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Facile synthesis of alkylidene cyclopentenes via palladium catalyzed ring opening of fulvene derived bicyclic hydrazines

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ABSTRACT

A facile synthesis of substituted alkylidene cyclopentenes through a palladium catalyzed ring opening of fulvene derived bicyclic hydrazines with various organometallic reagents is described. The products are versatile synthons with multiple points for functionalization and can be used in the synthesis of a number of biologically active molecules.

1. Introduction

Since its discovery at the turn of the century, the theoretical, mechanistic, and synthetic importance of fulvenes has intrigued chemists and has been the subject of extensive investigation.[1] Among various fulvenes, pentafulvenes hold special attention as a valuable building block to access polycyclic cyclopentanoids through a diverse array of cyclizations.[2] They have found extensive use as key intermediates in the synthesis of natural products such as hirsutene,[3] capnellene,[4] β-vetivone,[5] hinesol,[6] silphinene,[7] etc. Pentafulvenes are mainly utilized in cycloaddition reactions in which they can participate as 2π, 4π, or 6π component depending on the competing partner.[7a,8] Investigations from our own laboratory have exploited the different reactivity modes of pentafulvenes in cycloaddition reactions.[9] Through a series of papers, Hong and co-workers have demonstrated that pentafulvenes can be effectively utilized in the synthesis of a number of molecular frameworks of biological interest.[10] They have applied the intramolecular Diels–Alder cycloadditions of fulvenes for the synthesis of kigelinol, neoamphilactane, and kempane skeletons.[11] More recently Barluenga and co-workers have reported some novel cycloaddition reactions of pentafulvenes with Fischer carbene complexes.[12] Fulvenes have also been utilized for the synthesis of titanocene anticancer drugs[13] and various aminocyclopentitols with glycosidase inhibitory activity.[14]

Although the addition of hetero dienophiles to fulvenes was reported as early as 1968,[15] to date, there is no detailed study on the synthetic utility of these adducts. Recently, Little and co-workers have shown that rudmollin, which displays in vivo acivity against P-388 lymphoid leukemia, can be synthesized from pentafulvene derived bicyclic hydrazine, through atom transfer cyclization.[16]

In the context of our general interest in the chemistry of pentafulvenes,[9] we have explored the synthetic utility of fulvene derived bicyclic hydrazines toward functionalized carbocycles. Recently, we have developed a general and efficient methodology for the stereoselective synthesis of *trans*-vicinal disubstituted hydrazino-cyclopentenes through a single step ring opening of bicyclic hydrazines with organostannanes and organoboronic acids.[17] Intrigued by these results, we have carried out an investigation on the palladium/Lewis acid mediated reactions of various pentafulvene derived bicyclic hydrazines with organostannanes. The preliminary results of our investigations have shown that the palladium catalyzed desymmetrization of these substrates is an efficient route toward the stereoselective synthesis of substituted alkylidene cyclopentenes in good to excellent yields.[18a] The results of our detailed studies on the desymmetrization of a number of pentafulvene derived bicyclic hydrazines with various organometallic reagents are described in this manuscript. In addition to this, the results obtained with the desymmetrization using azidostannane/silane are also discussed.

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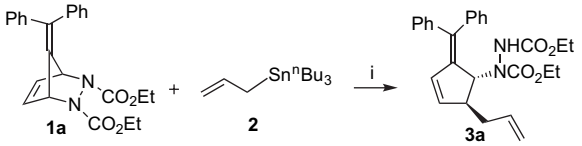
2. Results and discussion

2.1. Reactions with allylstannane

We initiated our experiments with the reaction of 2,3-carbethoxy-7,7-diphenylmethylene-2,3-diazabicyclo [2.2.1] hept-5-ene **1a** with allyltributyltin **2** in presence of $[Pd(allyl)Cl]_2$, dppe, and $Sc(OTf)_3$ in dry toluene. The reaction afforded the substituted alkylidene cyclopentene **3a** in 80% yield (Scheme 1).



Scheme 1. (i) $[Pd(allyl)Cl]_2$ (5 mol %), dppe (10 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h, 80%.

In search for a suitable catalytic system, detailed screening studies[18a] were carried out using different catalysts, ligands, and Lewis acids. After a series of experiments, we found that 5 mol % $Pd_2(dba)_3 \cdot CHCl_3$ along with 20 mol % PPh_3 and 2 mol % $Sc(OTf)_3$ with toluene (at 60 °C) as the solvent is the best condition for this transformation.

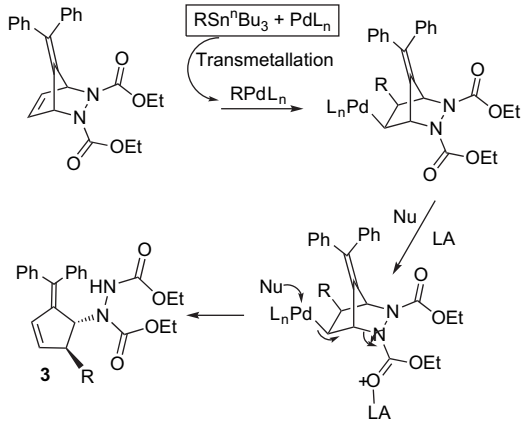
To explore the scope and generality of the method, the reaction of allyltributyltin **2** was repeated using different fulvene derived bicyclic hydrazines and the results are presented in Table 1. The structures of the products were assigned based on spectral analysis and by comparison with the literature data.[17–19]

Mechanism of the reaction was found to be similar to the one proposed for the ring opening of cyclopentadiene derived bicyclic hydrazines on reaction with organostannanes.[17a–c] The catalytic cycle involves transmetalation of organostannane with PdL_n forming $RPdL_n$. Next step is the co-ordination followed by the addition of this species into the C–C double bond. Elimination of L_n–Pd–Nu along with the Lewis acid assisted C–N bond cleavage gives the product **3** (Scheme 2).

Table 1
Reactions of pentafulvene derived bicyclic hydrazines with allyl stannane

Entry	Bicyclic hydrazine	Product	Yield (%)
1	**1a** R=Et	**3a**	88
2	**1b** R=^{i}Pr	**3b**	64
3	**1c** R=^{t}Bu	**3c**	43
4	**1d** R=Bn	**3d**	80
5	**1e** R=Et	**4a**	64
6	**1f** R=^{i}Pr	**4b**	74
7	**1g** R=Bn	**4c**	56
8	**1h** R=Et	**5a**	70
9	**1i** R=^{i}Pr	**5b**	88
10	**1j** R=Bn	**5c**	63

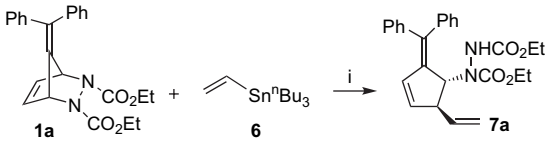
Reaction conditions: adduct (2 equiv), stannane (1 equiv), $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h.



Scheme 2. Proposed mechanism of the reaction.

2.2. Reactions with vinylstannane

Vinyltributyltin **6** under the optimized conditions showed similar reactivity with **1a** to afford the corresponding vinyl substituted alkylidene cyclopentene **7a** in 55% yield (Scheme 3).



Scheme 3. i) $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h, 55%.

The generality of this method was exemplified by the reaction of other pentafulvene derived bicyclic hydrazines with **6**, and the results are summarized in Table 2.

2.3. Reactions with heteroaryl stannanes

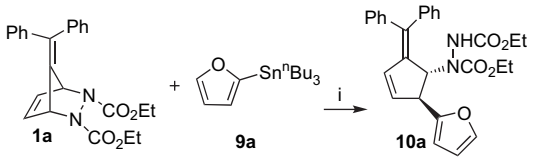
Encouraged by the above results, we examined the reactivity of heterocyclic stannanes in the palladium catalyzed ring opening reactions of these bicyclic substrates. A model reaction using 2-(tributylstannyl) furan **9a** and bicyclic hydrazine **1a** gave the product **10a**, in 35% yield (Scheme 4). This prompted us for detailed optimization studies and the details are given in Table 3.

After the optimization studies, the combination of 5 mol % $Pd(OAc)_2$, 10 mol % of PPh_3, and 2 mol % of $Sc(OTf)_3$ was found to be

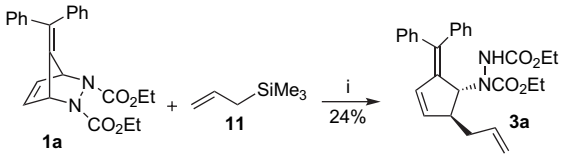
Table 2
Reaction of pentafulvene derived bicyclic hydrazines with vinyl stannane

Entry	Bicyclic hydrazine	Product	Yield (%)
1	**1a**	**7a** R=Et	55
2	**1b**	**7b** R=^{i}Pr	53
3	**1c**	**7c** R=^{t}Bu	51
4	**1d**	**7d** R=Bn	68
5	**1e**	**8a** R=Et	52
6	**1f**	**8b** R=^{i}Pr	64

Reaction conditions: adduct (2 equiv), stannane (1 equiv), PPh_3 (20 mol %), $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h.



Scheme 4. (i) $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h, 35%.



Scheme 5. (i) $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h.

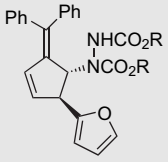
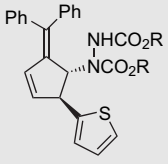
Table 3
Optimization studies using different catalysts/ligands

Entry	Catalyst	Ligand	Lewis acid	Yield (%)
1	$Pd_2(dba)_3 \cdot CHCl_3$	PPh_3	$Sc(Otf)_3$	35
2	$Pd_2(dba)_3 \cdot CHCl_3$	dppe	$Sc(Otf)_3$	33
3	$Pd_2(dba)_3 \cdot CHCl_3$	dppm	$Sc(Otf)_3$	26
4	$Pd_2(dba)_3 \cdot CHCl_3$	dppf	$Sc(Otf)_3$	24
5	$Pd(OAc)_2$	PPh_3	$Sc(Otf)_3$	38
6	$Pd(OAc)_2$	dppe	$Sc(Otf)_3$	29
7	$Pd(OAc)_2$	dppm	$Sc(Otf)_3$	27
8	$Pd(OAc)_2$	PPh_3	$Yb(Otf)_3$	26
9	$Pd(OAc)_2$	PPh_3	$Sn(Otf)_3$	37
10	$Pd(OAc)_2$	PPh_3	$CuOTf)_3$	23
11	$Pd(OAc)_2$	PPh_3	I_2	25

Reaction conditions: **1a** (2 equiv), **9a** (1 equiv), catalyst (5 mol %), ligand (10 mol %), Lewis acid (2 mol %), toluene, 60 °C, 10 h.

the best condition for this transformation. Under this condition, the reaction was repeated using 2-(tributylstannyl)thiophene **9b** and a number of bicyclic olefins. To our dismay, the reaction afforded the products in only 38–47% yields (Table 4). To the best of our knowledge, this is the first report on the single step synthesis of furyl and thienyl substituted alkylidene cyclopentenes.

Table 4
Reaction of pentafulvene derived bicyclic hdrazines with heteroaryl stannane

Entry	Bicyclic hydrazine	Stannane	Product		Yield (%)
1	**1a**	 **9a**		**10a** R=Et	38
2	**1b**			**10b** R=^{i}Pr	47
3	**1a**	 **9b**		**10c** R=Et	47
4	**1b**			**10d** R=^{i}Pr	38

Reaction conditions: **1a**,**b** (2 equiv), **9a**,**b** (1 equiv), $Pd(OAc)_2$(5 mol %), PPh_3 (10 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h.

2.4. Reactions with allylsilane

The next part of our investigations involved the transformations using allyltrimethylsilane, a well known candidate in palladium catalyzed cross-coupling reactions.[20] With the idea of replacing toxic stannane with silane, we have carried out the desymmetrization reactions using allyltrimethylsilane as the allylating agent. As expected, the reaction of bicyclic hydrazine **1a** with allyltrimethylsilane **11** in the presence of Pd/Lewis acid, afforded the product **3a** in 24% yield (Scheme 5).

The reaction was found to be general with other pentafulvene derived bicyclic hydrazines and the results are presented in Table 5.

Table 5
Reaction of pentafulvene derived bicycle hydrazines with allyl silanes

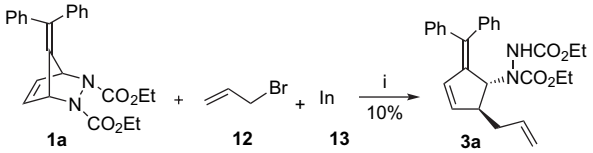
Entry	Bicyclic hydrazine	Product	Yield (%)
1	**1a**	**3a**	24
2	**1b**	**3b**	16
3	**1c**	**3c**	Trace
4	**1d**	**3d**	22
5	**1e**	**6a**	13
6	**1f**	**6b**	15
7	**1g**	**6c**	13
8	**1h**	**8a**	23
9	**1i**	**8b**	15
10	**1j**	**8c**	12

Reaction conditions: **1a**–**j** (2 equiv), allylsilane (1 equiv), PPh_3 (20 mol %), $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 10 h.

2.5. Reactions with allylindium reagent

Recently, organoindium mediated reactions have received significant attention in modern organic synthesis, due to the low heterophilicity, handling easiness, and non-toxicity of indium metal. Reactions of organoindium proceed with exceptional regio- and stereoselectivity.[21] It was reported that allylindium reagents can be effectively used for the regio- and stereoselective allylation of alkynes[22] and allenes.[23] However, the reactivity of these reagents toward carbon–carbon double bonds has received only scant attention.[24] In this context, we have previously reported[25] a novel reactivity of organoindium reagents with azabicyclic olefins under palladium catalysis. Intrigued by this observation, we have carried out the palladium catalyzed ring opening of **1a** with easily available and non-toxic allylindium reagent, and the results are presented below.

The reaction of azabicyclic olefin **3a** with allylindium (generated in situ from the reaction of allyl bromide **12** and indium **13**) in THF in presence of $[Pd(allyl)Cl]_2$/dppe/$Yb(OTf)_3$ catalyst system afforded expected alkylidene cyclopentene **3a** in 10% yield (Scheme 6).



Scheme 6. (i) $[Pd(allyl)Cl]_2$ (5 mol %), dppe (10 mol %), $Yb(OTf)_3$ (2 mol %), THF, 60 °C, 12 h.

After detailed screening experiments, the best condition for the reaction was found to be 1 equiv of bicyclic alkene, 3 equiv of allylbromide, 2 equiv of indium, 5 mol % $Pd_2(dba)_3 \cdot CHCl_3$ along with 20 mol % PPh_3 and 2 mol % $Yb(OTf)_3$ in THF as solvent. The generality of this method was exemplified by the reactions with other pentafulvene derived bicyclic hydrazines, and these results are summarized in Table 6.

Thus we have synthesized substituted alkylidene cyclopentenes from fulvene derived bicyclic hydrazines using various organometallic reagents like organostannanes, silanes, and indium reagents,

Table 6
Reaction of pentafulvene derived bicyclic hydrazine with allylindium reagent

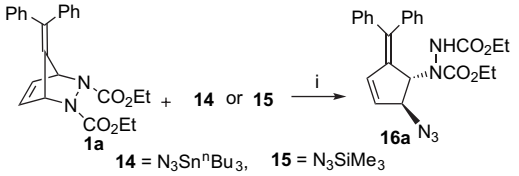
Entry	Bicyclic hydrazine	Product	Yield (%)
1	**1a**	**3a**	40
2	**1b**	**3b**	35
3	**1c**	**3c**	Trace
4	**1d**	**3d**	35
5	**1e**	**6a**	38
6	**1f**	**6b**	45
7	**1g**	**6c**	Trace
8	**1h**	**8a**	Trace
9	**1i**	**8b**	42
10	**1j**	**8c**	50

Reaction conditions: **1a–j** (2 equiv), allylbromide (3 equiv), In (2 equiv), PPh_3 (20 mol %), $Pd_2(dba)_3{\cdot}CHCl_3$ (5 mol %), $Yb(OTf)_3$ (2 mol %), THF, 60 °C, 12 h.

among which stannanes gave better yields. This can be attributed to the difference in the efficiency of transmetallation in various organometallic reagents. Organostannanes are known to undergo an easy transmetallation with palladium compared to the organoindium and silicon reagents.

2.6. Reactions using azidostannane/silane

In the next phase of our work, encouraged by the possibility of converting azido and hydrazino groups into amines, we decided to explore the scope of this reaction using organic azides. So far we were using carbon nucleophiles in the desymmetrization of bicyclic hydrazines. Heteroatom nucleophiles like azide, which can be generated from azidostannanes also seemed to be good nucleophiles for the palladium/Lewis acid mediated synthetic transformations of bicyclic hydrazines. Therefore, in view of our previous report on the desymmetrization of pentafulvene derived bicyclic hydrazines,[13] we have carried out the reactions with $Pd_2(dba)_3{\cdot}CHCl_3/PPh_3/Sc(OTf)_3$ catalyst system in dry toluene as the solvent. Under this condition, the reaction of bicyclic hydrazine **1a** with azidostannane **14** afforded 3-azido-4-hydrazino alkylidene cyclopentene **16a** in 93% yield. Similar reactivity was observed with trimethylsilylazide **15** leading to the product **16a** in 72% yield (Scheme 7).



Scheme 7. (i) $Pd_2(dba)_3{\cdot}CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 12 h, **14** gave 93% and **15** gave 72% yield.

The generality of this method was exemplified by the reaction of **14** and **15** with a number of pentafulvene derived bicyclic olefins and the results are summarized in Table 7. The reactions using the azidosilane were found to be more clean and neat when compared to azidostannane. Moreover we could replace the toxic stannanes with less toxic silanes.

2.7. Reactions with cyclopentadiene derived bicyclic hydrazine using azidotributyltin

Due to our sustained interest in the chemistry of bicyclic hydrazines and in connection with the above studies, we have also examined the desymmetrization reactions of cyclopentadiene derived bicyclic hydrazines with azidostannanes leading to the facile

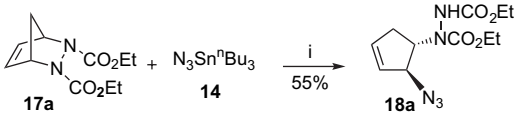
Table 7
Palladium catalyzed ring opening of fulvene derived azabicyclic olefins using azidostannane/silane

Entry	Bicyclic hydrazine	Product	Yield (%)	
			Stannane	Silane
1	**1a** R=Et	**16a**	93	72
2	**1b** R=^{i}Pr	**16b**	70	75
3	**1c** R=^{t}Bu	**16c**	83	46
4	**1d** R=Bn	**16d**	67	81
5	**1e** R=Et	**16e**	54	43
6	**1f** R=^{i}Pr	**16f**	61	58
7	**1g** R=Bn	**16g**	60	55
8	**1h** R=Et	**16h**	70	64
9	**1j** R=^{i}Pr	**16l**	84	77

Reaction conditions: adduct (2 equiv), azidostannane/silane (1 equiv), $Pd_2(dba)_3{\cdot}CHCl_3$ (5 mol %), PPh_3 (20 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 12 h.

synthesis of *trans*-3-azido-4-hydrazinocyclopentenes. These results are described in the following section.

Our investigations begin with the reaction of bicyclic hydrazine **17a** with azidotributyltin **14** in presence of $[Pd(allyl)Cl]_2$, dppe, and $Sc(OTf)_3$ in dry toluene. The reaction afforded *trans*-3-azido-4-hydrazinocyclopentene **18a** in 55% yield (Scheme 8). The structure of the product was assigned based on spectroscopic data and it was further confirmed by HOMO-COSY analysis and by comparison with the literature data.[17]



Scheme 8. (i) $[Pd(allyl)Cl]_2$ (5 mol %), dppe (10 mol %), $Sc(OTf)_3$ (2 mol %), toluene, 60 °C, 12 h.

After optimization studies, the yield was increased to 70% in presence of 5 mol % $[Pd(allyl)Cl]_2$ as the catalyst, 10 mol % dppf as ligand, and 2 mol % $Sc(OTf)_3$ as Lewis acid. Under this condition, the reaction was repeated with a number of bicyclic hydrazines and the corresponding 3-azido-4-hydrazino cyclopentenes (**18a–d**) were obtained in good yields. The results are shown in the Table 8.

The products of the above mentioned reactions, azido substituted hydrazinocyclopentenes/alkylidene cyclopentenes are susceptible to further synthetic transformations. These compounds

Table 8
Reaction of cyclopentadiene derived bicyclic hydrazines with azidostannane

Entry	Bicyclic hydrazine	Product	Yield (%)
1	**17a** R=Et	**18a**	70
2	**17b** R=^{i}Pr	**18b**	79
3	**17c** R=^{t}Bu	**18c**	77
4	**17d** R=Bn	**18d**	50

Reaction conditions: adduct (2 equiv), azidostannane (1 equiv), $[Pd(allyl)Cl]_2$ (5 mol %), dppf (10 mol %), $Sc(Otf)_3$ (2 mol %), toluene, 60 °C, 12 h.

can be easily converted to synthetically and biologically useful *trans*-cyclopentane-1,2-diamine derivatives.[26] The scarcity of efficient routes as well as the complexity of the existing methodologies[27] for the synthesis of these compounds makes our strategy more appealing.

3. Conclusions

In summary, we have unraveled a facile method for the functionalization of pentafulvenes via Pd/Lewis acid mediated ring opening of fulvene derived azabicyclic olefins with organostannanes, allylsilanes, allylindium, and azido stannane/silane reagent. Among the various organometallic reagents studied, organostannanes were more reactive than the corresponding silanes and indium reagents. The described methodology offers a conceptually new approach toward the synthesis of allyl, vinyl, heteroaryl, and hetero atom substituted alkylidene cyclopentenes. It is noteworthy that alkylidene cyclopentanes are key intermediates in the synthesis of a number of biologically active molecules[6a,28] and the efforts in this direction are currently underway.

4. Experimental

4.1. General

All reactions were carried out in oven dried Wheaton vial under nitrogen atmosphere. Progress of the reaction was monitored by thin layer chromatography, which was performed on Merck precoated plates (silica gel 60 F_{254}, 0.25 mm) and was visualized by fluorescence quenching under UV light or by staining with Enholm yellow solution. Column chromatography was done using 60–120 mesh silica gel and appropriate mixture of petroleum ether (60–80 °C) and ethyl acetate for elution. The solvents were removed using Buchi rotary evaporator. The IR spectra were recorded on Nicolet FT-IR spectrometer. NMR spectra were recorded on Bruker FT-NMR spectrometer using $CDCl_3$ or $CDCl_3/CCl_4$ mixture (7:3) as solvent. TMS was used as internal standard and chemical shifts are in δ-scale. High resolution mass spectra were recorded under EI/HRMS (at 5000 resolution) using JEOL JMS 600H mass spectrometer. Abbreviations used in ^{1}H NMR are s-singlet, br s-broad singlet, d-doublet, dd-doublet of doublet, q-quartet, and m-multiplet.

4.2. General experimental procedure for 3a–d, 4a–c, 5a–c, 7a–d, and 8a,b

Bicyclic hydrazine (2 equiv) and stannane/silane (1 equiv) were taken in a Wheaton vial, and dissolved in dry toluene (4 mL). PPh_3 (20 mol %) and $Pd_2(dba)_3\cdot CHCl_3$ (5 mol %) were added to the reaction mixture followed by addition of $Sc(OTf)_3$ (2 mol %). The reaction mixture was stirred at 60 °C for 10 h. Completion of the reaction was monitored by TLC and the reaction mixture on silica gel (60–120 mesh) column chromatography using 20% ethyl acetate in hexane afforded the product in good yield.

4.3. Typical experimental procedure for ring opening with allylindium reagent

Bicyclic hydrazine (1 equiv), PPh_3 (20 mol %), $Pd_2(dba)_3\cdot CHCl_3$ (5 mol %), and $Yb(OTf)_3$ (5 mg, 2 mol %) were charged in a Schlenk tube. The allylindium reagent was generated by stirring allyl bromide (3 equiv) and indium powder (2 equiv) in THF under argon atmosphere for 10 min and was carefully transferred to the Schlenk tube. The reaction mixture was again degassed with argon and allowed to stir at 60 °C for 12 h. Extent of the reaction was monitored by TLC and on completion, the reaction mixture was evaporated and subjected to column chromatography (silica gel 60–120 mesh, 20% EtOAc/hexane) to afford the product in moderate yield.

4.3.1. Data for **3a**

White solid; mp 135–137 °C; R_f 0.60 (25% EtOAc/hexane); IR (neat) ν_{max}: 3302, 3057, 2978, 1742, 1713, 1489, 1412, 1300, 1220, 1124, 751, 696 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30–7.14 (m, 10H), 6.34–6.31 (m, 1H), 6.06 (d, J=3.9 Hz, 1H), 5.84–5.78 (m, 1H), 5.56–5.46 (m, 1H), 5.17–5.06 (m, 2H), 4.15–4.11 (m, 2H), 3.89–3.88 (m, 2H), 3.31–3.18 (m, 1H), 2.58–2.43 (m, 1H), 2.30–2.20 (m, 1H), 1.24 (t, J=6.9 Hz, 3H), 1.03 (t, J=6.6 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.3, 153.5, 140.7, 138.2, 136.5, 135.9, 132.2, 130.0, 129.7, 128.6, 128.0, 127.1, 116.9, 62.1, 61.9, 61.3, 49.4, 37.5, 14.9, 14.5; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{27}H_{30}N_2O_4$: 469.2206, found: 469.97. Anal. Calcd for $C_{27}H_{30}N_2O_4$: C, 72.62; H, 6.77; N, 6.27. Found: C, 72.49; H, 6.82, N, 6.23.

4.3.2. Data for **3b**

White solid; mp 126–128 °C; R_f 0.39 (25% EtOAc/hexane); IR (neat) ν_{max}: 3308, 2982, 2936, 1728, 1715, 1588, 1469, 1375, 1229, 1181, 1145, 1109, 1034, 921, 760, 702 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30–7.19 (m, 10H), 6.32–6.29 (m, 1H), 6.05 (s, 1H), 5.85–5.75 (m, 1H), 5.55–5.44 (m, 2H), 5.17–5.08 (m, 2H), 4.87–4.78 (m, 1H), 4.65–4.59 (m, 1H), 3.28–3.15 (m, 1H), 2.52–2.50 (m, 1H), 2.23–2.15 (m, 1H), 1.25–1.20 (m, 6H), 1.07–0.88 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.7, 155.9, 139.4, 133.0, 132.5, 132.1, 130.5, 130.3, 129.7, 129.3, 128.9, 128.4, 128.1, 127.9, 124.8, 118.6, 70.3, 69.8, 61.6, 53.2, 41.8, 22.3, 22.0, 21.5, 21.0; MS (LR-FAB): $(M+1)^+$ calculated for $C_{29}H_{34}N_2O_4$: 475.2519, found: 475.04.

4.3.3. Data for **3c**

Light yellow solid; mp 104–105 °C; R_f 0.53 (25% EtOAc/hexane); IR (neat) ν_{max}: 3330, 2923, 1742, 1725, 1392, 1366, 1257, 1158, 1021, 913, 752 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40–7.14 (m, 10H), 6.38–6.29 (m, 1H), 6.08–6.05 (m, 1H), 5.92–5.70 (m, 1H), 5.53–5.25 (m, 2H), 5.10–5.04 (m, 2H), 3.39–3.27 (m, 1H), 2.57–2.49 (m, 1H), 2.27–2.17 (m, 1H), 1.56–1.22 (m, 18H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.7, 155.3, 142.9, 140.9, 139.5, 136.4, 136.2, 133.3, 132.5, 130.7, 130.2, 129.1, 128.8, 128.7, 127.5, 116.9, 80.9, 80.6, 64.1, 49.4, 37.6, 31.1, 29.9, 28.4, 27.7; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{31}H_{38}N_2O_4$: 525.2832, found: 525.19.

4.3.4. Data for **3d**

White solid; mp 139–142 °C; R_f 0.31 (25% EtOAc/hexane); IR (neat) ν_{max}:3298, 2974, 1742, 1694, 1504, 1423, 1308, 1219, 1139, 756, 698 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.35–7.13 (m, 20H), 6.31 (d, J=4.5 Hz, 1H), 6.08–6.05 (m, 1H), 5.96–5.70 (m, 2H), 5.58–5.50 (m, 1H), 5.18–4.68 (m, 6H), 3.35 (s, 1H), 2.55–2.40 (m, 1H), 2.35–2.23 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.4, 154.8, 140.5, 139.2, 136.0, 135.6, 133.8, 130.0, 129.8, 128.8, 128.7, 128.6, 128.3, 128.1, 127.9, 127.8, 116.0, 68.3, 68.0, 67.4, 53.2, 40.6; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{37}H_{34}N_2O_4$: 593.2519, found: 593.30. Anal. Calcd for $C_{37}H_{34}N_2O_4$: C, 77.87; H, 6.01; N, 4.91. Found: C, 77.70; H, 6.07, N, 4.88.

4.3.5. Data for **4a**

Yellow viscous liquid; R_f 0.41 (25% EtOAc/hexane); IR (neat) ν_{max}: 3295, 2928, 2854, 1751, 1714, 1517, 1416, 1384, 1228, 1124, 1063, 913, 758 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.33 (d, J=5.7 Hz, 1H), 6.11 (s, 1H), 5.88–5.75 (m, 2H), 5.10–4.85 (m, 3H), 4.25–4.10 (m, 4H), 3.16–2.95 (m, 1H), 2.36–2.20 (m, 3H), 2.15–2.11 (m, 3H), 1.83–1.40 (m, 6H), 1.31–1.22 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.0, 155.5, 137.1, 136.4, 133.7, 129.8, 127.3, 116.5, 62.5, 62.0, 61.7, 50.0, 39.1, 32.1, 31.3, 28.3, 27.1, 26.8, 14.9, 14.7; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{20}H_{30}N_2O_4$: 385.2206, found: 385.12.

4.3.6. Data for ***4b***

Yellow viscous liquid; R_f 0.38 (25% EtOAc/hexane); IR (neat) ν_{max}: 3292, 2980, 2928, 2854, 1752, 1705, 1468, 1385, 1297, 1232, 1180, 1109, 1036, 912, 758 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.32 (d, J=5.7 Hz, 1H), 5.98 (br s, 1H), 5.86–5.74 (m, 2H), 5.10–4.75 (m, 5H), 3.09–3.05 (m, 1H), 2.35–2.25 (m, 3H), 2.16–2.11 (m, 3H), 1.85–1.40 (m, 6H), 1.33–1.19 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.1, 154.9, 136.9, 135.9, 134.0, 130.1, 129.7, 116.5, 69.9, 69.5, 61.9, 49.9, 39.1, 32.1, 31.3, 29.9, 28.5, 26.8, 22.9, 22.4, 22.2; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{22}H_{34}N_2O_4$: 413.2519, found:413.37.

4.3.7. Data for ***4c***

Yellow solid; mp 82–84 °C; R_f 0.41 (25% EtOAc/hexane); IR (neat) ν_{max}: 3296, 2926, 1750, 1710, 1413, 1377, 1311, 1229, 1059, 916, 752, 696 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.35–7.20 (m, 10H), 6.29–6.21 (m, 2H), 5.84–5.58 (m, 2H), 5.20–5.02 (m, 8H), 2.89–2.76 (m, 1H), 2.61–2.56 (m, 1H), 2.25–1.86 (m, 4H), 1.62–1.25 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.9, 154.4, 143.3, 142.6, 135.9, 134.8, 132.3, 130.1, 128.5, 128.3, 128.2, 120.9, 116.4, 68.0, 67.5, 62.1, 51.0, 38.9, 35.8, 31.8, 30.4, 29.8, 28.2, 26.5; MS (LR-FAB): m/z calculated for $C_{30}H_{34}N_2O_4$: 486.2519, found: 486.43. Anal. Calcd for $C_{30}H_{34}N_2O_4$: C, 74.05; H, 7.04; N, 5.76. Found: C, 73.98; H, 7.09, N, 5.71.

4.3.8. Data for ***5a***

Brownish yellow viscous liquid, R_f 0.33 (25% EtOAc/hexane); IR (neat) ν_{max}: 3294, 2908, 2849, 1755, 1705, 1412, 1302, 1214, 1119, 1062, 910, 757 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.32 (d, J=5.8 Hz, 1H), 6.09–6.04 (br s, 1H), 5.92–5.72 (m, 2H), 5.10–4.99 (m, 3H), 4.19–4.12 (m, 4H), 3.17–3.09 (m, 1H), 2.91 (s, 1H), 2.74–2.59 (m, 1H), 2.35–2.09 (m, 2H), 1.96–1.56 (m, 12H), 1.25 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.2, 155.1, 143.7, 136.1, 135.8, 129.6, 129.1, 116.3, 62.2, 61.8, 61.6, 49.4, 39.9, 39.5, 39.0, 38.8, 37.0, 34.9, 34.7, 28.1, 14.7, 14.5; HRMS (EI): m/z calculated for $C_{24}H_{34}N_2O_4$: 414.2519, found: 414.2520.

4.3.9. Data for ***5b***

Light yellow viscous liquid; R_f 0.46 (25% EtOAc/hexane); IR (neat) ν_{max}: 3290, 3073, 2849, 1750, 1714, 1468, 1404, 1295, 1231, 1110, 1036, 912, 758, 735, 647 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.34–6.32 (d, J=6.0 Hz, 1H), 6.04 (br s, 1H), 5.88–5.77 (m, 2H), 5.11–4.95 (m, 5H), 3.14–3.09 (m, 1H), 2.89 (s, 1H), 2.72–2.60 (m, 1H), 2.48–2.14 (m, 2H), 1.96–1.77 (m, 12H), 1.35–1.22 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.2, 154.6, 143.9, 136.2, 130.1, 129.4, 129.0, 116.1, 69.7, 69.4, 61.9, 49.2, 39.5, 38.9, 38.7, 36.9, 34.9, 34.1, 28.0, 27.9, 26.8, 22.1, 21.9; HRMS (EI): m/z calculated for $C_{26}H_{38}N_2O_4$: 442.2832, found: 442.2851.

4.3.10. Data for ***5c***

Light yellow viscous liquid; R_f 0.56 (25% EtOAc/hexane); IR (neat) ν_{max}: 3291, 2908, 2848, 1755, 1713, 1449, 1407, 1297, 1214, 1123, 1046, 912, 753, 696 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.33–7.20 (m, 10H), 6.28–6.20 (m, 2H), 6.01 (br s, 1H), 5.83–5.69 (m, 3H), 5.12–4.85 (m, 6H), 3.11 (s, 1H), 2.86 (s, 1H), 2.56–2.40 (m, 1H), 2.20–2.16 (m, 1H), 1.96–1.60 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.4, 155.8, 141.2, 140.1, 139.4, 138.5, 136.4, 135.9, 130.2, 128.5, 128.3, 128.2, 126.8, 124.5, 116.4, 69.5, 67.6, 61.8, 49.8, 39.7, 39.4, 39.1, 36.9, 34.9, 34.3, 28.0; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{34}H_{38}N_2O_4$: 561.2832, found: 561.03.

4.3.11. Data for ***7a***

Brownish yellow solid; mp 85–87 °C; R_f 0.55 (25% EtOAc/hexane); IR (neat) ν_{max}: 3302, 3065, 2980, 1744, 1716, 1594, 1489, 1443, 1413, 1382, 1303, 1267, 1219, 1171, 1026, 918, 756, 701 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.41–7.29 (m, 10H), 6.37–6.35 (m, 1H), 6.03–6.01 (m, 2H), 5.54–5.51 (m, 2H), 5.19–5.06 (m, 2H), 4.15–4.13 (m, 2H), 3.89–3.87 (m, 2H), 3.86–3.85 (m, 1H), 1.25 (t, J=6.9 Hz, 3H), 1.03 (t, J=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.9, 155.0, 142.5, 141.6, 139.4, 138.9, 135.1, 134.3, 133.2, 130.1, 128.7, 127.3, 126.6, 123.1, 115.6, 67.1, 62.7, 62.1, 53.7, 14.6, 13.9; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{26}H_{28}N_2O_4$: 455.2049, found: 455.45. Anal. Calcd for $C_{26}H_{28}N_2O_4$: C, 72.20; H, 6.53; N, 6.48. Found: C, 72.04; H, 6.57, N, 6.45.

4.3.12. Data for ***7b***

Brownish yellow viscous liquid; R_f 0.40 (25% EtOAc/hexane); IR (neat) ν_{max}: 3368, 2980, 2932, 1750, 1716, 1469, 1386, 1301, 1269, 1181, 1109, 1032, 917, 757, 701 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.30–7.15 (m, 10H), 6.37–6.35 (m, 1H), 6.05–5.98 (m, 2H), 5.63–5.35 (m, 2H), 5.23–5.07 (m, 2H), 4.91–4.86 (m, 1H), 4.64–4.55 (m, 1H), 3.91–3.81 (m, 1H), 1.28–1.22 (m, 8H), 1.20–0.95 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.7, 155.3, 140.3, 139.2, 138.6, 135.4, 134.6, 133.0, 130.5, 129.1, 128.0, 127.3, 126.6, 123.2, 115.0, 69.8, 69.5, 61.6, 53.2, 22.8, 22.3, 21.7; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{28}H_{32}N_2O_4$: 483.2362, found: 483.54.

4.3.13. Data for ***7c***

Yellow solid; mp 106–108 °C; R_f 0.44 (25% EtOAc/hexane); IR (neat) ν_{max}: 3368, 3058, 2927, 1745, 1713, 1622, 1452, 1392, 1336, 1246, 1158, 1018, 917, 767, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.42–7.20 (m, 10H), 6.40–6.31 (m, 1H), 6.18–5.99 (m, 2H), 5.59–5.38 (m, 2H), 5.21–5.05 (m, 2H), 3.95–3.86 (m, 1H), 1.46–1.25 (m, 18H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.5, 155.2, 139.8, 139.1, 138.2, 134.8, 133.1, 130.5, 129.9, 129.6, 129.5, 128.9, 128.5, 128.3, 127.6, 127.0, 126.9, 125.4, 114.8, 80.7, 80.5, 65.4, 53.0, 30.1, 29.7, 29.5, 28.1; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{30}H_{36}N_2O_4$: 511.2675, found: 511.10. Anal. Calcd for $C_{30}H_{36}N_2O_4$: C, 73.74; H, 7.43; N, 5.73. Found: C, 73.81; H, 7.42, N, 5.70.

4.3.14. Data for ***7d***

Off white solid; mp 158–159 °C; R_f 0.34 (25% EtOAc/hexane); IR (neat) ν_{max}: 3310, 3065, 2927, 1739, 1697, 1596, 1504, 1419, 1314, 1218, 1134, 1046, 916, 755, 699 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.39–7.13 (m, 20H), 6.34 (s, 1H), 6.05–5.81 (m, 2H), 5.70–5.52 (m, 1H), 5.26–4.73 (m, 7H), 3.91 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 157.2, 154.1, 140.5, 139.6, 136.0, 135.6, 135.2, 133.8, 130.0, 129.8, 128.8, 128.7, 128.6, 128.3, 128.1, 127.9, 127.8, 127.6, 127.4, 124.2, 115.7, 68.4, 67.6, 67.4, 53.2; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{36}H_{32}N_2O_4$: 579.2362, found: 579.25.

4.3.15. Data for ***8a***

Yellow viscous liquid; R_f 0.37 (25% EtOAc/hexane); IR (neat) ν_{max}: 3296, 2926, 1750, 1710, 1413, 1377, 1311, 1229, 1059, 916, 752 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.39 (d, J=5.7 Hz, 1H), 6.20–6.09 (m, 1H), 5.88–5.82 (m, 2H), 5.08–4.98 (m, 3H), 4.23–4.19 (m, 4H), 3.67–3.64 (m, 1H), 2.35–2.10 (m, 4H), 1.80–1.40 (m, 6H), 1.31–1.25 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.1, 155.7, 139.3, 136.3, 129.2, 124.3, 124.1, 114.6, 62.4, 62.0, 61.8, 50.5, 31.5, 30.3, 29.4, 28.2, 26.6, 14.7, 14.2; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{19}H_{28}N_2O_4$: 371.2049, found: 371.13.

4.3.16. Data for ***8b***

Yellow viscous liquid; R_f 0.44 (25% EtOAc/hexane); IR (neat) ν_{max}: 3296, 2926, 1750, 1710, 1413, 1377, 1311, 1229, 1059, 916, 752 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.39 (d, J=5.6 Hz, 1H), 6.01 (br s, 1H), 5.84–5.80 (m, 3H), 5.07–4.98 (m, 4H), 3.64–3.50 (m, 1H), 2.30–2.08 (m, 4H), 1.79–1.40 (m, 6H), 1.38–1.19 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.4, 155.8, 139.4, 136.4, 128.8, 124.3, 124.1, 114.1, 70.1, 69.8, 62.1, 53.2, 31.9, 30.3, 29.4, 28.2, 26.6, 22.9, 22.4, 22.2; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{21}H_{32}N_2O_4$: 399.2362, found: 399.14.

4.4. General experimental procedure for 10a–d

Bicyclic hydrazine (2 equiv) and heterocyclic stannane (1 equiv) were taken in a Wheaton vial, and dissolved in dry toluene (4 mL). PPh_3 (10 mol %) and $Pd(OAc)_2$ (5 mol %) were added to the reaction mixture followed by addition of $Sc(OTf)_3$ (2 mol %). The reaction mixture was stirred at 60 °C for 10 h. Completion of the reaction was monitored by TLC and the reaction mixture on silica gel (60–120 mesh) column chromatography using 20% ethyl acetate in hexane afforded the product in moderate to low yield.

4.4.1. Data for **10a**

Light brown viscous liquid; R_f 0.36 (25% EtOAc/hexane); IR (neat) ν_{max}: 3374, 2924, 2852, 1753, 1722, 1487, 1409, 1380, 1218, 1124, 1060, 971, 754, 702 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.35–7.16 (m, 12H), 6.49–6.46 (m, 1H), 6.29 (s, 1H), 6.26–6.11 (m, 2H), 5.68–5.50 (m, 1H), 4.51 (m, 1H), 4.17–4.13 (m, 2H), 3.96–3.78 (m, 2H), 1.28–1.24 (m, 3H), 1.09–0.98 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.7, 154.1, 141.8, 141.7, 137.2, 136.7, 136.5, 135.7, 135.6, 133.7, 133.1, 129.8, 129.6, 128.7, 128.5, 128.2, 128.1, 127.7, 110.3, 63.2, 62.2, 55.3, 49.2, 14.3, 14.2; HRMS (EI): *m/z* calculated for $C_{28}H_{28}N_2O_5$: 472.1998, found: 472.1986.

4.4.2. Data for **10b**

Light brown viscous liquid; R_f 0.47 (25% EtOAc/hexane); IR (neat) ν_{max}: 3368, 2981, 2934, 1750, 1715, 1597, 1443, 1385, 1298, 1227, 1178, 1108, 1031, 957, 756, 701, 598 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.35–7.19 (m, 12H), 6.46–6.44 (m, 1H), 6.30–6.21 (m, 2H), 6.13–6.00 (m, 1H), 5.77–5.53 (m, 2H), 4.89 (m, 1H), 4.61–4.56 (m, 1H), 1.24–0.86 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.1, 155.3, 141.5, 140.8, 137.2, 136.9, 136.5, 135.2, 132.9, 132.1, 130.2, 129.9, 128.2, 127.9, 127.7, 127.5, 127.3, 127.1, 126.8, 110.2, 105.3, 70.1, 69.8, 64.4, 49.5, 22.6, 21.9; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{30}H_{32}N_2O_5$: 523.2311, found: 523.35.

4.4.3. Data for **10c**

Light brown viscous liquid; R_f 0.24 (25% EtOAc/hexane); IR (neat) ν_{max}: 3363, 3291, 2924, 2851, 1722, 1596, 1484, 1407, 1381, 1300, 1223, 1119, 1059, 1028, 756, 701 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.38–7.18 (m, 12H), 6.96 (m, 1H), 6.50 (s, 1H), 6.17–6.11 (m, 1H), 5.89–5.40 (m, 2H), 5.03–4.90 (m, 1H), 4.30–4.12 (m, 2H), 3.86–3.75 (m, 2H), 1.42–1.25 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.2, 154.4, 141.3, 140.7, 139.5, 137.6, 137.2, 134.3, 129.8, 129.7, 128.7, 128.2, 127.6, 126.7, 123.8, 113.8, 70.6, 62.5, 62.0, 49.0, 14.3, 14.0; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{28}H_{28}N_2O_4S$: 511.1770, found: 511.06.

4.4.4. Data for **10d**

Light brown viscous liquid; R_f 0.33 (25% EtOAc/hexane); IR (neat) ν_{max}: 3368, 2978, 1748, 1716, 1682, 1597, 1468, 1386, 1314, 1234, 1105, 1028, 754, 702 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.31–7.09 (m, 12H), 6.95 (m, 1H), 6.50–6.48 (m, 1H), 6.27–6.14 (m, 1H), 5.60–5.47 (m, 2H), 5.11–4.92 (m, 1H), 4.67–4.57 (m, 1H), 1.28–1.21 (m, 6H), 1.06–0.91 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.1, 154.0, 141.6, 140.8, 136.2, 135.7, 133.6, 133.0, 129.8, 129.6, 128.9, 128.7, 128.5, 128.4, 128.2, 128.0, 127.6, 127.5, 127.4, 127.0, 70.9, 70.2, 66.3, 48.6, 21.8, 21.7; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{30}H_{32}N_2O_4S$: 539.2083, found: 538.99.

4.5. General experimental procedure for 16a–i

Bicyclic hydrazine (2 equiv), tributyltinazide/trimethylsilylazide (1 equiv), PPh_3 (20 mol %), $Pd_2(dba)_3 \cdot CHCl_3$ (5 mol %), and $Sc(OTf)_3$ (2 mol %) were taken in a Wheaton reactor. The mixture was dissolved in dry toluene (4 mL) and stirred at 60 °C for 12 h. After the completion of the reaction, the mixture on silica gel (60–120 mesh) column chromatography using 15% ethyl acetate in hexane afforded the products in good to excellent yield.

4.5.1. Data for **16a**

White solid; mp 119–121 °C; R_f 0.45 (25% EtOAc/hexane); IR (neat) ν_{max}: 3312, 2981, 2102, 1740, 1698, 1598, 1492, 1418, 1384, 1305, 1222, 1134, 1061, 954, 756, 703 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.33–7.12(m, 10H), 6.52 (dd, J_1=5.6 Hz, J_2=12.4 Hz, 1H), 5.99 (s, 1H), 5.67–5.45 (m, 2H), 5.08–4.93 (m, 1H), 4.19–4.09 (m, 2H), 4.03–3.92 (m, 2H), 1.32–1.23 (m, 4H), 1.06 (t, J=6.9 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.2, 154.4, 141.5, 140.7, 138.2, 136.5, 135.8, 135.6, 133.7, 129.8, 129.7, 128.6, 128.4, 128.3, 128.1, 127.6, 70.2, 67.8, 62.7, 62.2, 14.4; HRMS (EI): *m/z* calculated for $C_{24}H_{25}N_5O_4$: 447.1907, found: 447.1917. Anal. Calcd for $C_{24}H_{25}N_5O_4$: C, 64.42; H, 5.63; N, 15.65. Found: C, 64.47; H, 5.65, N, 15.60.

4.5.2. Data for **16b**

Light yellow solid; mp 91–93 °C; R_f 0.55 (25% EtOAc/hexane); IR (neat) ν_{max}: 3362, 2981, 2100, 1720, 1593, 1467, 1385, 1302, 1228, 1108, 1031, 961, 757, 702 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.31–7.13 (m, 10H), 6.51(d, J=5.4 Hz, 1H), 5.98–5.83 (m, 1H), 5.61–5.44 (m, 2H), 5.10–4.67 (m, 3H), 1.28–1.22 (m, 8H), 1.09–0.95 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.1, 154.0, 141.6, 140.8, 136.2, 135.7, 133.6, 132.9, 129.8, 129.7, 128.9, 128.7, 128.5, 128.2, 128.1, 127.6, 70.9, 70.2, 67.9, 66.3, 22.6, 22.1, 21.9; HRMS (EI): *m/z* calculated for $C_{26}H_{29}N_5O_4$: 475.2220, found: 475.2252.

4.5.3. Data for **16c**

White solid; mp 97–99 °C; R_f 0.65 (25% EtOAc/hexane); IR (neat) ν_{max}: 3375, 2978, 2931, 2100, 1716, 1599, 1477, 1368, 1307, 1252, 1155, 1026, 955, 854, 756, 702, 536 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.46–7.14 (m, 10H), 6.58–6.49 (m, 1H), 5.98 (d, J=3.6 Hz, 1H), 5.38–5.30 (m, 2H), 5.10–4.97 (m, 1H), 1.48–1.22 (m, 18H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.3, 153.4, 141.7, 141.0, 136.6, 135.7, 133.7, 132.8, 129.8, 129.6, 128.7, 128.5, 128.4, 128.1, 128.0, 127.6, 127.5, 82.3, 81.2, 70.2, 65.5, 28.2, 28.1, 28.0; MS (LR-FAB): *m/z* calculated for $C_{28}H_{33}N_5O_4$: 503.2533, found: 503.31. Anal. Calcd for $C_{28}H_{33}N_5O_4$: C, 66.78; H, 6.60; N, 13.91. Found: C, 66.89; H, 6.59, N, 13.87.

4.5.4. Data for **16d**

White solid; mp 161–163 °C; R_f 0.48 (25% EtOAc/hexane); IR (neat) ν_{max}: 3302, 2917, 2104, 1737, 1695, 1526, 1500, 1418, 1303, 1216, 1133, 1021, 752, 695 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.40–7.05 (m, 20H), 6.52–6.47 (m, 1H), 6.03–6.01 (m, 1H), 5.93–5.81 (m, 1H), 5.70–5.50 (m, 1H), 5.14–4.93 (m, 4H), 4.82–4.78 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.4, 154.8, 141.6, 136.0, 135.6, 133.8, 130.0, 129.8, 128.8, 128.7, 128.6, 128.3, 128.1, 127.9, 127.8, 70.6, 68.3, 68.0, 65.4; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{34}H_{29}N_5O_4$: 594.2220, found: 593.91.

4.5.5. Data for **16e**

Brown viscous liquid; R_f 0.43 (25% EtOAc/hexane); IR (neat) ν_{max}: 3285, 2925, 2857, 2097, 1715, 1410, 1380, 1300, 1230, 1125, 1059, 966, 760 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.67 (d, J=5.7 Hz, 1H), 6.15 (s, 1H), 5.87 (s, 1H), 5.33–5.03 (m, 1H), 4.78 (s, 1H), 4.30–4.13 (m, 4H), 2.36–2.08 (m, 4H), 1.80–1.50 (m, 6H), 1.42–1.22 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.6, 155.4, 135.0, 131.0, 124.4, 119.3, 70.7, 63.2, 62.4, 61.2, 31.5, 30.5, 29.9, 28.2, 25.7, 14.5, 14.4; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{17}H_{25}N_5O_4$: 363.1907, found: 386.11.

4.5.6. Data for **16f**

Brown viscous liquid; R_f 0.50 (25% EtOAc/hexane); IR (neat) ν_{max}: 3306, 2982, 2936, 2103, 1715, 1468, 1375, 1240, 1181, 1107, 1041, 762. cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.67 (s, 1H), 6.31–6.12 (m, 1H), 5.86 (s, 1H), 5.20–4.80 (m, 4H), 2.34–2.14 (m, 4H), 1.66–1.58

(m, 6H), 1.30–1.20 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.0, 153.3, 135.0, 129.7, 123.5, 118.5, 70.6, 70.2, 69.4, 61.9, 32.0, 31.5, 29.9, 28.2, 26.5, 22.8, 22.4, 21.6; HRMS (EI): *m*/*z* calculated for $C_{19}H_{29}N_5O_4$: 391.2220, found: 391.2235.

4.5.7. Data for ***16g***

Light yellow viscous liquid; R_f 0.53 (25% EtOAc/hexane); IR (neat) ν_{max}: 3296, 2927, 2834, 2100, 1729, 1428, 1388, 1302, 1218, 1050, 1017, 755 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30–7.10 (m, 10H), 6.60 (s, 1H), 6.22 (s, 1H), 5.83(s, 1H), 5.53–5.33 (m, 1H), 5.16–4.78 (m, 4H), 4.67 (s, 1H), 2.31–1.99 (m, 4H), 1.58–1.23 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.3, 155.1, 140.3, 135.9, 135.7, 134.9, 131.0, 130.1, 129.7, 128.7, 128.5, 128.4, 128.3, 127.9, 114.5, 69.3, 68.7, 68.3, 68.0, 31.5, 29.9, 28.2, 28.0, 26.5; MS (LR-FAB): *m*/*z* calculated for $C_{27}H_{29}N_5O_4$: 487.2220, found: 487.37.

4.5.8. Data for ***16h***

Light yellow viscous liquid; R_f 0.46 (3:1 hexane/EtOAc); IR (neat) ν_{max}: 3296, 2912, 2851, 2095, 1747, 1714, 1449, 1409, 1382, 1303, 1229, 1171, 1061, 942, 750 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.67 (d, *J*=5.3 Hz, 1H), 6.15 (s, 1H), 5.87–5.85 (m, 1H), 5.20–4.97 (m, 1H), 4.81–4.56 (m, 1H), 4.24–4.11 (m, 4H), 2.94 (s, 1H), 2.58 (s, 1H), 1.98–1.55 (m, 12H), 1.40–1.23 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.2, 155.0, 147.4, 134.4, 129.2, 127.1, 70.1, 63.7, 62.8, 62.1, 40.3, 39.6, 39.4, 38.9, 37.8, 36.8, 35.0, 34.7, 30.8, 14.6, 14.4; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{21}H_{29}N_5O_4$: 438.2220, found: 438.91.

4.5.9. Data for ***16i***

Light yellow viscous liquid; R_f 0.50 (25% EtOAc/hexane); IR (neat) ν_{max}: 3301, 2917, 2859, 2099, 1750, 1716, 1448, 1382, 1308, 1235, 1184, 1062, 948, 758 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.67 (s, 1H), 6.15–6.06 (m, 1H), 5.85 (s, 1H), 5.22–5.18 (m, 1H), 5.00–4.80 (m, 3H), 2.94 (s, 1H), 2.59 (s, 1H), 1.98–1.42 (m, 12H), 1.37–1.25 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.7, 155.0, 147.1, 135.3, 129.4, 127.9, 70.8, 69.6, 69.3, 66.9, 40.8, 39.7, 38.8, 37.6, 36.7, 35.7, 35.6, 33.6, 26.8, 22.7, 21.7, 21.1; MS (LR-FAB): $(M+Na)^+$ calculated for $C_{23}H_{33}N_5O_4$: 466.2533, found: 466.34.

4.6. General experimental procedure for 18a–d

Bicyclic hydrazine (2 equiv) and tributyltinazide (1 equiv) were taken in a Wheaton vial, and dissolved in dry toluene (4 mL). $[Pd(allyl)Cl]_2$ (5 mol %) and dppf (10 mol %), were added to the reaction mixture followed by the addition of $Sc(OTf)_3$ (2 mol %). The reaction mixture was stirred at 60 °C for 12 h. Completion of the reaction was monitored by TLC and the reaction mixture on silica gel (60–120 mesh) column chromatography using 20% ethyl acetate in hexane afforded the product in good yield.

4.6.1. Data for ***18a***

Colorless viscous liquid; R_f 0.40 (25% EtOAc/hexane); IR (neat) ν_{max}: 3297, 2957, 2926, 2855, 2100, 1716, 1465, 1414, 1377, 1233, 1096, 1064, 761 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.31 (s, 1H), 5.58 (s, 2H), 4.88 (s, 1H), 4.16–4.08 (m, 5H), 2.53–2.34 (m, 2H), 1.26–1.19 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.7, 155.8, 135.5, 128.9, 64.5, 62.4, 61.9, 57.5, 35.9, 14.6, 14.5; HRMS (EI): *m*/*z* calculated for $C_{11}H_{17}N_5O_4$: 283.1281, found: 283.1255.

4.6.2. Data for ***18b***

Colorless viscous liquid; R_f 0.45 (25% EtOAc/hexane); IR (neat) ν_{max}: 3301, 3051, 2967, 2926, 2857, 2100, 1712, 1613, 1467, 1375, 1236, 1179, 1109, 1041, 762 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.25 (s, 1H), 5.66 (s, 2H), 4.99–4.93 (m, 3H), 4.23–4.22 (m, 1H), 2.62–2.54 (m, 2H), 1.27–1.24 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.4, 155.5, 130.9, 128.8, 70.0, 69.7, 68.1, 57.3, 35.8, 22.0, 21.9; HRMS (EI): *m*/*z* calculated for $C_{13}H_{21}N_5O_4$: 311.1594, found: 311.1608.

4.6.3. Data for ***18c***

Colorless viscous liquid; R_f 0.49 (25% EtOAc/hexane); IR (neat) ν_{max}: 3310, 3054, 2976, 2923, 2857, 2101, 1698, 1514, 1476, 1391, 1247, 1153, 855, 755 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.49 (s, 1H), 5.65 (s, 2H), 4.91 (s, 1H), 4.54–4.49 (m, 1H), 2.52–2.36 (m, 2H), 1.48 (s, 18H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 155.6, 154.9, 134.4, 128.9, 81.4, 80.9, 65.1, 57.1, 35.8, 28.4, 28.1; HRMS (E1): *m*/*z* calculated for $C_{15}H_{25}N_5O_4$: 339.1907, found: 339.1888.

4.6.4. Data for ***18d***

Colorless viscous liquid; R_f 0.44 (3:1 hexane/EtOAc); IR (neat) ν_{max}: 3294, 3060, 2950, 2857, 2093, 1715, 1495, 1454, 1411, 1226, 1124, 1050, 749, 696 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.29–7.16 (m, 10H), 6.38 (s, 1H), 5.57 (s, 2H), 5.07–4.93 (m, 5H), 4.62 (s, 1H), 2.57–2.41 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 156.5, 154.6, 135.9, 135.7, 128.9, 128.5, 128.4, 128.2, 127.9, 127.5, 69.5, 68.1, 67.8, 57.7, 36.1; HRMS (E1): *m*/*z* calculated for $C_{21}H_{21}N_5O_4$: 407.1594, found: 407.1599.

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References and notes

1. Neuenschwander, M. In *The Chemistry of Double Bonded Functional Groups*; Patai, S., Ed.; John Wiley and Sons: Chichester, UK, 1989; Vol. 2, p 1131.
2. (a) Gleiter, R.; Borzyk, O. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1001; (b) Hong, B.-C.; Gupta, A. K.; Wu, M.-F.; Liao, J.-H. *Tetrahedron Lett.* **2004**, *45*, 1663; (c) Little, R. D.; Muller, G. W. *J. Am. Chem. Soc.* **1979**, *101*, 7129; (d) Stone, K. J.; Little, R. D. *J. Org. Chem.* **1984**, *49*, 1849 and references cited therein.
3. Wang, J.-C.; Krische, M. J. *Angew. Chem., Int. Ed.* **2003**, *42*, 5855.
4. (a) Wang, Y.; Mukherjee, D.; Birney, D.; Houk, K. N. *J. Org. Chem.* **1990**, *55*, 4504; (b) Little, R. D.; Carroll, G. L.; Petersen, J. L. *J. Am. Chem. Soc.* **1983**, *105*, 928.
5. Revial, G.; Jahin, I.; Pfau, M. *Tetrahedron: Asymmetry* **2000**, *11*, 4975.
6. (a) Maulide, N.; Vanherck, J.-C.; Marko, I. E. *Eur. J. Org. Chem.* **2004**, *19*, 3962; (b) Du, Y.; Lu, X. *J. Org. Chem.* **2003**, *68*, 6463.
7. (a) Himeda, Y.; Yamataka, H.; Ueda, I.; Hatanaka, M. *J. Org. Chem.* **1997**, *62*, 6529; (b) Hu, Q.-Y.; Zhou, G.; Corey, E. J. *J. Am. Chem. Soc.* **2004**, *126*, 13708.
8. For [2+2], see: (a) Imafuku, K.; Arai, K. *Synthesis* **1989**, 501; (b) Paquette, L. A.; Colapret, J. A.; Andrews, D. R. *J. Org. Chem.* **1985**, *50*, 201; For [4+2], see: (c) Harre, M.; Raddatz, P.; Walenta, R.; Winterfeldt, E. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 480; For [2+4], see Ref. 7a; For [6+4], see: (d) Gupta, Y. N.; Doa, M. J.; Houk, K. N. *J. Am. Chem. Soc.* **1982**, *104*, 7336; (e) Yoshida, Z.-I.; Shibata, M.; Ogino, E.; Sugimoto, T. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 60; For [6+2] and [6+3], see: (f) Suda, M.; Hafner, K. *Tetrahedron Lett.* **1977**, *18*, 2543; (g) Wu, T. C.; Houk, K. N. *J. Am. Chem. Soc.* **1985**, *107*, 5308; (h) Hong, B.-C.; Sun, S. S.; Tsai, Y. C. *J. Org. Chem.* **1997**, *62*, 7717.
9. (a) Nair, V.; Anilkumar, G.; Radhakrishnan, K. V.; Nandakumar, M. V.; Kumar, S. *Tetrahedron* **1997**, *53*, 15903 and references cited therein; (b) Radhakrishnan, K. V.; Krishnan, K. S.; Bhadbhade, M. M.; Bhosekar, G. V. *Tetrahedron Lett.* **2005**, *46*, 4785; (c) Krishnan, K. S.; Sajisha, V. S.; Anas, S.; Suresh, C. H.; Bhadbhade, M. M.; Bhosekar, G. V.; Radhakrishnan, K. V. *Tetrahedron* **2006**, *62*, 5952; (d) Anas, S.; Krishnan, K. S.; Sajisha, V. S.; Anju, K. S.; Radhakrishnan, K. V.; Suresh, E.; Suresh, C. H. *New J. Chem.* **2007**, *31*, 237; (e) Krishnan, K. S.; Smitha, M.; Suresh, E.; Radhakrishnan, K. V. *Tetrahedron* **2006**, *62*, 12345.
10. (a) Hong, B.-C.; Sun, H. I.; Chen, Z. Y. *Chem. Commun.* **1999**, 2125; (b) Hong, B.-C.; Jiang, Y. F.; Kumar, E. S. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 1981; (c) Hong, B.-C.; Gupta, A. K.; Wu, M.-F.; Liao, J.-H. *Org. Lett.* **2003**, *5*, 1689; (d) Hong, B.-C.; Wu, J.-L.; Gupta, A. K.; Hallur, M. S.; Liao, J.-H. *Org. Lett.* **2004**, *6*, 3453; (e) Hong, B.-C.; Shr, Y. J.; Wu, J.-L.; Gupta, A. K.; Lin, K. *Org. Lett.* **2002**, *4*, 2249.
11. Hong, B.-C.; Chen, F. L.; Chen, S. H.; Liao, J. H.; Lee, G. H. *Org. Lett.* **2005**, *7*, 557.
12. (a) Barluenga, J.; Martinez, S.; Suarez-Sobrino, A. L.; Tomas, M. *J. Am. Chem. Soc.* **2001**, *123*, 11113; (b) Barluenga, J.; Martinez, S.; Suarez-Sobrino, A. L.; Tomas, M. *J. Am. Chem. Soc.* **2002**, *124*, 5948.
13. Tacke, M.; Allen, L. T.; Cuffe, L.; Gallagher, W. M.; Lou, Y.; Mendoza, O.; Muller-Bunz, H.; Rehmann, F. K.; Sweeney, N. *J. Organomet. Chem.* **2004**, 2242.
14. Georing, B. K.; Li, J.; Ganem, B. *Tetrahedron Lett.* **1995**, *36*, 8905.
15. Marullo, N. P.; Alford, J. A. *J. Org. Chem.* **1968**, *33*, 2368.
16. Carroll, G. L.; Allan, A. K.; Schwaebe, M. K.; Little, R. D. *Org. Lett.* **2000**, *2*, 2531.
17. (a) Radhakrishnan, K. V.; Sajisha, V. S.; Anas, S.; Krishnan, K. S. *Synlett* **2005**, 2273; (b) Sajisha, V. S.; Mohanlal, S.; Anas, S.; Radhakrishnan, K. V. *Tetrahedron*

2006, *62*, 3997; (c) Sajisha, V. S.; Radhakrishnan, K. V. *Adv. Synth. Catal.* **2006**, *348*, 924; (d) John, J.; Sajisha, V. S.; Mohanlal, S.; Radhakrishnan, K. V. *Chem. Commun.* **2006**, 3510.
18. (a) Anas, S.; Sajisha, V. S.; Mohanlal, S.; Radhakrishnan, K. V. *Synlett* **2006**, 2399; (b) Anas, S.; John, J.; Sajisha, V. S.; John, J.; Rajan, R.; Radhakrishnan, K. V. *Org. Biomol. Chem.* **2007**, *5*, 4010.
19. Barluenga, J.; Vincete, R.; Lopez, L. A.; Tomas, M. *J. Am. Chem. Soc.* **2006**, *128*, 7050.
20. (a) Hallberg, A.; Westerlund, C. *Chem. Lett.* **1993**, 1982; (b) *Hand Book of Organopalladium Chemistry for Organic Synthesis*; Negishi, E., Ed.; Wiley-Interscience: New York, NY, 2002.
21. (a) Li, C.-J. *Chem. Rev.* **1993**, *93*, 2023; (b) Li, C.-J. *Tetrahedron* **1996**, *52*, 5643; (c) Issac, M. B.; Chan, T. H. *Tetrahedron Lett.* **1995**, *36*, 8957; (d) Paquette, L. A.; Mitzel, T. M. *J. Org. Chem.* **1996**, *61*, 8799.
22. (a) Araki, S.; Imai, A.; Shimizu, K.; Butsugan, Y. *Tetrahedron Lett.* **1992**, *33*, 2581; (b) Araki, S.; Imai, A.; Shimizu, K.; Yamada, M.; Mori, A.; Butsugan, Y. *J. Org. Chem.* **1995**, *60*, 1841; (c) Fujiwara, N.; Yamamoto, Y. *J. Org. Chem.* **1997**, *62*, 2318.
23. Araki, S.; Usui, H.; Kato, M.; Butsugan, Y. *J. Am. Chem. Soc.* **1996**, *118*, 4699.
24. (a) Araki, S.; Horie, T.; Kato, M.; Hirashita, T.; Yamamura, H.; Kawai, M. *Tetrahedron Lett.* **1999**, *40*, 2331; (b) Lee, P. H.; Seomon, D.; Lee, K.; Heo, Y. *J. Org. Chem.* **2003**, *68*, 2510.
25. John, J.; Anas, S.; Sajisha, V. S.; Viji, S.; Radhakrishnan, K. V. *Tetrahedron Lett.* **2007**, *48*, 7225.
26. (a) Michalson, E. T.; Szmuszkovic, J. *Prog. Drug Res.* **1989**, *33*, 135; (b) Review: Lucet, D.; Le Gall, T.; Mioskowski, C. *Angew. Chem., Int. Ed.* **1998**, *37*, 2580; (c) Khokhar, A. R.; Al-Baker, S.; Shamsuddin, S.; Siddik, Z. H. *Bioorg. Med. Chem. Lett.* **1997**, *40*, 112; (d) Reedijk, J. *Chem. Commun.* **1996**, 801; (e) Togni, A.; Venanzi, L. M. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 497; (f) Blazis, V. J.; Koeller, K. J.; Spilling, C. D. *Tetrahedron: Asymmetry* **1994**, *5*, 499.
27. (a) Toftlund, H.; Pederson, E. *Acta Chem. Scand.* **1972**, *26*, 4019; (b) Luna, A.; Alfonso, I.; Gotor, V. *Org. Lett.* **2002**, *4*, 3627; (c) de Parrodi, C. A.; Walsh, P. J. *Synlett* **2004**, 2417; (d) Myers, M. C.; Witschi, M. A.; Larionova, N. V.; Franck, J. M.; Haynes, R. D.; Hara, T.; Grajkowski, A.; Apella, D. H. *Org. Lett.* **2003**, *5*, 2695.
28. (a) Brady, S. F.; Singh, M. P.; Janso, J.; Clardy, J. *J. Am. Chem. Soc.* **2000**, *122*, 2116; (b) Puder, C.; Krastel, P.; Zeeck, A. *J. Nat. Prod.* **2000**, *63*, 1258; (c) Maruyama, H.; Okamoto, S.; Kubo, Y.; Tsuji, G.; Fujii, I.; Ebizuka, Y.; Furihata, K.; Hayakawa, Y.; Nagasawa, H.; Sakuda, S. *J. Antibiot.* **2003**, *56*, 801; (d) Morita, A.; Kuwahara, S. *Org. Lett.* **2006**, *8*, 1613; (e) Bian, J.; Wingerden, M. V.; Ready, J. M. *J. Am. Chem. Soc.* **2006**, *128*, 7428; (f) Trost, B. M.; Dong, L.; Schroeder, G. M. *J. Am. Chem. Soc.* **2005**, *127*, 10259.