Regio- and Stereochemically Controlled Formation of Hydroxamic Acid Containing *anti*- or *syn*-1,4-Cycloalkenols from Acylnitroso-Derived Diels−Alder Adducts

Matthew D. Surman and Marvin J. Miller*

Department of Chemistry and Biochemistry, University of Notre Dame, Notre Dame, Indiana 46556

marvin.j.miller.2@nd.edu

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Treatment of acylnitroso hetero Diels−Alder cycloadducts **2** with iron(III) or copper(II) in an alcohol solvent induces ring opening to afford predominantly monocyclic *anti*-1,4-hydroxamic acids **3**. However, treatment of cycloadducts **2** with copper(II) in toluene reverses the stereoselectivity of the ring opening to afford *syn*-1,4-hydroxamic acids **4**. These regio- and stereoselective processes separately provide *anti*-1,4- and *syn*-1,4-disubstituted cyclopentenes while regenerating a hydroxamic acid moiety, thus enhancing the chemical versatility of the Diels−Alder cycloadducts.

The hydroxamic acid moiety is an important functionality found in a wide range of biologically active compounds.[1] The activity of compounds containing hydroxamic acids often relies on their ability to effectively bind metals such as iron(III), nickel(II), and zinc(II). Thus, hydroxamates often act as inhibitors of metal-containing enzymes such as 5-lipoxygenase,[2] urease,[3] and matrix metalloproteinases.[4] Previously, we reported the first example of regio- and stereoselective Lewis acid mediated ring openings of 3-aza-2-oxabicyclo[2.2.1]hept-5-ene systems (**2a**) to selectively form *anti*-1,4-disubstituted cyclopentene-derived hydroxamic acids (**3a**, Scheme 1).[5] This offered a new route to synthetically useful 1,4-aminocyclopentenols,[6] while retaining a hydroxamic acid moiety for further elaboration or for possible biological activity. Herein we wish to report recent advances in this area that expand the versatility of the Lewis acid mediated ring opening methodology by offering greater stereochemical control and application to a wider range of acylnitroso hetero Diels−Alder cycloadducts (**2b**−**d**).

Our previous studies[5] involved treating cycloadducts (**2a**), derived from the hetero Diels−Alder reaction between transient nitroso species and cyclopentadiene,[7] with $FeCl_3$ to induce ring opening at the C(1) position, followed by attack of methanol to obtain primarily the *anti*-1,4-hydroxamic acid product **3a**, in addition to minor amounts of the *syn*-1,4- (**4a**) and *anti*-1,2-products (**5a**). Subsequent investigation showed that the regio- and stereoselectivity of this Lewis acid mediated ring opening reaction could be altered by modifying the steric bulk of the nucleophilic solvent. By changing the solvent from methanol to 2-propanol, the preference for *anti*-1,4-product **3** formation decreased (Table 1, entries 1 and 2). This trend continued in going from 2-propanol to *tert*-butyl alcohol (Table 1, entries 2 and 3). In each case of increasing nucleophile size, a greater amount of *syn*-1,4-product **4** was formed.

The ability to control the stereochemical outcome of the Lewis acid mediated ring opening reaction was further enhanced by changing the Lewis acid from Fe(III) to Cu(II). The Cu(II) offered a more mild Lewis acid source, as was evident by the longer reaction times observed with the use of Cu(II). Initially, $CuSO_4$ was used as the source of Cu(II). When cycloadduct **2a** was treated with $CuSO_4$ in methanol, a 95% yield of a 10:1:1 ratio of *anti*-1,4-:*syn*-1,4-:*anti*-1,2-products (**3a**:**4a**:**5a**) was formed (Table 1, entry 4). This offered a significant improvement in stereoselectivity over the Fe(III)-mediated reaction.

* Ph: (219) 631-7571. Fax: (219) 631-6652.

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Scheme 1

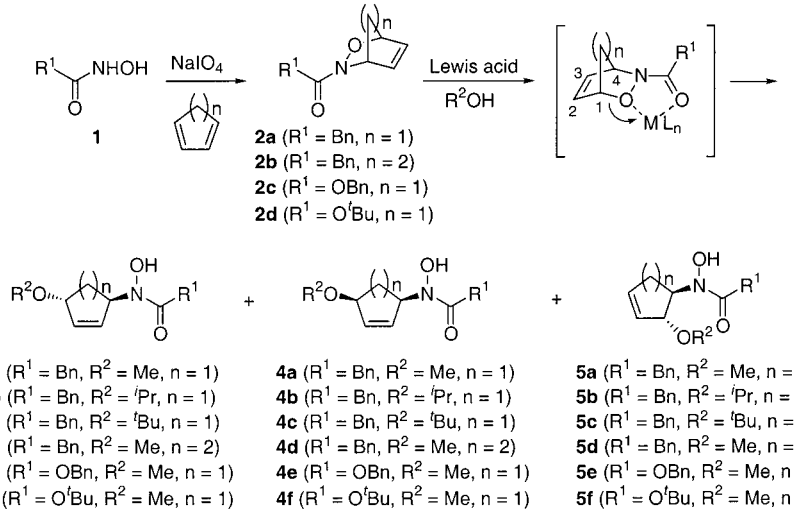

Table 1. Fe(III)- and Cu(II)-Mediated Ring Openings of Cycloadduct 2a (R¹ = Bn, *n* = 1)

entry	conditions	products	yield	product ratios, **3**:**4**:**5**	R^2
1	$FeCl_3$,[a] MeOH	**3a**−**5a**	74%	7:1.7:1	CH_3
2	$FeCl_3$,[a] ^{i}PrOH	**3b**−**5b**	62%	18:6:1	$CH(CH_3)_2$
3	$FeCl_3$,[a] ^{t}BuOH	**3c**−**5c**	80%	12:7:1	$C(CH_3)_3$
4	$CuSO_4$,[b] MeOH	**3a**−**5a**	95%	10:1:1	CH_3
5	$CuCl_2$,[b] MeOH	**3a**−**5a**	78%	14:5:1	CH_3
6	$CuCl_2$,[b] ^{i}PrOH	**3b**−**5b**	88%	11:8:1	$CH(CH_3)_2$
7	$CuCl_2$,[b] ^{t}BuOH	**3c**−**5c**	75%	22:77:1	$C(CH_3)_3$
8	$CuCl_2$,[b] MeOH, $PhCH_3$	**3a**−**5a**	69%	9:90:1	CH_3
9	$CuCl_2$,[b] ^{i}PrOH, $PhCH_3$	**3b**−**5b**	73%	1:14:trace	$CH(CH_3)_2$
10	$CuCl_2$,[b] ^{t}BuOH, $PhCH_3$	**3c**−**5c**	57%	trace:1:trace	$C(CH_3)_3$

[a] 0.5 equiv of Fe(III). [b] 0.7 equiv of Cu(II).

However, when $CuSO_4$ was used with more bulky nucleophiles (2-propanol and *tert*-butyl alcohol), the reactions were extremely sluggish and afforded very little product formation. By switching to a different source of Cu(II), larger nucleophiles could be tolerated but at the cost of reducing the stereoselectivity of the ring opening in methanol. When cycloadduct **2a** was treated with $CuCl_2$ in methanol, a 78% yield of a 14:5:1 ratio of *anti*-1,4-:*syn*-1,4-:*anti*-1,2-products (**3a**:**4a**:**5a**) was formed (Table 1, entry 5). As was the case in the $FeCl_3$ reactions, increasing the size of the nucleophile increased the amount of *syn*-1,4-product **4** formation. Treatment of cycloadduct **2a** with $CuCl_2$ in 2-propanol gave an 88% yield of an 11:8:1 ratio of *anti*-1,4-:*syn*-1,4-:*anti*-1,2-products (**3b**:**4b**:**5b**) (Table 1, entry 6). Increasing the nucleophile size even further had a dramatic effect on the stereochemical outcome of the ring opening reaction. When cycloadduct **2a** was opened in the presence of $CuCl_2$ and *tert*-butyl alcohol, the stereoselectivity of the reaction reversed, giving a 75% yield of a 22:77:1 ratio of *anti*-1,4-:*syn*-1,4-:*anti*-1,2-products (**3c**:**4c**:**5c**) (Table 1, entry 7).

The *syn*-1,4-hydroxamic acid could also be obtained preferentially by varying the reaction conditions to include 4 equiv of nucleophile in a nonpolar solvent. Treatment of cycloadduct **2a** with $CuCl_2$ and 4 equiv of methanol in toluene gave a 69% yield of a 9:90:1 ratio of *anti*-1,4-:*syn*-1,4-:*anti*-1,2-products (**3a**:**4a**:**5a**) (Table 1, entry 8). This offered a complete reversal in stereoselectivity from the reaction in which $CuSO_4$ was used in methanol solvent (Table 1, entry 4). The preference for *syn*-1,4-hydroxamic acid **4** formation was enhanced by increasing the size of the nucleophile. Use of 2-propanol gave a 73% yield of a 1:14 ratio of *anti*-1,4-:*syn*-1,4-products (**3b**:**4b**) with only a trace amount of the *anti*-1,2-compound (**5b**). Likewise, when *tert*-butyl alcohol was used as the nucleophile, a 57% yield of the *syn*-1,4-product (**4c**) was formed with only trace amounts of the *anti*-1,4- and *anti*-1,2-products (**3c** and **5c**).

These trends in product selectivity offered some mechanistic insight into the cycloadduct ring opening reaction. A control reaction was run in which the both the *anti*-1,4- and *syn*-1,4-hydroxamic acid products (**3a** and **4a**) were resubjected to the ring opening conditions ($CuCl_2$ and methanol). The *anti*-1,4- and *syn*-1,4-compounds were recovered unchanged, thus indicating that the product ratios were not the result of a product equilibrium. While rigorous mechanistic studies have yet to be conducted, a plausible mechanism involves an initial Lewis acid mediated opening of the cycloadduct to give a tight ion pair (Scheme 2). The fate of this tight ion pair is determined by the reaction conditions. If the reaction takes place in a small nucleophilic solvent (such as methanol), the solvent can attack the tight ion pair from the face opposite to the hydroxamate to give the *anti*-1,4-product **3** (path A). However, if the nucleophile is too large or if the concentration of the nucleophile is too low, an intramolecular release of the nucleophile from the metal can occur to set up an attack *syn* to the hydroxamate to give the *syn*-1,4-product **4** (path B).

The Lewis acid mediated ring opening methodology was also applied to different acylnitroso Diels−Alder cycloadduct systems. The [2.2.2] cycloadduct **2b** was opened under $FeCl_3$ and $CuCl_2$ conditions in good yields, however, with reduced stereoselectivity favoring the *syn*-1,4-product **4d** (Table 2, entries 1 and 2). As a result of

Scheme 2

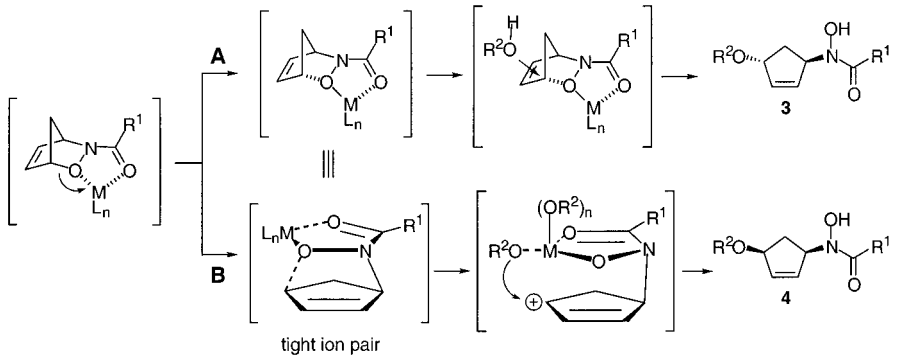

Table 2. Fe(III)- and Cu(II)-Mediated Ring Openings of Cycloadducts 2b−2d

entry	substrate	conditions	products	yield	product ratios: **3**:**4**:**5**	R^1	R^2
1	**2b**	$FeCl_3$,[a] MeOH	**3d**−**5d**	73%	1:3:1	Bn	CH_3
2	**2b**	$CuCl_2$,[b] MeOH	**3d**−**5d**	79%	1:2:1	Bn	CH_3
3	**2c**	$FeCl_3$,[a] MeOH	**3e**−**5e**	47%	4:2:1	OBn	CH_3
4	**2c**	$CuCl_2$,[b] MeOH	**3e**−**5e**	78%	3:4:1	OBn	CH_3
5	**2c**	$CuSO_4$,[b] MeOH	**3e**−**5e**	76%	2:1:1	OBn	CH_3
6	**2d**	$FeCl_3$,[a] MeOH	**3f**−**5f**	72%	1.8:1.2:1	O^{t}Bu	CH_3
7	**2d**	$CuCl_2$,[b] MeOH	**3f**−**5f**	41%	2.4:1.4:1	O^{t}Bu	CH_3
8	**2d**	$CuSO_4$,[b] MeOH	**3f**−**5f**	94%	4.3:1:2	O^{t}Bu	CH_3

[a] 0.5 equiv. of Fe(III). [b] 0.7 equiv. of Cu(II).

the lack of ring strain associated with the [2.2.2] cycloadduct (**2b**), the application of heat was necessary to induce ring opening, especially when $CuCl_2$ was used as the Lewis acid. The extra energy supplied by the increased temperature could be the source of the compromised stereoselectivity.

N-Carbamate cycloadducts **2c** and **2d** also could be opened successfully under Lewis acid conditions. *N*-Cbz and *N*-Boc cycloadducts (**2c** and **2d**) were treated under $FeCl_3$, $CuCl_2$, and $CuSO_4$ conditions in methanol to afford the corresponding hydroxamic acid products (**3e**−**5e** and **3f**−**5f**) in variable yields without loss of the carbamate protecting groups (Table 2, entries 3−8). The regio- and stereoselectivities of these reactions were low and somewhat unpredictable. In most cases, the *anti*-1,4-products (**3**) were favored, as expected. However, in some cases, the *syn*-1,4- (**4**) or the *anti*-1,2-products (**5**) were formed preferentially (Table 2, entries 4 and 8). The low and unpredictable regio- and stereoselectivities observed in these cases could be due to the lower Fe(III) and Cu(II) binding affinity of the *N*-carbamate hydroxamic acids.

In summary, we found that the Lewis acid mediated ring opening methodology is applicable to a variety of acylnitroso hetero Diels−Alder cycloadduct systems. Also, we found that, by varying the size of the nucleophile and/or the reaction conditions, either the *anti*-1,4- (**3**) or the *syn*-1,4-hydroxamic acid products (**4**) can be obtained selectively. While the mechanistic details responsible for this interesting product selectivity are currently under further consideration, the results described here serve to enhance the synthetic utility of this novel route to 1,4-aminocycloalkenols incorporating the biologically important hydroxamic acid functionality.

Experimental Section

General Methods. Melting points were taken on a Thomas-Hoover capillary melting point apparatus and are uncorrected. ^1H and ^{13}C NMR spectra were obtained on a Varian 300 spectrometer and were referenced to residual DMSO. Infrared spectra were recorded on a Perkin-Elmer Paragon 1000 FT-IR spectrometer, and TF refers to thin film. Analytical TLC was carried out using Merck aluminum-backed 0.2 mm silica gel 60 F-254 plates. Column chromatography was conducted using Merck silica gel 60 (230−400) mesh.

All reactions were periodically monitored by TLC and worked up after the complete consumption of starting materials unless specified otherwise. All purchased reagents were of reagent grade quality and were used without further purification.

General Procedure for Cycloadduct Ring Opening with $FeCl_3$. A solution of cycloadduct **2** (0.33 mmol) in alcohol (3 mL) was treated at room temperature (except when cycloadduct **2b** was used, in which case the reaction was heated to reflux) with anhydrous $FeCl_3$ (33 mg, 0.20 mmol) and stirred under argon for 15 min to 10 h (*N*-carbamate cycloadducts required longer reaction times). The mixture was concentrated in vacuo to a slurry, then a 3 N citric acid solution saturated with ascorbic acid was added until the deep purple color was removed, and the solution was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, filtered, concentrated in vacuo, and chromatographed (silica gel; eluted with 3−6% MeOH−CH_2Cl_2) to give *anti*-1,4-hydroxamic acid **3** in addition to a (generally inseparable) mixture of *syn*-1,4- and *anti*-1,2-products (**4** and **5**). Reaction with [2.2.2] cycloadduct **2b** gave *syn*-1,4-hydroxamic acid **4d** as the major product, in addition to a mixture of **3d** and **5d**.

General Procedure for Cycloadduct Ring Opening with Copper(II). A solution of cycloadduct **2** (0.78 mmol) in alcohol (6 mL) was treated at room temperature (except when cycloadduct **2b** was used, in which case the reaction was heated to reflux) with anhydrous $CuSO_4$ or $CuCl_2$ (82 mg, 0.61 mmol) and stirred under argon for 1−24 h (*N*-carbamate cycloadducts required longer reaction times). The mixture was concentrated in vacuo to a slurry, then a saturated solution of Na_2EDTA was added, and the solution was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, filtered, concentrated in vacuo, and chromatographed (silica gel; eluted with 3−6% MeOH−CH_2Cl_2) to give *anti*-1,4-hydroxamic acid **3** or *syn*-1,4-hydroxamic acid **4** as the major product.

General Procedure for Cycloadduct Ring Opening with $CuCl_2$ in Toluene. A solution of cycloadduct **2** (0.55 mmol) in $PhCH_3$ (5 mL) was treated at room temperature with anhydrous $CuCl_2$ (74 mg, 0.55 mmol) and alcohol (2.2 mmol) and stirred under argon for 15−22 h. The mixture was

concentrated in vacuo to a slurry, then a saturated solution of Na_2EDTA was added, and the solution was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, filtered, concentrated in vacuo, and chromatographed (silica gel; eluted with 3−6% MeOH−CH_2Cl_2) to give *syn*-1,4-hydroxamic acid **4** as the major product.

All product ratios were determined by ^1H NMR spectroscopy of the crude reaction mixtures. Full characterization of the major products follow.

***anti*-1,4-Hydroxamic acid 3a:** white solid; mp 90−91 °C; IR (TF) 3140, 2898, 1598, 1442, 1089 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.84 (bm, 1H), 2.04 (ddd, J = 3.9, 6.9, 13.8 Hz, 1H), 3.20 (s, 3H), 3.70 (s, 2H), 4.52 (bs, 1H), 5.57 (bs, 1H), 5.78 (d, J = 3.9 Hz, 1H), 6.12 (d, J = 4.5 Hz, 1H), 7.24 (m, 5H), 9.57 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 33.09, 38.78, 55.50, 60.14, 84.35, 126.06, 127.92, 129.27, 133.70, 135.04, 135.66, 171.11; HRMS (FAB) calcd for $C_{14}H_{18}NO_3$ $(M + H)^+$ 248.1287, found 248.1282.

***syn*-1,4-Hydroxamic acid 4a:** white solid; mp 106−107 °C; IR (TF) 3152, 2895, 1608, 1431, 1107 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.67 (overlapping ddd, J = 6.6, 6.6, 12.6 Hz, 1H), 2.43 (overlapping ddd, J = 7.8, 7.8, 12.6 Hz, 1H), 3.24 (s, 3H), 3.72 (s, 2H), 4.28 (bs, 1H), 5.34 (bs, 1H), 5.74 (d, J = 4.8 Hz, 1H), 6.05 (d, J = 5.4 Hz, 1H), 7.26 (m, 5H), 9.59 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 32.80, 38.73, 55.44, 58.48, 83.10, 126.21, 128.07, 129.44, 133.19, 134.18, 135.79, 170.91; HRMS (FAB) calcd for $C_{14}H_{18}NO_3$ $(M + H)^+$ 248.1287, found 248.1285.

***anti*-1,4-Hydroxamic acid 3b:** white solid; mp 102−103 °C; IR (TF) 3160, 2971, 1609, 1431, 1127 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.06 (d, J = 6.0 Hz, 6H), 1.77 (m, 1H), 2.06 (ddd, J = 3.6, 7.2, 13.5 Hz, 1H), 3.62 (q, J = 6.0 Hz, 1H), 3.69 (s, 2H), 4.69 (bs, 1H), 5.54 (bs, 1H), 5.71 (d, J = 4.2 Hz, 1H), 6.04 (d, J = 4.8 Hz, 1H), 7.24 (m, 5H), 9.54 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 22.61, 22.72, 34.68, 38.78, 60.13, 69.26, 80.57, 126.18, 128.06, 129.36, 132.49, 135.78, 136.74, 171.09; HRMS (FAB) calcd for $C_{16}H_{22}NO_3$ $(M + H)^+$ 276.1600, found 276.1602.

***syn*-1,4-Hydroxamic acid 4b:** white solid; mp 134−135 °C; IR (TF) 3142, 2969, 1596, 1434, 1159 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.08 (dd, J = 1.8, 6.3 Hz, 6H), 1.64 (overlapping ddd, J = 6.6, 6.6, 12.9 Hz, 1H), 2.44 (overlapping ddd, J = 7.5, 7.5, 12.9 Hz, 1H), 3.67 (q, J = 6.0 Hz, 1H), 3.71 (s, 2H), 4.44 (bt, J = 6.3 Hz, 1H), 5.30 (bs, 1H), 5.67 (d, J = 5.4 Hz, 1H), 5.94 (d, J = 5.1 Hz, 1H), 7.25 (m, 5H), 9.57 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 22.61, 22.88, 34.49, 38.71, 58.45, 69.38, 79.37, 126.18, 128.03, 129.39, 132.19, 135.59, 135.79, 170.87; HRMS (FAB) calcd for $C_{16}H_{22}NO_3$ $(M + H)^+$ 276.1600, found 276.1597.

***anti*-1,4-Hydroxamic acid 3c:** white solid; mp 108−109 °C; IR (TF) 3172, 2974, 1612, 1432, 1062 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.13 (s, 9H), 1.71 (overlapping ddd, J = 3.6, 8.1, 13.2 Hz, 1H), 2.07 (ddd, J = 3.6, 7.2, 13.8 Hz, 1H), 3.69 (s, 2H), 4.79 (bs, 1H), 5.52 (dm, J = 6.0 Hz, 1H), 5.63 (d, J = 4.8 Hz, 1H), 5.89 (d, J = 5.4 Hz, 1H), 7.24 (m, 5H), 9.52 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 28.23, 36.62, 38.82, 60.16, 72.87, 75.67, 126.22, 128.09, 129.40, 131.22, 135.84, 138.63, 171.05; HRMS (FAB) calcd for $C_{17}H_{24}NO_3$ $(M + H)^+$ 290.1756, found 290.1746.

***syn*-1,4-Hydroxamic acid 4c:** white solid; mp 99−100 °C; IR (TF) 3223, 2973, 1617, 1437, 1085 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.14 (s, 9H), 1.63 (overlapping ddd, J = 6.6, 6.6, 12.6 Hz, 1H), 2.39 (overlapping ddd, J = 7.2, 7.2, 12.6 Hz, 1H), 3.71 (s, 2H), 4.54 (bs, 1H), 5.27 (bs, 1H), 5.63 (d, J = 5.1 Hz, 1H), 5.79 (d, J = 5.1 Hz, 1H), 7.25 (m, 5H), 9.54 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 28.19, 36.50, 38.73, 58.56, 72.81, 74.10, 126.16, 128.03, 129.39, 131.39, 135.81, 137.12, 170.83; HRMS (FAB) calcd for $C_{17}H_{24}NO_3$ $(M + H)^+$ 290.1757, found 290.1766.

***syn*-1,4-Hydroxamic acid 4d:** white solid; mp 126−127 °C; IR (TF) 3162, 1610, 1453, 1098 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.40 (m, 1H), 1.73 (bs, 2H), 2.12 (m, 1H), 3.24 (s, 3H), 3.70 (s, 2H), 3.81 (bs, 1H), 4.95 (bs, 1H), 5.51 (d, J = 9.9 Hz, 1H), 5.88 (d, J 9.3 Hz, 1H), 7.24 (m, 5H), 9.63 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 23.68, 27.52, 38.66, 52.00, 54.91, 74.23, 126.21, 128.08, 129.35, 129.51, 132.06, 135.81, 171.25; HRMS (FAB) calcd for $C_{15}H_{20}NO_3$ $(M + H)^+$ 262.1443, found 262.1447.

***anti*-1,4-Hydroxamic acid 3e:** clear oil; IR (TF) 3264, 2936, 1696, 1306, 1089 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.84 (ddd, J = 3.3, 8.1, 13.8 Hz, 1H), 2.06 (ddd, J = 3.9, 6.9, 13.8 Hz, 1H), 3.19 (s, 3H), 4.48 (m, 1H), 5.10 (s, 2H), 5.23 (m, 1H), 5.81 (dm, J = 5.7 Hz, 1H), 6.09 (dm, J = 5.7 Hz, 1H), 7.34 (m, 5H), 9.19 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 33.09, 55.54, 63.56, 66.42, 84.33, 127.75, 127.91, 128.36, 133.76, 135.02, 136.60, 156.41; HRMS (FAB) calcd for $C_{14}H_{17}NO_4$ $(M + H)^+$ 264.1237, found 264.1275.

***anti*-1,4-Hydroxamic acid 3f:** clear oil; IR (TF) 3293, 2979, 1691, 1368, 1109 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.41 (s, 9H), 1.81 (ddd, J = 3.3, 8.1, 13.8 Hz, 1H), 2.02 (ddd, J = 4.2, 6.9, 13.8 Hz, 1H), 3.19 (s, 3H), 4.45 (m, 1H), 5.14 (m, 1H), 5.79 (dm, J = 6.0 Hz, 1H), 6.05 (dm, J = 5.7 Hz, 1H), 8.89 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 28.00, 33.05, 55.53, 63.48, 79.67, 84.39, 134.16, 134.57, 155.94; HRMS (FAB) calcd for $C_{11}H_{20}NO_4$ $(M + H)^+$ 230.1393, found 230.1388.

***anti*-1,2-Hydroxamic acid 5f:** clear oil; IR (TF) 3306, 2929, 1689, 1368, 1108 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.41 (s, 9H), 2.35 (dm, J = 16.8 Hz, 1H), 2.49 (m, 1H), 3.25 (s, 3H), 4.46 (m, 2H), 5.14 (m, 1H), 5.76 (dm, J = 6.3 Hz, 1H), 5.86 (dm, J = 6.3 Hz, 1H), 9.19 (s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6) δ 28.00, 33.12, 55.66, 63.75, 79.68, 87.01, 130.06, 132.73, 155.53; HRMS (FAB) calcd for $C_{11}H_{20}NO_4$ $(M + H)^+$ 230.1392, found 230.1386.

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Supporting Information Available: NMR spectra for products **3**−**5**. This material is available free of charge via the Internet at http://pubs.acs.org.

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