1243.

3.4.1.4. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-phenyl-5-(*S*)-α-phenylethyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 8a. Yield 43%; mp 115–117 °C; $[\alpha]_D^{21} = -32.2$ (c 1.80, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.65 (d, J = 5.4 Hz, 3H), 2.89 (dd, J = 5.4, 13.5 Hz, 1H), 3.11 (d, J = 13.5 Hz, 1H), 3.75 (d, J = 13.5 Hz, 1H), 3.91 (t, J = 8.1 Hz, 1H), 4.01 (d, J = 13.5 Hz, 1H), 4.22 (d, J = 5.4 Hz, 1H), 4.70 (q, J = 5.4 Hz, 1H), 4.81 (dd, J = 2.7, 8.1 Hz, 1H), 7.27–7.44 (m, 13H), 7.55 (d, J = 8.1 Hz, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 19.5, 46.0, 54.0, 58.8, 72.1, 73.4, 74.5, 127.0, 127.3, 127.7, 127.9, 128.0, 128.4, 128.5, 128.6, 128.9, 135.5, 136.4, 139.8; IR (KBr): 1610, 1457, 1294, 1229, 1150, 737 cm^{-1}; MS (FAB) *m/z*: 435 $(M+H)^+$, 419, 331, 236,

105, 91; $C_{25}H_{26}N_2O_3S$ requires 434; HRMS (ESI) *m/z* $C_{25}H_{26}N_2O_3S$ $(M)^+$. Calcd: 434.1664. Found: 434.1660.

3.4.1.5. (3*S*,3a*S*,6a*S*)-2-Benzyl-3-phenyl-5-(*S*)-α-phenylethyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 9a. Yield 40%; mp 125–127 °C; $[\alpha]_D^{20} = -14.0$ (*c* 1.50, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 1.67 (d, *J* = 8.1 Hz, 3H), 3.03 (d, *J* = 13.5 Hz, 1H), 3.25 (dd, *J* = 5.4, 13.5 Hz, 1H), 3.63 (d, *J* = 13.5 Hz, 1H), 3.90–3.98 (m, 2H), 4.18 (d, *J* = 8.1 Hz, 1H), 4.89 (q, *J* = 2.7 Hz, 1H), 5.06 (dd, *J* = 8.1, 13.5 Hz, 1H), 7.22–7.47 (m, 13H), 7.56 (d, *J* = 5.4 Hz, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 17.2, 44.5, 50.0, 58.9, 71.5, 74.6, 74.7, 126.8, 127.3, 127.5, 127.9, 128.0, 128.3, 128.4, 128.7, 128.9, 135.5, 136.6, 139.5; IR (KBr): 1612, 1493, 1296, 1151, 1000, 762 cm^{-1}; MS (FAB) *m/z*: 435 $(M+H)^+$, 419, 331, 236, 105, 91; $C_{25}H_{26}N_2O_3S$ requires 434; HRMS (ESI) *m/z* $C_{25}H_{26}N_2O_3S$ $(M)^+$. Calcd: 434.1664. Found: 434.1661.

3.4.1.6. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-pyrenyl-5-(*S*)-α-phenylethyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 8b. Yield 38%; $[\alpha]_D^{20} = -36.7$ (*c* 2.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 1.74 (d, *J* = 7.2 Hz, 1H), 2.99 (dd, *J* = 4.4, 12.0 Hz, 1H), 3.23 (d, *J* = 11.6 Hz, 1H), 3.85 (d, *J* = 14.4 Hz, 1H), 3.96 (d, *J* = 14.4 Hz, 1H), 4.34 (s, 1H), 4.76 (dd, *J* = 6.4, 13.2 Hz, 1H), 5.06 (dd, *J* = 4.0, 6.8 Hz, 1H), 5.23 (br m, 1H), 7.20–7.41 (m, 10H), 8.00–8.11 (m, 3H), 8.19–8.22 (m, 4H), 8.31 (d, *J* = 7.6 Hz, 1H), 8.79 (d, *J* = 9.2 Hz, 1H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 19.6, 46.1, 54.2, 59.2, 60.3, 72.5, 75.4, 123.0, 124.6, 125.2, 125.4, 125.6, 126.1, 127.2, 127.3, 127.4, 128.0, 128.1, 128.2, 128.3, 128.4, 128.7, 128.8, 129.6, 130.6, 131.2, 131.7, 136.6, 140.1; IR (KBr): 3042, 2938, 2871, 1643, 1503, 1467, 1312, 1141, 851, 706 cm^{-1}; HRMS (ESI) *m/z* $C_{35}H_{30}N_2NaO_3S$ $(M+Na)^+$. Calcd: 581.1875. Found: 581.1878.

3.4.2. Debenzylation of *N*-alkyl bicyclic sultams. A mixture of *N*-alkyl bicyclic sultams (1.0 mmol) and freshly distilled formic acid (20 mL) was stirred under nitrogen for 12 h. Then, the mixture was heated to 70 °C, and stirred for 8 h. Formic acid was removed under reduced pressure to give the crude product. To the crude product was added 10% KOH in ethanol (30 mL). The mixture was stirred at room temperature for 12 h, and acidified with 6 N HCl (pH 3). The mixture was concentrated under reduced pressure. The residue was extracted with dichloromethane (5 × 15 mL). Removal of solvent gave crude product, which was purified by column chromatography on silica gel (ethyl acetate/petroleum ether = 1:3, v/v) to afford pure products.

3.4.2.1. (3a*R*,6a*R*)-3-Phenyl-4,5-thiazolidine-4,4-dioxide-[3,4-*d*]-2-isoxazoline 10a. Yield 85%; mp 157–159 °C; $[\alpha]_D^{21} = -141.5$ (*c* 0.43, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 3.60 (dtd, *J* = 2.8, 3.2, 5.6 Hz, 1H), 3.81 (dd, *J* = 6.0, 14.4 Hz, 1H), 4.62 (dd, *J* = 6.0, 11.6 Hz, 1H), 5.01 (d, *J* = 8.0 Hz, 1H), 5.73 (dd, *J* = 2.8, 8.4 Hz, 1H), 7.45 (m, 3H), 7.76 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 46.6, 69.0, 88.6, 126.9, 127.4, 129.0, 131.2, 152.4; IR (KBr): 3248, 3000, 2966, 1446, 1394, 1352, 1324, 1184, 1144, 928, 840, 768 cm^{-1}; HRMS (ESI) *m/z* $C_{10}H_{11}N_2O_3S$ $(M+H)^+$. Calcd: 239.0490. Found: 239.0488.

3.4.2.2. (3a*R*,6a*R*)-3-*t*-Butyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]-2-isoxazoline 10b. Yield 74%; $[\alpha]_D^{21} = -6.5$ (*c* 1.02, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 1.34 (s, 9H), 3.52 (dqd, *J* = 2.4, 3.0, 3.0 Hz, 1H), 3.73 (dd, *J* = 5.4, 14.3 Hz, 1H), 4.52 (d, *J* = 7.6 Hz, 1H), 4.10 (s, br, 1H), 5.10 (m, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 29.44, 33.72, 45.95, 70.10, 88.67, 162.46; IR (KBr): 3224, 3167, 2997, 1481, 1412, 1340, 1186, 1150, 901, 752 cm^{-1}; MS (FAB) *m/z* 219 $(M+1)^+$, 146, 162, 57; $C_8H_{14}N_2O_3S$ requires 218; HRMS (ESI) *m/z* $C_8H_{15}N_2O_3S$ $(M+H)^+$. Calcd: 219.0803. Found: 219.0808.

3.4.2.3. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-phenyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 12a. Yield 40%; mp 121–124 °C; $[\alpha]_D^{21} = -55.3$ (*c* 1.25, $CHCl_3$); ^1H NMR (400 MHz, acetone-d_6): δ 2.89 (s, 1H), 3.24 (d, *J* = 14.0 Hz, 1H), 3.38 (d, *J* = 14.4 Hz, 1H), 3.74 (d, *J* = 14.8 Hz, 1H), 3.88 (d, *J* = 14.4 Hz, 1H), 3.98 (dd, *J* = 6.8, 14.0 Hz, 1H), 4.14 (d, *J* = 6.8 Hz, 1H), 5.16 (dd, *J* = 2.8, 5.2 Hz, 1H), 7.20–7.32 (m, 5H), 7.35–7.46 (m, 3H), 7.57–7.59 (m, 2H); ^{13}C NMR (100.6 MHz, acetone-d_6): δ 44.6, 59.2, 72.1, 74.5, 83.3, 127.2, 128.2, 128.6, 128.7, 128.9, 129.2, 137.0, 138.0; IR (KBr): 3232, 2903, 1463, 1283, 1132 cm^{-1}; HRMS (ESI) *m/z* $C_{17}H_{19}N_2O_3S$ $(M+H)^+$. Calcd: 331.1116. Found: 331.1114.

3.4.2.4. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-pyrenyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 12b. Yield 38%; mp 125 °C (dec); $[\alpha]_D^{21} = -42.1$ (*c* 1.70, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 3.43 (ddd, *J* = 2.8, 11.6, 14.0 Hz, 1H), 3.57 (dd, *J* = 6.0, 14.4 Hz, 1H), 3.85 (d, *J* = 14.6 Hz, 1H), 3.95 (d, *J* = 14.6 Hz, 1H), 4.28 (m, 1H), 4.80 (dd, *J* = 6.0, 11.2 Hz, 1H), 5.36 (m, 1H), 7.26 (m, 5H), 8.04–8.15 (m, 3H), 8.22–8.26 (m, 4H), 8.34 (m, 1H), 8.78 (m, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 22.7, 31.6, 44.6, 59.5, 83.6, 122.7, 124.6, 125.2, 125.6, 125.7, 126.3, 126.8, 126.9, 127.3, 127.6, 127.7, 128.3, 128.4, 128.6, 129.5, 130.6, 131.3, 131.8, 136.5; IR (KBr): 3238, 2904, 1472, 1298, 1143, 787 cm^{-1}; HRMS (ESI) *m/z* $C_{27}H_{22}N_2NaO_3S$ $(M+Na)^+$. Calcd: 477.1248. Found: 477.1232.

3.5. General procedure for the *N*-acylation of bicyclic sultams

To a solution of bicyclic sultam (1.0 mmol) in dry THF (15 mL) was added *n*-butyl lithium (1.2 mmol, 1.6 M solution in hexane) under nitrogen at −78 °C. The mixture was stirred at −78 °C for 15 min. Cooling bath was removed, and allowed the reaction temperature to warm to room temperature. After stirring at room temperature for 1 h, the reaction mixture again cooled down to −78 °C. A solution of freshly distilled acid chloride (1.2 mmol) in 3 mL of dry THF was added. Stirring the reaction mixture at −78 °C for 15 min, the reaction temperature was brought up to room temperature and stirred for 2 h.

Water (1 mL) was added to quench the reaction. After the removal of solvent, the residue was treated with water (10 mL) and ethyl acetate (15 mL). Organic phase was separated, and aqueous was extracted with ethyl acetate (3 × 10 mL). The combined organic phase was dried over anhydrous $MgSO_4$. Solvent was removed, and the residue was subjected to column chromatography on silica gel (ethyl acetate/petroleum ether = 1:3, v/v) to give pure *N*-enoyl sultam.

3.5.1. (3a*R*,6a*R*)-3-Phenyl-5-*trans*-crotonyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]-2-isoxazoline 15a. Yield 85%; mp 174–176 °C; $[\alpha]_D^{21} = +151.8$ (*c* 0.90, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 1.90 (dd, *J* = 1.6, 6.8 Hz, 3H), 4.01 (dd, *J* = 4.3, 13.5 Hz, 1H), 4.72 (d, *J* = 13.8 Hz, 1H), 5.27 (d, *J* = 9.2 Hz, 1H), 5.55 (dd, *J* = 3.2, 9.2 Hz, 1H), 6.55 (qq, *J* = 1.6, 15.1 Hz, 1H), 7.15 (dq, *J* = 7.0, 14.9 Hz, 1H), 7.48 (m, 3H), 7.74 (m, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 18.5, 46.7, 71.4, 79.8, 121.1, 126.7, 127.1, 129.0, 131.2, 147.9, 151.5, 162.6; IR (KBr): 300, 2948, 1690, 1446, 1338, 1074, 923, 773, 685 cm^{-1}; MS (FAB) *m*/*z*: 307 $(M+H)^+$, 239, 77, 69; $C_{14}H_{14}N_2O_4S$ requires 306; HRMS (ESI) *m*/*z* $C_{14}H_{15}N_2O_4S$ $(M+H)^+$. Calcd: 307.0751. Found: 307.0748.

3.5.2. (3a*S*,6a*S*)-5-Acryloyl-3-phenyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]-2-isoxazoline 15c. Yield 37%; mp 174–176 °C; $[\alpha]_D^{21} = -257.0$ (*c* 0.90, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 4.03 (dd, *J* = 4.3, 14.0 Hz, 1H), 4.72 (d, *J* = 13.5 Hz, 1H), 5.28 (d, *J* = 6.8 Hz, 1H), 5.56 (dd, *J* = 4.0, 9.7 Hz, 1H), 5.89 (dd, *J* = 1.6, 10.3 Hz, 1H), 6.59 (dd, *J* = 1.6, 16.7 Hz, 1H), 6.82 (m, 1H), 7.46–7.75 (m, 5H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 46.6, 71.4, 79.9, 126.6, 126.7, 127.2, 129.1, 131.2, 132.8, 151.5, 162.6; IR (KBr): 2998, 2950, 1686, 1642, 1443, 1328, 1068, 920, 772 cm^{-1}; HRMS (ESI) *m*/*z* $C_{13}H_{12}N_2O_4S$ $(M)^+$. Calcd: 292.0518. Found: 292.0516.

3.5.3. (3a*R*,6a*R*)-3-*t*-Butyl-5-*trans*-crotonyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]-2-isoxazoline 15d. Yield 85%; $[\alpha]_D^{21} = +52.5$ (*c* 2.00, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 1.35 (s, 9H), 1.95 (dd, *J* = 1.6, 7.0 Hz, 3H), 4.05 (dd, *J* = 4.9, 13.8 Hz, 1H), 4.54 (d, *J* = 13.5 Hz, 1H), 4.83 (d, *J* = 7.8 Hz, 1H), 5.32 (dd, *J* = 3.8, 8.1 Hz, 1H), 6.57 (dd, *J* = 1.6, 14.8 Hz, 1H), 7.16 (m, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 18.54, 28.70, 33.76, 46.07, 71.78, 79.80, 121.06, 147.54, 161.84, 162.53; IR (KBr): 2936 1684, 1442, 1321, 1068, 768 cm^{-1}; MS (FAB) *m*/*z* 287 $(M+1)^+$, 218, 57; $C_{12}H_{18}N_2O_4S$ requires 286; HRMS (ESI) *m*/*z* $C_{12}H_{18}N_2NaO_4S$ $(M+Na)^+$. Calcd: 309.0885. Found: 309.0895.

3.5.4. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-phenyl-5-*trans*-crotonyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 15e. Yield 85%; mp 132–134 °C; $[\alpha]_D^{21} = -14.9$ (*c* 1.67, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 1.97 (dd, *J* = 1.6, 7.0 Hz, 3H), 3.64 (dd, *J* = 4.6, 13.8 Hz, 1H), 3.77 (d, *J* = 14.0 Hz, 1H), 3.95 (d, *J* = 14.3 Hz, 1H), 4.15 (dd, *J* = 7.3, 14.0 Hz, 1H), 4.34 (d, *J* = 10.3 Hz, 1H), 4.37 (d, *J* = 17.3 Hz, 1H), 4.96 (dd, *J* = 4.3, 7.3 Hz, 1H), 6.74 (qq, *J* = 1.6, 14.8 Hz, 1H), 7.17 (m, 1H), 7.25–7.53 (m, 10H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 18.6, 45.0, 59.3, 73.8, 74.0, 74.8, 121.5, 127.5, 128.0, 128.2, 128.6, 129.1, 129.2, 135.3, 136.4, 147.1, 163.5; IR (KBr): 3031, 2964, 2881, 1683, 1644, 1462, 1340, 1247, 1195, 1141, 699 cm^{-1}; HRMS (ESI) *m*/*z* $C_{21}H_{22}N_2O_4S$ $(M)^+$. Calcd: 398.4767. Found: 398.4765.

3.5.5. (3*R*,3a*R*,6a*R*)-5-Acryloyl-2-benzyl-3-phenyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 15g. Yield 33%; mp 120–122 °C; $[\alpha]_D^{21} = -6.4$ (*c* 1.02, $CHCl_3$); ^1H NMR (270 MHz, $CDCl_3$): δ 3.66 (dd, *J* = 4.0, 13.6 Hz, 1H), 3.77 (d, *J* = 14.4 Hz, 1H), 3.95 (d, *J* = 14.4 Hz, 1H), 4.17 (t, *J* = 6.8 Hz, 1H), 4.32 (d, *J* = 6.0 Hz, 1H), 4.42 (d, *J* = 14.4 Hz, 1H), 4.98 (dd, *J* = 4.4, 6.8 Hz, 1H), 5.96 (dd, *J* = 1.2, 10.4 Hz, 1H), 6.59 (dd, *J* = 1.2, 16.4 Hz, 1H), 7.02 (dd, *J* = 10.4, 16.4 Hz, 1H), 7.29–7.33 (m, 5H), 7.39–7.45 (m, 3H), 7.51–7.53 (m, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 44.8, 59.2, 73.8, 74.9, 74.6, 127.0, 127.6, 128.0, 128.3, 128.7, 129.2, 129.3, 132.4, 135.2, 136.4, 163.4; IR (KBr): 3032, 2961, 2881, 1685, 1648, 1463, 1342, 1242, 1196, 1142, 672 cm^{-1}; HRMS (ESI) *m*/*z* $C_{20}H_{20}N_2O_4NaS$ $(M+Na)^+$. Calcd: 407.1041. Found: 407.1045.

3.5.6. (3*R*,3a*R*,6a*R*)-2-Benzyl-3-pyrenyl-5-*trans*-crotonyl-4,5-thiazoline-4,4-dioxide[3,4-*d*]isoxazolidine 15h. Yield 85%; $[\alpha]_D^{21} = +26.2$ (*c* 1.4, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 2.01 (dd, *J* = 1.6, 2.8 Hz, 3H), 3.74 (dd, *J* = 4.8, 13.6 Hz, 1H), 3.92 (s, 2H), 4.48 (d, *J* = 9.6 Hz, 2H), 5.19 (m, 1H), 6.82 (m, 1H), 7.21 (m, 1H), 7.24 (m, 5H), 8.03–8.14 (m, 3H), 8.22–8.24 (m, 4H), 8.33 (m, br, 1H), 8.69 (m, br, 1H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 18.53, 44.87, 59.67, 60.37, 74.36, 75.13, 121.52, 124.57, 125.12, 125.25, 125.63, 125.81, 126.28, 127.21, 127.55, 127.69, 128.20, 128.30, 128.46, 128.50, 128.69, 128.77, 129.39, 130.52, 131.20, 131.83, 136.48, 147.42, 163.66; IR (KBr): 3031, 1688, 1642, 1452, 1343, 1295, 1249, 1195, 1140, 847, 756 cm^{-1}; HRMS (ESI) *m*/*z* $C_{31}H_{26}N_2NaO_4S$ $(M+Na)^+$. Calcd: 545.1511. Found: 545.1516.

3.6. General procedure for the asymmetric Diels–Alder reaction

To a solution of *N*-enoyl bicyclic sultam (1.0 mmol) in dry dichloromethane (10 mL) was added titanium(IV) chloride (0.6 mmol, 1 M solution in dichloromethane) under nitrogen at room temperature. After stirring for 0.5 h, the reaction mixture was cooled down to −78 °C. A solution of cyclopentadiene (15 mmol) in 2 mL of dry dichloromethane was added. The mixture was stirred under nitrogen at −78 °C for 12 h. The course of the reaction was monitored by TLC. When *N*-enoyl sultam was consumed, water (2 mL) was added. The mixture was filtered through a short column packed with Celite, washed with dichloromethane. The combined organic phase was dried over anhydrous $MgSO_4$. After the removal of solvent, the residue was subjected to column chromatography on silica gel (ether acetate/petroleum ether = 1:4, v/v) to give pure cycloadducts.

3.6.1. (3a*R*,6a*R*)-5-*N*-{(1*R,2*S**,3*R**,4*S**)-3-Methylbicyclo[2,2,1]hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]-2-isoxazoline 16a.** Yield 73%; mp 216–218 °C; $[\alpha]_D^{18} = +294$ (*c* 0.81, $CHCl_3$); ^1H

NMR (270 MHz, $CDCl_3$): δ 1.14 (d, J = 7.0 Hz, 3H), 1.39 (dd, J = 1.6, 8.9 Hz, 1H), 1.54 (br s, 1H), 1.99 (m, 1H), 2.50 (br s, 1H), 2.92 (t, J = 4.1 Hz, 1H), 3.19 (br s, 1H), 4.00 (dd, J = 4.3, 13.8 Hz, 1H), 4.55 (d, J = 13.8 Hz, 1H), 5.29 (d, J = 9.2 Hz, 1H), 5.53 (dd, J = 3.5, 9.2 Hz, 1H), 5.84 (dd, J = 2.7, 5.7 Hz, 1H), 6.34 (dd, J = 3.2, 5.7 Hz, 1H), 7.50 (m, 3H), 7.76 (m, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 20.4, 38.5, 47.1, 47.4, 48.5, 49.6, 53.2, 71.6, 79.5, 126.8, 127.2, 129.1, 131.2, 139.1, 151.7, 172.4; IR (KBr): 2927, 1718, 1651, 1446, 1353, 1336, 1235, 1209, 1132, 917, 773 cm^{-1}; HRMS (ESI) m/z $C_{19}H_{20}N_2O_4NaS$ $(M+Na)^+$. Calcd: 395.1041. Found: 395.1043.

3.6.2. (3a*R*,6a*R*)-5-*N*-{(1*S,2*R**,3*S**,4*R**)-3-Methylbicyclo[2,2,1]hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide-[3,4-*d*]-2-isoxazoline 17a.** Yield 7%; $[\alpha]_D^{18} = -308$ (c 0.42, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.08 (d, J = 7.0 Hz, 3H), 1.45 (dd, J = 1.6, 8.8 Hz, 1H), 1.57 (br m, 1H), 1.95 (m, 1H), 2.65 (br m, 1H), 3.06 (t, J = 4.0 Hz, 1H), 3.28 (br m, 1H), 3.85 (dd, J = 4.3, 13.8 Hz, 1H), 4.63 (d, J = 14.0 Hz, 1H), 5.31 (d, J = 9.2 Hz, 1H), 5.51 (dd, J = 3.2, 9.2 Hz, 1H), 5.84 (dd, J = 2.7, 5.8 Hz, 1H), 6.32 (dd, J = 2.7, 5.8 Hz, 1H), 7.46 (m, 3H), 7.73 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 20.0, 37.8, 46.8, 47.3, 47.8, 49.2, 52.3, 71.6, 80.0, 126.7, 127.2, 129.0, 131.1, 139.4, 151.8, 172.4; HRMS (ESI) m/z $C_{19}H_{20}N_2O_4NaS$ $(M+Na)^+$. Calcd: 395.1041. Found: 395.1047.

3.6.3. (3a*S*,6a*S*)-5-*N*-{(1*S,2*R**,4*R**)-Bicyclo[2,2,1]hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide-[3,4-*d*]-2-isoxazoline 17c.** Yield 62%; mp 218–220 °C; $[\alpha]_D^{18} = -239.2$ (c 0.80, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.24–1.54 (m, 3H), 1.83–1.89 (m, 1H), 2.91 (br s, 1H), 3.39 (br s, 1H), 3.55 (m, 1H), 3.88 (dd, J = 4.0, 14.0 Hz, 1H), 4.74 (d, J = 13.6 Hz, 1H), 5.30 (dd, J = 8.8, 17.2 Hz, 1H), 5.53 (m, 1H), 5.88 (dd, J = 2.8, 5.6 Hz, 1H), 6.25 (dd, J = 2.8, 5.6 Hz, 1H), 7.50 (m, 3H), 7.76 (m, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 30.8, 42.8, 44.9, 47.0, 47.1, 49.9, 71.6, 79.8, 127.3, 129.1, 131.3, 132.1, 137.6, 138.1, 151.6, 171.8; IR (KBr): 2977, 1711, 1565, 1447, 1350, 1241, 1178, 915, 772 cm^{-1}; HRMS (ESI) m/z $C_{18}H_{18}N_2O_4NaS$ $(M+Na)^+$. Calcd: 381.0884. Found: 381.0910.

3.6.4. (3*R*,3a*R*,6a*R*)-5-*N*-{(1*R,2*S**,3*R**,4*S**)-3-Methylbicyclo[2,2,1]hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]isoxazolidine 16e.** Yield 81%; $[\alpha]_D^{18} = +42.4$ (c 1.05, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.15 (d, J = 7.0 Hz, 3H), 1.50 (d, J = 8.6 Hz, 1H), 1.70 (d, J = 8.9 Hz, 1H), 2.03 (m, 1H), 2.55 (br m, 1H), 3.01 (t, J = 3.5 Hz, 1H), 3.37 (s, 1H), 3.62 (dd, J = 4.3, 13.5 Hz, 1H), 3.78 (d, J = 14.3 Hz, 1H), 4.03 (d, J = 14.3 Hz, 1H), 4.13 (d, J = 6.8 Hz, 1H), 4.20 (d, J = 13.5 Hz, 1H), 4.35 (d, J = 6.8 Hz, 1H), 4.94 (dd, J = 4.3, 7.0 Hz, 1H), 5.89 (dd, J = 2.7, 5.7 Hz, 1H), 6.39 (dd, J = 2.7, 5.7 Hz, 1H), 7.26 (m, 5H), 7.42 (m, 3H), 7.53 (d, J = 9.2 Hz, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 20.4, 38.1, 45.5, 47.1, 48.2, 49.5, 52.8, 59.0, 73.2, 73.7, 74.7, 127.4, 127.8, 128.1, 128.6, 129.0, 129.1, 131.0, 135.2, 135.9, 139.1, 172.9; IR (KBr): 2923, 2876, 1705, 1457, 1394, 1016, 918, 706 cm^{-1}; HRMS (ESI) m/z $C_{20}H_{29}N_2O_4S$ $(M+H)^+$. Calcd: 465.1848. Found: 465.1852.

3.6.5. (3*R*,3a*R*,6a*R*)-5-*N*-{(1*S,2*R**,3*S**,4*R**)-3-Methylbicyclo[2,2,1]hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]isoxazolidine 17e.** Yield 9%; $[\alpha]_D^{18} = -22$ (c 0.38, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.14 (d, J = 7.0 Hz, 3H), 1.51 (d, J = 8.6 Hz, 1H), 1.62 (d, J = 8.8 Hz, 1H), 2.01 (m, 1H), 2.62 (br s, 1H), 3.00 (t, J = 3.5 Hz, 1H), 3.37 (br s, 1H), 3.63 (dd, J = 4.2, 13.6 Hz, 1H), 3.76 (d, J = 13.6 Hz, 1H), 4.06 (d, J = 13.6 Hz, 1H), 4.10 (d, J = 6.8 Hz, 1H), 4.15 (d, J = 13.6 Hz, 1H), 4.35 (d, J = 6.8 Hz, 1H), 4.94 (dd, J = 4.3, 7.2 Hz, 1H), 5.88 (dd, J = 2.7, 5.7 Hz, 1H), 6.38 (dd, J = 2.7, 5.7 Hz, 1H), 7.29 (m, 5H), 7.43 (m, 3H), 7.53 (m, 2H); HRMS (ESI) m/z $C_{20}H_{29}N_2O_4S$ $(M+H)^+$. Calcd: 465.1848. Found: 465.1856.

3.6.6. (3*R*,3a*R*,6a*R*)-5-*N*-{(1*R,2*S**,4*S**)-Bicyclo[2,2,1]-hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide-[3,4-*d*]isoxazolidine 16g.** Yield 65%; $[\alpha]_D^{21} = +15.8$ (c 0.60, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.26 (br s, 1H), 1.37–1.50 (m, 3H), 2.00–2.08 (m, 1H), 2.95 (br m, 1H), 3.40 (br m, 1H), 3.51–3.59 (m, 1H), 3.71–3.79 (m, 1H), 3.99 (t, J = 14.3 Hz, 1H), 4.11–4.18 (m, 1H), 4.24–4.41 (m, 2H), 4.93 (dd, J = 4.1, 7.0 Hz, 1H), 5.93 (qq, J = 3.0, 7.0 Hz, 1H), 6.25 (dd, J = 3.0, 7.0 Hz, 1H), 7.27–7.54 (m, 10H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 30.1, 30.8, 42.9, 43.9, 44.7, 47.0, 49.9, 59.1, 73.7, 74.8, 127.5, 128.0, 128.2, 128.7, 129.1, 129.2, 132.1, 135.2, 136.1, 137.7, 172.9; IR (KBr): 2971, 2876, 1701, 1456, 1348, 1331, 1247, 1190, 1027, 699 cm^{-1}; HRMS (ESI) m/z $C_{25}H_{26}N_2NaO_4S$ $(M+Na)^+$. Calcd: 473.1511. Found: 473.1515.

3.6.7. (3*R*,3a*R*,6a*R*)-5-*N*-{(1*S,2*R**,4*R**)-Bicyclo[2,2,1]-hept-5-en-2-formyl}-3-phenyl-4,5-thiazolidine-4,4-dioxide-[3,4-*d*]isoxazolidine 17g.** Yield 18%; $[\alpha]_D^{18} = -11$ (c 0.35, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.28 (m, 1H), 1.40–1.56 (m, 3H), 1.88–2.06 (m, 1H), 3.05 (m, 1H), 3.43 (m, 1H), 3.49–3.57 (m, 1H), 3.65–3.76 (m, 1H), 4.02 (t, J = 14.3 Hz, 1H), 4.12–4.17 (m, 1H), 4.26–4.38 (m, 2H), 4.95 (dd, J = 4.0, 7.2 Hz, 1H), 5.87 (dd, J = 3.0, 5.7 Hz, 1H), 6.18 (dd, J = 3.0, 5.7 Hz, 1H), 7.25–7.56 (m, 10H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 31.3, 32.0, 42.8, 43.9, 45.3, 47.1, 50.2, 59.1, 73.8, 74.0, 127.3, 127.8, 128.2, 128.7, 129.1, 129.2, 131.1, 135.4, 136.2, 137.9, 172.5; HRMS (ESI) m/z $C_{25}H_{26}N_2NaO_4S$ $(M+Na)^+$. Calcd: 473.1511. Found: 473.1518.

3.6.8. (3*R*,3a*R*,6a*R*)-5-*N*-{(1*R,2*S**,3*R**,4*S**)-3-Methylbicyclo[2,2,1]hept-5-en-2-formyl}-3-pyrenyl-4,5-thiazolidine-4,4-dioxide[3,4-*d*]isoxazolidine 16h.** Yield 80%; $[\alpha]_D^{21} = +83.3$ (c 1.7, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.16 (d, J = 6.8 Hz, 3H), 1.55–1.60 (m, 2H), 1.75 (d, J = 8.4 Hz, 1H), 2.05 (m, 1H), 2.57 (s, 1H), 3.08 (t, J = 3.6 Hz, 1H), 3.51 (s, 1H), 3.74 (dd, J = 4.4, 13.6 Hz, 1H), 3.98 (q, J = 14.4 Hz, 2H), 4.30 (d,

J = 13.2 Hz, 1H), 4.48 (m, 1H), 5.18 (t, J = 5.6 Hz, 1H), 5.98 (d d, J = 2.4, 5.2 Hz, 1H), 6.44 (dd, J = 3.2, 5.6 Hz, 1H), 7.22–7.27 (m, 5H), 8.03–8.15 (m, 3H), 8.25 (t, J = 6.8 Hz, 1H), 8.36 (d, J = 6.4 Hz, 1H), 8.69 (d, J = 6.8 Hz, 1H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 20.35, 38.26, 45.44, 47.23, 48.56, 49.60, 52.80, 59.54, 73.98, 75.23, 122.32, 124.59, 125.15, 125.25, 125.65, 125.82, 126.30, 127.22, 127.61, 128.22, 128.29, 128.47, 128.73, 128.89, 129.34, 130.53, 131.22, 131.31, 131.84, 136.18, 139.44, 173.26; IR (KBr): 2960, 1688, 1648, 1438, 1312, 1236, 1112, 1148, 708 cm^{-1}; HRMS (ESI) m/z $C_{36}H_{32}N_2NaO_4S$ $(M+Na)^+$. Calcd: 611.1980. Found: 611.1954.

3.7. General procedure for the saponification of cycloadducts

To a solution of $LiOH{\cdot}H_2O$ (8.0 mmol) in THF/H_2O (5:1, v/v) (5 mL/mmol) was added cycloadduct **15e** (1.0 mmol). The mixture was vigorously stirred at room temperature for 24 h. When the reaction was completed (monitored by TLC), solvents were removed. To the residue was added water (20 mL/mmol) and adjusted to pH 10 by adding saturated $NaHCO_3$. The basic solution was extracted with dichloromethane (3×15 mL). The extracts were washed with brine, dried over anhydrous $MgSO_4$, concentrated under reduced pressure to recover the chiral sultam auxiliary.

The aqueous layer was acidified by 6 N HCl to pH 1, and then extracted with ethyl acetate (3×15 mL). The combined organic phase was dried over anhydrous $MgSO_4$, and concentrated to give carboxylic acid.

3.7.1. (2-*endo*,3-*exo*)-3-Methyl-bicyclo[2,2,1]hept-5-en-2-carboxylic acid 18a. Yield 82%; $[\alpha]_D^{22} = -138$ (c 0.96, 95% ethanol; lit.:[17] −140); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.20 (d, J = 7.0 Hz, 1H), 1.46 (dd, J = 1.5, 8.6 Hz, 1H), 1.56 (d, J = 8.6 Hz, 1H), 1.83 (m, 1H), 2.41 (t, J = 4.0 Hz, 1H), 2.48 (br s, 1H), 3.13 (br s, 1H), 6.04 (dd, J = 2.6, 5.6 Hz, 1H), 6.28 (dd, J = 3.3, 5.6 Hz, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 21.0, 38.0, 45.9, 46.1, 48.9, 52.4, 133.2, 138.7, 180.2.

3.7.2. (2-*endo*)-Bicyclo[2,2,1]hept-5-en-2-carboxylic acid 18b. Yield 73%; $[\alpha]_D^{22} = -136$ (c 0.69, 95% ethanol; lit.:[17b] −138); ^{1}H NMR (270 MHz, $CDCl_3$): δ 1.21–1.51 (m, 3H), 1.85–2.03 (m, 1H), 2.85–3.06 (m, 2H), 3.24 (br s, 1H), 6.01 (dd, J = 2.7, 5.6 Hz, 1H), 6.23 (dd, J = 2.7, 5.6 Hz, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ 29.3, 42.8, 43.9, 45.8, 50.0, 132.7, 138.0, 181.5.

Acknowledgements

The work described in the paper was fully supported by grants from the University Grants Committee of the Hong Kong Special Administrative Region, China (AOE/p-10/01 and HKBU 2024/OOP) and a grant from the Hong Kong Baptist University (PRG/01-02/II-41).

References

1. Seyden-Penne, J. *Chiral Auxiliaries and Ligands in Asymmetric Synthesis*; John Wiley & Sons: New York, 1995.
2. *Handbook of Reagents for Organic Synthesis—Reagents, Auxiliaries and Catalysts for C–C bonds*; Coates, R. M., Denmark, S. E., Eds.; John Wiley & Sons: New York, 1999.
3. Myers, A. G.; Yang, B. H.; Chen, H.; Gleason, J. L. *J. Am. Chem. Soc.* **1994**, *116*, 9361.
4. Vicario, J. L.; Badia, D.; Carrillo, L. *J. Org. Chem.* **2001**, *66*, 9030.
5. Davies, G. S.; Sanganee, H. J. *Tetrahedron: Asymmetry* **1995**, *6*, 671.
6. Boeckman, R. K.; Laci, M. A.; Johnson, A. T. *Tetrahedron: Asymmetry* **2001**, *12*, 205.
7. Kawecki, R. *Tetrahedron: Asymmetry* **2003**, *14*, 2827–2832.
8. Shing, T. K. M.; Chow, H. F.; Chung, I. H. F. *Tetrahedron Lett.* **1996**, *37*, 3713–3716.
9. Nouguier, R.; Mignon, V.; Gras, J.-L. *J. Org. Chem.* **1999**, *64*, 1412.
10. Evans, D. A.; Chapman, K. T.; Bisaha, J. *J. Am. Chem. Soc.* **1988**, *110*, 1238.
11. Oppolzer, W. *Pure Appl. Chem.* **1990**, *62*, 1241.
12. (a) Akkari, R.; Calmes, M.; Escale, F.; Iapichella, J.; Rolland, M.; Martinez, J. *Tetrahedron: Asymmetry* **2004**, *15*(16), 2515; (b) Boeckman, R. K., Jr.; Reeder, L. M. *Synlett* **2004**, *8*, 1399; (c) Kobayashi, T.; Tanaka, K.; Miwa, J.; Katsumura, S. *Tetrahedron: Asymmetry* **2004**, *15*(2), 185; (d) Robiette, R.; Cheboub-Benchaba, K.; Peeters, D.; Marchand-Brynaert, J. *J. Org. Chem.* **2003**, *68*(25), 9809; (e) Ding, X.; Ukaji, Y.; Fujinami, S.; Inomata, K. *Chem. Lett.* **2003**, *32*(7), 582; (f) Lait, S. M.; Parvez, M.; Keay, B. A. *Tetrahedron: Asymmetry* **2003**, *14*(6), 749; (g) Fernandez, F.; Garcia-Mera, X.; Rodriguez-Borges, J. E.; Vale, M. L. C. *Tetrahedron Lett.* **2003**, *44*(3), 431; (h) Lakner, F. J.; Negrete, G. R. *Synlett* **2002**(4), 643; (i) Boeckman, R. K., Jr.; Laci, M. A.; Johnson, A. T. *Tetrahedron: Asymmetry* **2001**, *12*(2), 205; (j) Jiang, L.-S.; Chan, W.-H.; Li, W.-M. *Zhongshan Daxue Xuebao, Ziran Kexueban* **2000**, *39*(4), 131; (k) Carriere, A.; Virgili, A. *Tetrahedron: Asymmetry* **1996**, *7*(1), 227.
13. (a) Cipiciani, A.; Fringuelli, F.; Piermatti, O.; Pizzo, F.; Ruzziconi, R. *J. Org. Chem.* **2002**, *67*, 2665; (b) Oppolzer, W.; Blagg, J.; Rodriguez, I.; Walther, E. *J. Am. Chem. Soc.* **1990**, *112*, 2767; (c) Evans, D. A.; Chapman, T.; Bisaha, J. *J. Am. Chem. Soc.* **1984**, *106*, 4261; (d) Mayer, S. C.; Pfizenmayer, A. J.; Cordova, R.; Li, W.-R.; Joullie, M. M. *Tetrahedron: Asymmetry* **1994**, *5*, 519; (e) Chapuis, C.; Rzepecki, P.; Bauer, T.; Jurczak, J. *Helv. Chim. Acta* **1994**, *78*, 145.
14. (a) Chan, W. H.; Lee, A. W. M.; Jiang, L. S.; Mak, T. C. W. *Tetrahedron: Asymmetry* **1997**, *8*, 2501; (b) Lin, J.; Chan, W. H.; Lee, A. W. M.; Wong, W. Y. *Tetrahedron* **1999**, *55*, 13983; (c) Jiang, L. S.; Chan, W. H.; Lee, A. W. M. *Tetrahedron* **1999**, *55*, 2245.
15. Zhang, H.; Chan, W. H.; Lee, A. W. M.; Xia, P.-F.; Wong, W. Y. *Lett. Org. Chem.* **2004**, *1*, 63.
16. Thom, C.; Kocieński, P. *Synthesis* **1992**, 582.
17. (a) Krotz, A.; Helmchen, G. *Tetrahedron: Asymmetry* **1990**, *1*(8), 537; (b) Akiyama, T.; Horiguchi, N.; Ida, T.; Ozaki, S. *Chem. Lett.* **1995**, 975; (c) Wrobleski, A.; Saharabudhe, K.; Aube, J. *J. Am. Chem. Soc.* **2002**, *124*, 9974.
18. Zhang, H.; Chan, W. H.; Lee, A. W. M.; Wong, W. Y. *Tetrahedron Lett.* **2003**, *44*, 395.