Diastereoselective Diels−Alder Reaction of 2-(α,*β*-Unsaturated)acyl-3-phenyl-*l*-menthopyrazoles

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The reaction of 2-(α,*β*-unsaturated)acyl-3-phenyl-*l*-menthopyrazoles (**9**) with dienes gave Diels−Alder adducts in good yield. The addition of $MgBr_2$·OEt_2 or $ZnCl_2$ accelerated these reactions through the formation of chelating bonds such as N···Mg···O═C or N···Zn···O═C. The structural fixation by these catalysts also promoted the endo and diastereoselectivities of the Diels−Alder addition on the *Re*-face of the dienophiles. These results were supported by PM3 calculations, in which the heats of formation of the transition states anticipated the remarkable differences between the *Re*- and *Si*-facial attacks of the dienes.

We have recently developed a method of preparation for 3-phenyl-*l*-menthopyrazole (**1**) as a new chiral auxiliary,[1] which has unique structure and properties that are different from the conventional chiral auxiliaries.[2] The most important characteristics of this auxiliary are that the substrate terminates in the nitrogen atom of a heteroaromatic pyrazole ring in a chiral environment. The steric hindrance of **1** is especially relaxed by the twisting of the benzene ring, which overlaps one side of the terminal nitrogen atom.[1] This structural feature causes a diastereofacial effect in the reactions on the substrate moiety. Moreover, the lone pair of electrons on the adjacent nitrogen play the role of a Lewis base, causing the chelation of N···Li−O in the lithium enolate derived from *N*-acylpyrazoles. These chelations freeze the bond rotation of the acyl group so that it is fixed in a syn configuration. As a result, the chirality of the (4*R*)-methyl group of **1** causes a highly asymmetric induction on the acyl group of 2-acyl-3-phenyl-*l*-menthopyrazoles in the reactions with alkyl halides,[3] diphenyl disulfide,[4] acyl chloride,[5] aldehydes,[6] and C═N compounds.[7] A similar chelation of N···Mg···O═C, which is observed in the mixture of *N*-acylpyrazoles and $MgBr_2$·OEt_2,[8] induces the asymmetric addition of Grignard reagents[9] and 1,3-dipolar compounds[10] on *N*-(α,*β*-unsaturated)acylpyrazoles. Otherwise, *N*-acylheteroaromatics such as *N*-acylimidazoles are utilized as the activated acyl moiety in a wide variety of organic syntheses.[11] As analogues of these *N*-acylheteroaromatics, *N*-acylpyrazoles are easily converted into acyl derivatives by the action of nucleophiles such as alcohols,[12] amines,[13] Grignard reagents,[14] and organozinc compounds[15] under basic or acidic conditions.

Since the reaction proceeds by the facial attacks of dienes, asymmetric Diels−Alder reactions using chiral auxiliaries or catalysts have been widely reported.[16] For the further extended utility of **1** as a new chiral auxiliary, we report here the diastereofacial Diels−Alder reaction of 2-(α,*β*-unsaturated)acyl-3-phenyl-*l*-menthopyrazoles (**9**) and determine the steric properties of **1**.

Results and Discussion

To optimize conditions for the Diels−Alder reactions of *N*-(α,*β*-unsaturated)acylpyrazoles, the reaction of 1-acryloyl-3,5-dimethylpyrazole (**2a**) and cyclopentadiene (**3**) was first studied as the simplest and most convenient dienophile and diene (Scheme 1). When **2a** was treated with **3** in chloroform at room temperature, the reaction was complete in 2 h, giving a mixture of endo- and exo-

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(1) Kashima, C.; Fukuchi, I.; Takahashi, K.; Hosomi, A. *Tetrahedron Lett.* **1993**, *34*, 8305.

(2) For recent reviews, see: (a) *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press, Inc.: New York, 1983−1985; Vols. 1−5. (b) Kim, B. H.; Curran, D. P. *Tetrahedron* **1993**, *49*, 298. (c) Gant, T. G.; Meyers, A. I. *Tetrahedron* **1994**, *50*, 2297.

(3) Kashima, C.; Fukuchi, I.; Hosomi, A. *J. Org. Chem.* **1994**, *59*, 7821.

(4) Kashima, C.; Takahashi, K.; Hosomi, A. *Heterocycles* **1996**, *42*, 241.

(5) Kashima, C.; Fukuchi, I.; Takahashi, K.; Hosomi, A. *Tetrahedron* **1996**, *52*, 10335.

(6) Kashima, C.; Fukuchi, I.; Takahashi, K.; Fukusaka, K.; Hosomi, A. *Heterocycles* **1998**, *47*, 357

(7) Kashima, C.; Fukusaka, K.; Takahashi, K. *J. Heterocycl. Chem.* **1997**, *34*, 1559.

(8) Kashima, C.; Takahashi, K.; Fukusaka, K. *J. Heterocycl. Chem.* **1995**, *32*, 1775.

(9) Kashima, C.; Fukuchi, I.; Takahashi, K.; Hosomi, A. *J. Heterocycl. Chem.* **1998**, *35*, 503.

(10) Kashima, C.; Takahashi, K.; Fukuchi, I.; Fukusaka, K. *Heterocycles* **1997**, *44*, 289.

(11) (a) Staab, H. A. *Angew. Chem.* **1962**, *74*, 407. (b) Kamijo, T.; Harada, H.; Iizuka, K. *Chem. Pharm. Bull.* **1984**, *32*, 5044. (c) Kitagawa, T.; Kawaguchi, M.; Inoue, S.; Katayama, S. *Chem. Pharm. Bull.* **1991**, *39*, 3030.

(12) Kashima, C.; Harada, H.; Kita, I.; Fukuchi, I.; Hosomi, A. *Synthesis* **1994**, 61.

(13) Kashima, C.; Fukuchi, I.; Takahashi, K.; Hosomi, A. *Heterocycles* **1994**, *38*, 1407.

(14) Kashima, C.; Kita, I.; Takahashi, K.; Hosomi, A. *J. Heterocycl. Chem.* **1995**, *32*, 25.

(15) Kashima, C.; Kita, I.; Takahashi, K.; Hosomi, A. *J. Heterocycl. Chem.* **1995**, *32*, 723.

(16) (a) Paquette, L. A. In *Asymmetric Synthesis*; Morrison, J. D., Ed; Academic: New York, 1984; Vol. 3, Chapter 4. (b) Oppolzer, W. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 876. (c) Masamune, S.; Choy, W.; Petersen, J. S.; Sita, L. R. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 1. (d) Oppolzer, W.; Chapuis, C.; Bernardinelli, G. *Helv. Chim. Acta* **1984**, *67*, 1397. (e) Evans, D. A.; Chapman, K. T.; Bisaha, J. *J. Am. Chem. Soc.* **1984**, *106*, 4261. (f) Sibi, M. P.; Deshpande, P. K.; Ji, J. *Tetrahedron Lett.* **1995**, *36*, 8965. (g) Chapuis, C.; de Saint Laumer, J. Y.; Marty, M. *Helv. Chim. Acta* **1997**, *80*, 146. (h) Narasaka, K.; Iwasawa, N.; Inoue, M.; Yamada, T.; Nakashima, M.; Sugimori, J. *J. Am. Chem. Soc.* **1989**, *111*, 5340. (i) Corey, E. J.; Matsumura, Y. *Tetrahedron Lett.* **1991**, *32*, 6289. (j) Haase, C.; Sarko, C. R.; DiMare, M. *J. Org. Chem.* **1995**, *60*, 1777. (k) Seebach, D.; Dahinden, R.; Marti, R. E.; Beck, A. K.; Plattner, D. A.; Kuhnle, F. N. M. *J. Org. Chem.* **1995**, *60*, 1788. (l) Gothelf, K. V.; Jorgensen, K. A. *J. Org. Chem.* **1995**, *60*, 6847.

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Scheme 1

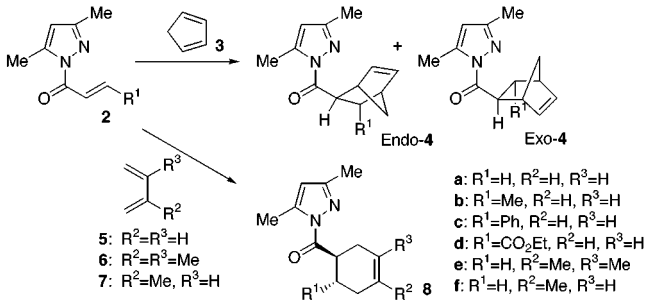

Table 1. Diels−Alder Reaction Rates of 1-Acryloyl-3,5-dimethylpyrazole (2a) with Cyclopentadiene (3)

run	*T* (°C)	solvent	Lewis acid	reaction rate (L/mol·s)	relative rate
1	0	Toluene	none	3.5×10^{-5}	1.0
2	0	THF	none	2.5×10^{-5}	0.7
3	0	$CHCl_3$	none	4.3×10^{-5}	1.2
4	32	Toluene	none	3.3×10^{-4}	9.4
5	32	THF	none	2.5×10^{-4}	7.1
6	32	$CHCl_3$	none	4.5×10^{-4}	13
7	0	Toluene	LiBr	3.4×10^{-5}	1.0
8	0	Toluene	$BF_3{\cdot}OEt_2$	1.8×10^{-3}	51
9	0	Toluene	$MgBr_2{\cdot}OEt_2$	8.8×10^{-4}	25
10	0	Toluene	$ZnCl_2$	3.3×10^{-3}	94

Diels−Alder adducts (**4a**). The endo−exo isomer ratios were evaluated by HPLC. The structure of **4a** was determined by derivatization into authentic benzyl bicyclo-[2.2.1]hept-5-ene-2-carboxylate. By monitoring **2a** using HPLC, toluene and chloroform were found to be the favorable solvents under ordinary pressure, and the reaction rate at 0 °C was evaluated to be about 4×10^{-5} L/mol·s, as summarized in Table 1 (runs 1 and 3). An acceleration of the reaction rates was observed with the addition of Lewis acids such as $BF_3{\cdot}OEt_2$ (run 8), $MgBr_2{\cdot}OEt_2$ (run 9), and $ZnCl_2$ (run 10), but LiBr was not effective (run 7). A preference for the endo isomer was observed with $BF_3{\cdot}OEt_2$ (run 3), $MgBr_2{\cdot}OEt_2$ (run 4), and $ZnCl_2$ (run 5), as summarized in Table 2. Strong Lewis acids such as $TiCl_4$ (run 6) and $AlCl_3$ (run 7) depressed the formation of Diels−Alder adducts due to the C−N bond cleavage of *N*-acylpyrazoles. Table 2 also shows that the Diels−Alder reaction of 1-cinnamoyl-3,5-dimethylpyrazole (**2c**) is very slow (runs 11 and 12) and that high-pressure conditions are necessary to produce the adduct in moderate yield (run 13). The addition of $MgBr_2{\cdot}OEt_2$ was less effective under high-pressure conditions (run 14). Similarly, the reaction of 1-crotonoyl-3,5-dimethylpyrazoles (**2b**) was accelerated when using either the $MgBr_2{\cdot}OEt_2$ catalyst (run 10) or high-pressure conditions (run 9). Further, **2a** gave the Diels−Alder adducts with 1,3-butadiene (**5**) and 2,3-dimethyl-1,3-butadiene (**6**) in high yield at room temperature in the presence of $MgBr_2{\cdot}OEt_2$ (run 16 and 17). In the case of 2-methyl-1,3-butadiene (**7**), 1-(4′-methyl-3′-cyclohexene)carbonyl-3,5-dimethylpyrazole (**8f**) was obtained without any regioisomer (run 18). On the basis of these results, the Diels−Alder reaction of *N*-(α,*β*-unsaturated)acylpyrazoles (**2**) was carried out in toluene under mild conditions and was accelerated with high stereoselectivity of endo isomers by the addition of Lewis acids such as $BF_3{\cdot}OEt_2$, $MgBr_2{\cdot}OEt_2$, and $ZnCl_2$. Even when the reaction was forced under high pressure and temperature, no adduct was obtained with anthracene, furan, or ethyl vinyl ether.

When 2-acryloyl-3-phenyl-*l*-menthopyrazole (**9a**) was treated with **3** for 17 h, the mixture of four stereoisomers was afforded in high yield, as listed in Table 3 and shown in Scheme 2. The diastereomer ratio was evaluated from the olefinic and 4-Me peak intensities of the ^{1}H NMR spectrum. The major product was found to be the endo cycloadduct having a 2′*R*- conformation ((**1′*S*,2′*R*,4′*R*)-10a**). On the basis of the HPLC and ^{1}H NMR peak intensities of the δ 5.7−6.3 ppm region, the endo−exo ratio was found to be 96:4, and the amount of the endo isomer was 15% that of the 2′*R* diastereomer excess (run 1). The formation of **10a** was catalyzed 10 times faster through the use of $BF_3{\cdot}OEt_2$ without any promotion of diastereoselectivity (run 2). The $MgBr_2{\cdot}OEt_2$ catalyst exhibited the reversed diastereoselectivity of an endo cycloadduct ((**1′*R*,2′*S*,4′*S*)-10a**) with high 2′*S*-preference (run 3). By the addition of $ZnCl_2$ (run 4), the endo cycloadduct was formed exclusively with high diastereoselectivity. The structure of (**1′*R*,2′*S*,4′*S*)-10a** was identified by conversion into benzyl bicyclo[2.2.1]hept-5-ene-2-carboxylate and the comparison of its optical rotation with the literature value.[17]

Table 2. Diels−Alder Reaction of 1-(α,*β*-Unsaturated)Acyl-3,5-dimethylpyrazole (2) with 1,3-Dienes (3, 5, 6, and 7) in Toluene

run	substrate	R^1	diene	*T* (°C)	pressure (bar)	Lewis acid	product	yield (%)	ratio endo:exo
1	**2a**	H	**3**	50	1	none	**4a**	99	87:13
2	**2a**	H	**3**	32	1	LiBr	**4a**	90	80:20
3	**2a**	H	**3**	32	1	$BF_3{\cdot}OEt_2$	**4a**	88	93: 7
4	**2a**	H	**3**	32	1	$MgBr_2{\cdot}OEt_2$	**4a**	90	90:10
5	**2a**	H	**3**	32	1	$ZnCl_2$	**4a**	95	97:3
6	**2a**	H	**3**	32	1	$TiCl_4$	**4a**	42	72:28
7	**2a**	H	**3**	32	1	$AlCl_3$	**4a**	52	89:11
8	**2b**	Me	**3**	80	1	none	**4b**	28	75:25
9	**2b**	Me	**3**	25	8000	none	**4b**	85	80:20
10	**2b**	Me	**3**	32	1	$MgBr_2{\cdot}OEt_2$	**4b**	93	89:11
11	**2c**	Ph	**3**	32	1	none	**4c**	17	67:33
12	**2c**	Ph	**3**	32	1	$MgBr_2{\cdot}OEt_2$	**4c**	33	78:22
13	**2c**	Ph	**3**	25	8000	none	**4c**	56	67:33
14	**2c**	Ph	**3**	25	8000	$MgBr_2{\cdot}OEt_2$	**4c**	60	74:26
15	**2d**	CO_2Et	**3**	32	1	$MgBr_2{\cdot}OEt_2$	**4d**	91	67:33
16	**2a**	H	**5**	32	1	$MgBr_2{\cdot}OEt_2$	**8a**	83	
17	**2a**	H	**6**	32	1	$MgBr_2{\cdot}OEt_2$	**8e**	90	
18	**2a**	H	**7**	32	1	$MgBr_2{\cdot}OEt_2$	**8f**	88	100:0[a]

[a] Regioisomer ratio of 4-methyl and 3-methyl derivatives of 1-(3-cyclohexene)carbonyl-3,5-dimethylpyrazoles.

Table 3. Diels−Alder Reaction of 2-(α,*β*-Unsaturated)Acyl-3-phenyl-*l*-menthopyrazole (9) with Cyclopentadiene (3)

run	substrate	R^1	Lewis acid	time (h)	yield (%)	ratio endo:exo	% de (endo) (conf)	% de (exo) (conf)
1	**9a**	H	none	17	98	96:4	15 (2′*R*)	
2	**9a**	H	BF_3·OEt_2	1.5	90	94:6	12 (2′*R*)	
3	**9a**	H	$MgBr_2$·OEt_2	2	98	96:4	84 (2′*S*)	
4	**9a**	H	$ZnCl_2$	1	98	>99:1	85 (2′*S*)	
5	**9b**	Me	none	17	56	60:40	12 (2′*S*)	27 (2′*S*)
6	**9b**	Me	$MgBr_2$·OEt_2	8	90	79:21	86 (2′*S*)	27 (2′*S*)
7	**9b**	Me	$ZnCl_2$	4	91	96:4	83 (2′*S*)	
8	**9c**	Ph	none	17	75	63:37	25 (2′*R*)	8 (2′*R*)
9	**9c**	Ph	$MgBr_2$·OEt_2	17	50	20:80	8 (2′*R*)	9 (1,*R*)
10	**9c**	Ph	$ZnCl_2$	17	65	20:80	11	1
11	**9d**	CO_2Et	none	2	99	76:24	20	
12	**9d**	CO_2Et	$MgBr_2$·OEt_2	1.5	95	60:40	80	
13	**9d**	CO_2Et	$ZnCl_2$	1	96	88:12	81 (2′*R*)	47 (2′*R*)

Scheme 2

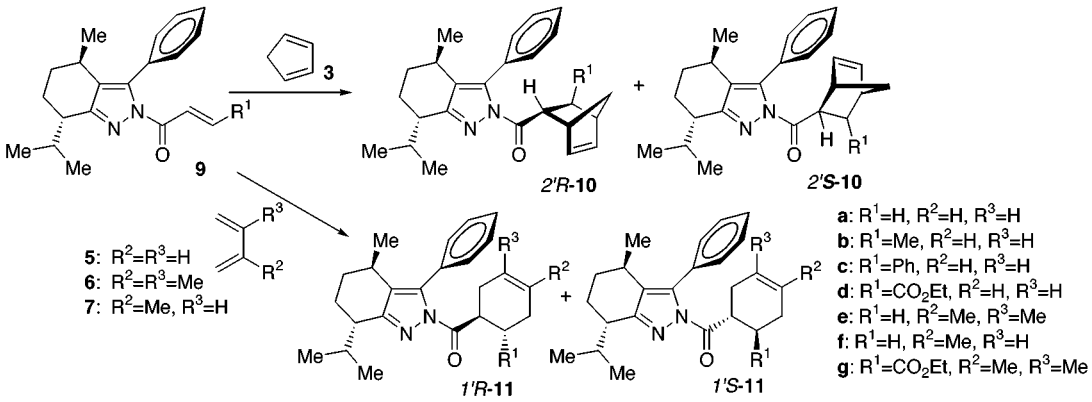

Table 4. Reaction of 2-(α,*β*-Unsaturated)acyl-3-phenyl-*l*-menthopyrazoles (9) with 1,3-Dienes (5−7)

run	dienophile	R^1	1,3-diene	R^2	R^3	Lewis acid	time (h)	product	yield (%)	% de (conf)
1	**9a**	H	**5**	H	H	None	42	**11a**	2	20(1′*R*)
2	**9a**	H	**5**	H	H	$MgBr_2$·OEt_2	17	**11a**	98	80(1′*S*)
3	**9a**	H	**5**	H	H	$ZnCl_2$	4	**11a**	97	90(1′*S*)
4	**9a**	H	**7**	Me	H	$ZnCl_2$	10	**11f**	95[a]	>95(1′*S*)
5	**9a**	H	**6**	Me	Me	None	80	**11e**	17	28(1′*R*)
6	**9a**	H	**6**	Me	Me	BF_3·OEt_2	12	**11e**	67	3(1′*S*)
7	**9a**	H	**6**	Me	Me	$MgBr_2$·OEt_2	15	**11e**	99	>95(1′*S*)
8	**9a**	H	**6**	Me	Me	$ZnCl_2$	7	**11e**	90	>95(1′*S*)
9	**9d**	CO_2Et	**5**	H	H	$ZnCl_2$	20	**11d**	90	75(1′*R*)
10	**9d**	CO_2Et	**6**	Me	Me	$MgBr_2$·OEt_2	3	**11g**	97	33(1′*S*)
11	**9d**	CO_2Et	**6**	Me	Me	$ZnCl_2$	2	**11g**	98	72(1′*R*)

[a] The regioisomer ratio was found to be 100:0.

The Diels−Alder reaction of 2-(*β*-substituted α,*β*-unsaturated)acyl-3-phenyl-*l*-menthopyrazoles (**9b**−**c**) required reaction conditions of higher pressure and/or temperature, and the formation of exo isomers (**10**) was increased, as summarized in Table 3. When the ethoxycarbonyl group at the *β*-position was introduced as an electron-withdrawing group, the reaction of **9d** was accelerated (runs 11−13). Similar reaction propensities were observed in the Diels−Alder reaction of **9** with **5** and **6**. Table 4 shows that either $MgBr_2$·OEt_2 or $ZnCl_2$ can catalyze the diastereoselective Diels−Alder reaction of **9** with 1,3-butadienes with 1′*S* preference (runs 2, 3, 7, and 8), while the alternate diastereoisomers are formed in the reactions without a catalyst (runs 1 and 5). In the case of **9d**, the stereocontrol effects of $MgBr_2$·OEt_2 and $ZnCl_2$ were rather small (runs 9−11). The stereostructure of the cycloadduct (**11**) was determined by the conversion into methyl 3-cyclohexene-1-carboxylate as well as the comparison of its optical rotation with authentic data.[18] In the case of **7**, the $ZnCl_2$-catalyzed reaction of **9a** afforded only one diastereoisomer of 2-(4′-methyl-3′-cyclohexene-1′-carbonyl)-3-phenyl-*l*-menthopyrazole ((**1′*S*)-11f**) in 95% yield (run 4).

To reveal the diastereofacial properties of **1** in more detail, a rational explanation of the diastereoselection in the Diels−Alder reaction of **9** was attempted through the use of PM3 calculations. From previous NMR studies,[9] the preferable structure of *N*-(α,*β*-unsaturated)acylpyrazoles was proposed to be the anti-s-cis form, in which the α-proton is deshielded by the anisotropic effect of the pyrazole ring. When *N*-acylpyrazoles were treated with $MgBr_2$·OEt_2, the structure changed into the syn-s-cis form, and the bond rotation between the acyl group and the pyrazole ring was fixed by the chelation of N···Mg·

(17) Evans, A.; Chapman, T. K.; Bisaha, J. *J. Am. Chem. Soc.* **1988**, *110*, 1238.

(18) Schwartz, H. M.; Wu, W.-S.; Marr, W. P.; Jones, J. B. *J. Am. Chem. Soc.* **1978**, *100*, 5199.

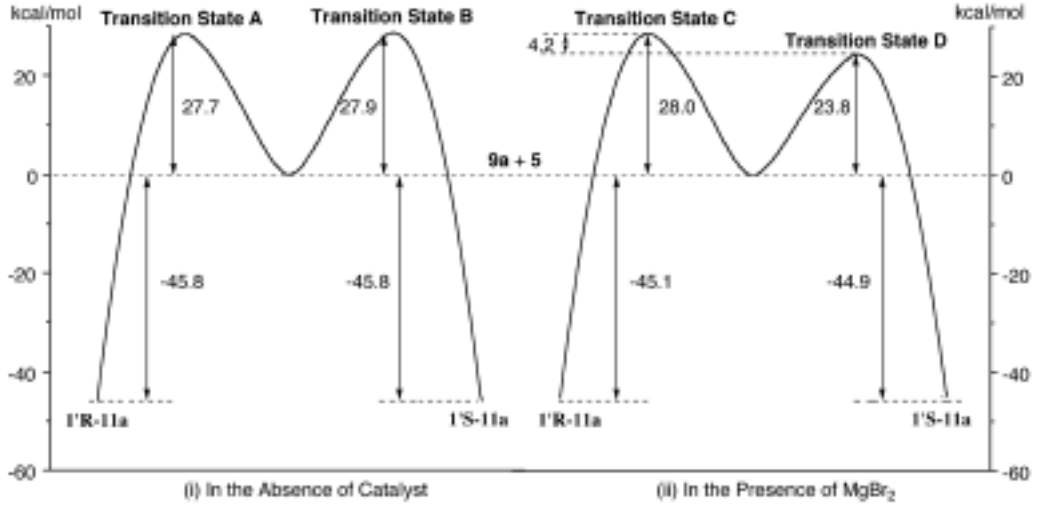

Figure 1. Reaction profile of **9a** with **5**.

Chart 1

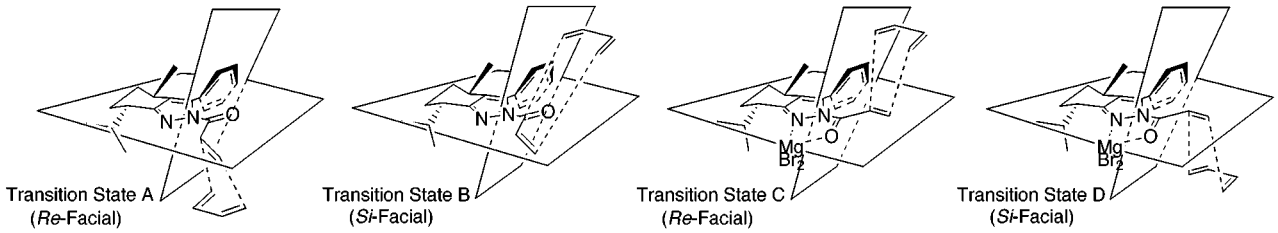

Table 5. Charges and Electron Densities of the Acrylic Moiety and the Heat of Formation (ΔH_f[a]) on 2-Acryloyl-3-phenyl-*l*-menthopyrazoles (9a)

	density		charge		ΔH_f[a]
	2′-C	3′-C	2′-C	3′-C	(kcal/mol)
9a	3.945	3.950	−0.213	0.023	55.43
9a + $MgBr_2$	3.930	3.926	−0.357	0.098	−49.18
9a + $ZnCl_2$	3.938	3.938	−0.384	0.053	2.15

[a] ΔH_f presented the heat of formation of the starting mixture of **9a** and **5** with catalyst.

··O═C. A similar structural change was anticipated with the addition of $ZnCl_2$. These structural aspects based on NMR spectra were supported by the PM3 calculation of **9a**. The electron densities of the 2′- and 3′-carbon atoms were decreased, and the double bond of the acrylic moiety was more polarized by Mg or Zn chelation, as summarized in Table 5. The bond features of the acrylic moiety also confirm previous results showing that the reaction rate is accelerated by the addition of $MgBr_2$·OEt_2 or $ZnCl_2$.

The calculation of the heats of formation (ΔH_f) was performed for the mixture of **5** and the anti-s-cis form of **9a**. The ΔH_f of the product (**11a**) was also obtained by the PM3 calculation**.** Moreover, four transition states were calculated dependent on two facial attacks of **5**, which included two transition state geometries of endo and exo approach due to the orientation of 1,3-butadiene, as summarized in Table 6 and Chart 1. The energy differences among these four transition states suggest that the diastereoselection is ineffective, and the reaction profile is shown in Figure 1i. These calculations anticipated the actual experimental fact that the reaction of **9a** and **5** in the absence of catalyst afforded (1′*R*)-2-(3′-cyclohexene-1′-carbonyl)-3-phenyl-*l*-menthopyrazole (**1′*R*-11a**) with low diastereoselectivity (Table 4, run 1).

Similarly, the reaction profile of **9a** with **5** was obtained by calculations based on the starting mixture, the transition state, and the product, including the chelating bond of N···Mg···O═C and N···Zn···O═C. The case of $MgBr_2$ shown in Figure 1ii indicates that the transition barrier of the *Re*-face attack was 4.2 kcal/mol lower than that of the *Si*-face attack. The difference of the transition barriers supported a diastereoselective reaction. Moreover, this reaction profile suggested that the diastereoselective reaction of **9a** with **5** is governed by kinetic control rather than thermodynamic control. Compared with the A and B transition states, the lower reaction barrier of transition state D could explain the acceleration of the reaction

Table 6. ΔH_f[a] (kcal/mol) of the Transition States of 2-Acryloyl-3-phenyl-*l*-menthopyrazoles (9a) and 1,3-Butadiene (5)

	none		$MgBr_2$		$ZnCl_2$	
transition state	ΔH_f[a]	ΔE[a]	ΔH_f[a]	ΔE[a]	ΔH_f[a]	ΔE[a]
Re-face/endo	83.35	27.91 (B)	−19.13	30.05	29.61	27.46
Re-face/exo	83.42	27.98	−25.42	23.76 (D)	27.17	25.02
Si-face/endo	83.92	28.48	−20.29	28.89	29.68	27.53
Si-face/exo	83.15	27.71 (A)	−21.22	27.97 (C)	28.66	26.51

[a] ΔH_f and ΔE refer to the heats of formation of the transition state and their differences from those of the starting mixture, respectively. [b] The transition states of the reaction profiles are presented in the parentheses.

by the addition of $MgBr_2 \cdot OEt_2$ (Table 4, run 2). The reaction profile of **9a** and **5** in the presence of $ZnCl_2$ (Table 4, run 3) was supported by the corresponding results of the PM3 transition-state calculations.

In conclusion, the reaction of 2-(α,β-unsaturated)acyl-3-phenyl-*l*-menthopyrazoles (**9**) with dienes gave Diels−Alder adducts in good yield. The addition of $MgBr_2 \cdot OEt_2$ or $ZnCl_2$ accelerated these reactions by the formation of chelate bonds such as N···Mg···O═C or N···Zn···O═C. The structural fixation by these catalysts also promoted the endo and diastereoselectivities of the Diels−Alder addition on the *Re*-face of the dienophile. These results were supported by PM3 transition-state calculations.

Experimental Section

^{1}H NMR data were collected on a Varian NMR Gemini-200 (200 MHz) spectrometer in deuteriochloroform with tetramethylsilane used as an internal standard. Optical rotations were observed using a JASCO DIP-370 digital polarimeter. The HPLC analysis was carried out using an SIL-C18 column on a JASCO BIP-I chromatograph using an aqueous methanol solvent. The reactions under high pressure were carried out in a Hikari-Kouatu-Kiki high-pressure reactor. The melting points are uncorrected. When the isomers of the products were hardly separated by chromatography, the elemental analyses of the isomer mixtures were performed.

Materials. Cyclopentadiene (**3**), which was freshly prepared from dicyclopentadiene by thermolysis, was used in this experiment. *N*-(α,β-Unsaturated)acylpyrazoles (**2** and **9**) were prepared by the method described previously.[9,10] 2-(2′-Ethoxycarbonyl)acryloyl-3-phenyl-*l*-menthopyrazole (**2d**) was prepared from **1** (2.54 g, 9.99 mmol) and fumaric acid monoethyl ester (1.58 g, 11.0 mmol) in the action of thionyl chloride (0.81 mL, 11.1 mmol): yield 55%; IR ($CHCl_3$) 3027, 1709, 1359, 1351, 1304; ^{1}H NMR δ 0.72 (3H, d, J = 6.8 Hz), 0.93 (3H, d, J = 6.6 Hz), 1.10 (3H, d, J = 7.0 Hz), 1.33 (3H, t, J = 7.1 Hz), 1.18−1.37 (1H, m), 1.44−1.59 (1H, m), 1.87−2.00 (2H, m), 2.45−2.54 (1H, m), 2.61−2.79 (2H, m), 4.28 (2H, q, J = 7.1 Hz), 6.90 (1H, d, J = 15.6 Hz), 7.26−7.44 (5H, m), 8.30 (1H, d, J = 15.8 Hz); ^{13}C NMR δ 13.6 (CH_3), 17.9 (CH_3), 19.6 (CH_3), 19.9 (CH_3), 22.2 (CH_2), 27.1 (CH), 29.3 (CH), 31.6 (CH_2), 40.9 (CH), 60.8 (CH_2), 127.6 (CH), 127.9 (CH), 128.9 (CH), 133.4 (CH), 133.6 (CH), 156.7 (C).

Anal. Calcd for $C_{23}H_{28}N_2O_3$: C, 72.60; H, 7.42; N, 7.36. Found: C, 72.30; H, 7.58; N, 7.29.

Optimization of the Reaction Conditions. To the mixture of **2a** (150 mg, 1.0 mmol), Lewis acid (1.1 mmol), and benzophenone (ca. 40 mg, as an internal standard) in various solvents (8 mL) was added **3** (0.83 mL, 10 mmol), and the mixture was kept at the observed temperature under nitrogen atmosphere. A part of the mixture was quenched with triethylamine at the indicated times and was monitored by HPLC. The results are summarized in Table 1.

General Procedure for the Diels−Alder Reaction. A mixture of *N*-(α,β-unsaturated)acylpyrazole (**2** or **9**) (0.55 mmol) and $MgBr_2 \cdot OEt_2$ (157 mg, 0.61 mmol) in toluene (4.4 mL) was kept for 15 min at 32 °C. 1,3-Diene (1.1 mmol) was added to the mixture and the resulting mixture kept at 32 °C for another 3 h with stirring. The reaction mixture was quenched with water and extracted with CH_2Cl_2. The organic layer was washed with dilute hydrochloric acid, water, aqueous $NaHCO_3$, and aqueous NaCl and dried over anhydrous $MgSO_4$. The solvent was removed. From the olefinic peak intensities in the ^{1}H NMR spectrum and/or the HPLC peaks, the diastereomer ratio was evaluated. The residue was then chromatographed on a silica gel column with a benzene−hexane mixture. In the case of a high-pressure reaction, the mixture was pressed for 17 h and then concentrated. The residue was worked up as described above.

Endo-1-(bicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3,5-dimethylpyrazole (4a): IR ($CHCl_3$) 3029, 1720, 1582, 1378, 1361; ^{1}H NMR δ 1.46−1.56 (3H, m), 1.83−2.03 (1H, m), 2.25 (3H, s), 2.48 (3H, d, J = 0.7 Hz), 2.96 (1H, s), 3.41 (1H, s), 4.08−4.14 (1H, m), 5.87−5.93 (1H, m), 5.93 (1H, s), 6.25−6.28 (1H, m); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 29.2 (CH_2), 42.5 (CH), 43.0 (CH), 47.0 (CH), 49.8 (CH_2), 110.3 (CH), 131.3 (CH), 137.5 (CH), 143.6 (C), 151.1 (C), 174.8 (C).

Anal. Calcd for $C_{13}H_{16}N_2O$: C, 72.19; H, 7.46; N, 12.95. Found: C, 71.82; H, 7.44; N, 12.99.

1-(3′-Methylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3,5-dimethylpyrazole (4b): IR ($CHCl_3$) 3026, 1717, 1582, 1380, 1333.

Anal. Calcd for $C_{14}H_{18}N_2O$: C, 73.01; H, 7.88; N, 12.16. Found: C, 72.77; H, 7.98; N, 12.29.

2′-Endo-3′-exo-isomer: ^{1}H NMR δ 1.20 (3H, d, J = 6.8 Hz), 1.44−1.49 (1H, m), 1.71−1.81 (1H, m), 2.01−2.11 (1H, m), 2.26 (3H, s), 2.48 (3H, d, J = 0.7 Hz), 2.54−2.55 (1H, m), 3.35 (1H, s), 3.62−3.65 (1H, m), 5.86−5.93 (1H, m), 5.94 (1H, s), 6.35−6.38 (1H, m); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 20.0 (CH_3), 36.5 (CH_2), 46.6 (CH), 47.9 (CH), 49.1 (CH), 51.5 (CH), 110.3 (CH), 131.6 (CH), 138.6 (CH), 143.6 (C), 151.0 (C), 174.6 (C).

2′-Exo-3′-endo-isomer: ^{1}H NMR δ 0.97 (3H, d, J = 6.8 Hz), 1.42−1.46 (1H, m), 1.75−1.87 (1H, m), 2.22 (3H, s), 2.47−2.55 (1H, m), 2.54 (3H, d, J = 0.7 Hz), 2.76 (1H, s), 2.98−3.04 (2H, m), 5.95 (1H, s), 6.18−6.21 (1H, m), 6.30−6.34 (1H, m).

1-(3′-Phenylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3,5-dimethylpyrazole (4c): mp 82−83 °C (from hexane); IR ($CHCl_3$) 3063, 3029, 1714, 1601, 1584, 1383, 1335.

Anal. Calcd for $C_{19}H_{20}N_2O$: C, 78.05; H, 6.9; N, 9.58. Found: C, 77.95; H, 6.93; N, 9.64.

2′-Endo-3′-exo-isomer: ^{1}H NMR δ 1.48−1.65 (2H, m), 1.99−2.03 (1H, m), 2.21 (3H, s), 2.50 (3H, s), 3.06 (1H, s), 3.56 (1H, s), 4.24−4.28 (1H, m), 5.93 (1H, s), 5.95−5.99 (1H, m), 6.51−6.55 (1H, m), 7.14−7.33 (5H, m); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 46.3 (CH_2), 47.8 (CH), 48.3 (CH), 48.9 (CH), 51.0 (CH), 110.5 (CH), 125.6 (CH), 127.3 (CH), 128.1 (CH), 132.6 (CH), 135.8 (C), 139.3 (CH), 143.8 (C), 151.3 (C), 174.0 (C).

2′-Exo-3′-endo-isomer: ^{1}H NMR δ 1.48−1.53 (1H, m), 1.92−1.99 (1H, m), 2.17 (3H, s), 2.53 (3H, s), 3.18 (1H, s), 3.34−3.37 (2H, m), 3.92−3.95 (1H, m), 5.93 (1H, s), 6.05−6.08 (1H, m), 6.45−6.53 (1H, m), 7.14−7.33 (5H, m).

1-(3′-Ethoxycarbonylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3,5-dimethylpyrazole (4d): IR ($CHCl_3$) 3027, 1720, 1583, 1379, 1335, 1271, 1183.

Anal. Calcd for $C_{16}H_{20}N_2O_3$: C, 66.65; H, 6.99; N, 9.72. Found: C, 66.50; H, 7.02; N, 9.66.

2′-Endo-3′-exo-isomer: ^{1}H NMR δ 1.27 (3H, t, J = 7.2 Hz), 1.41−1.51 (1H, m), 1.84−1.89 (1H, m), 2.22 (3H, s), 2.47 (3H, d, J = 0.6 Hz), 2.76−2.79 (1H, m), 3.14 (1H, d, J = 1.4 Hz), 3.49 (1H, d, J = 5 Hz), 4.08−4.24 (2H, m), 4.36−4.40 (1H, m), 5.93 (1H, d, J = 0.6 Hz), 6.07−6.11 (1H, m), 6.29−6.33 (1H, m); ^{13}C NMR δ 13.3 (CH_3), 13.8 (CH_3), 13.9 (CH_3), 45.2 (CH), 46.5 (CH), 47.0 (CH), 47.2 (CH_2), 60.2 (CH_2), 110.5 (CH), 134.6 (CH), 136.9 (CH), 143.6 (C), 151.4 (C), 173.1 (C), 174.3 (C).

2′-Exo-3′-endo-isomer: ^{1}H NMR δ 1.23 (3H, t, J = 7.2 Hz), 1.41−1.51 (1H, m), 1.65−1.70 (1H, m), 2.35 (3H, s), 2.53 (3H, d, J = 0.8 Hz), 3.20 (1H, s), 3.21 (1H, s), 3.48−3.55 (1H, m), 3.83−3.86 (1H, m), 4.05−4.24 (2H, m), 5.94 (1H, s), 6.13−6.17 (1H, m), 6.39−6.43 (1H, m).

1-(3′-Cyclohexenecarbonyl)-3,5-dimethylpyrazole (8a): IR ($CHCl_3$) 3030, 1721, 1384, 1344, 1335; ^{1}H NMR: δ 1.66−1.87 (1H, m), 1.99−2.20 (3H, m), 2.23 (3H, s), 2.31−2.35 (2H, m), 2.54 (3H, d, J = 1.0 Hz), 3.83−3.96 (1H, m), 5.73 (2H, s), 5.96 (1H, d, J = 0.4 Hz); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 24.0 (CH_2), 24.7 (CH_2), 27.3 (CH_2), 38.1 (CH), 110.7 (CH), 124.9 (CH), 126.1 (CH), 143.7 (C), 151.4 (C), 176.7 (C).

Anal. Calcd for $C_{12}H_{16}N_2O$: C, 70.56; H, 7.9; N, 13.71. Found: C, 70.61; H, 7.91; N, 13.77.

1-(3′,4′-Dimethyl-3′-cyclohexenecarbonyl)-3,5-dimethylpyrazole (8e): IR ($CHCl_3$) 3029, 1720, 1386, 1342; ^{1}H NMR δ 1.61 (6H, s), 1.67−1.82 (1H, m), 1.89−2.04 (3H, m), 2.21 (3H, s), 2.21−2.26 (1H, m), 2.51 (3H, m), 3.76−3.94 (1H, m), 5.92 (1H, s); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 18.3 (CH_3), 18.4 (CH_3), 25.4 (CH_2), 30.5 (CH_2), 33.7 (CH_2), 39.0 (CH), 110.6 (CH), 127.9 (C), 131.2 (C), 143.6 (C), 151.3 (C), 176.8 (C).

Anal. Calcd for $C_{14}H_{20}N_2O$: C, 72.38; H, 8.68; N, 12.06. Found: C, 72.33; H, 8.47; N, 12.07.

1-(4′-Methyl-3′-cyclohexenecarbonyl)-3.5-dimethylpyrazole (8f): IR ($CHCl_3$) 3030, 1721, 1385, 1338, 1221, 1210; ^{1}H NMR δ 1.68 (3H, s), 1.73−1.91 (2H, m), 1.94−2.40 (4H, m), 2.23 (3H, s), 2.53 (3H, d, J = 1.0 Hz), 3.75−3.90 (1H, m), 5.41−5.43 (1H, m), 5.95 (1H, s); ^{13}C NMR δ 13.3 (CH_3), 14.1 (CH_3), 22.9 (CH_3), 25.1 (CH_2), 27.6 (CH_2), 28.9 (CH_2), 38.1 (CH), 110.6 (CH), 119.0 (CH), 133.2 (C), 143.6 (C), 151.3 (C), 176.9 (C).

Anal. Calcd for $C_{13}H_{18}N_2O$: C, 71.53; H, 8.31; N, 12.83. Found: C, 71.62; H, 8.41; N, 12.79.

2-(Bicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3-phenyl-*l*-menthopyrazole (10a): IR ($CHCl_3$) 3063, 2960, 1723, 1572, 1360, 1280.

Anal. Calcd for $C_{25}H_{30}N_2O$: C, 80.17; H, 8.07; N, 7.48. Found: C, 79.78; H, 8.0; N, 7.45.

(1′*R*,2′*S*,4′*S*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.6 Hz), 0.94 (3H, d, J = 7.2 Hz), 1.09 (3H, d, J = 6.8 Hz), 1.18−1.32 (1H, m), 1.43−1.61 (4H, m), 1.85−1.97 (3H, m), 2.30−2.52 (1H, m), 2.59−2.79 (2H, m), 2.90 (1H, s), 3.43 (1H, s), 4.06−4.17 (1H, m), 5.95−5.99 (1H, m), 6.16−6.19 (1H, m), 7.11−7.40 (5H, m); ^{13}C NMR δ 18.2 (CH_3), 19.7 (CH_3), 19.9 (CH_3), 22.7 (CH_2), 26.9 (CH), 29.5 (CH_2), 29.5 (CH), 31.9 (CH_2), 41.0 (CH), 42.5 (CH), 43.8 (CH), 46.7 (CH), 49.6 (CH_2), 125.2 (C), 127.5 (CH), 127.6 (CH), 128.8 (CH), 131.7 (CH), 132.5 (C), 137.3 (CH), 140.5 (C), 154.9 (C), 173.6 (C).

(1′*S*,2′*S*,4′*S*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.6 Hz), 0.98 (3H, d, J = 6.8 Hz), 1.12 (3H, d, J = 5.8 Hz), 1.18−1.32 (1H, m), 1.43−1.61 (4H, m), 1.85−1.97 (3H, m), 2.30−2.52 (1H, m), 2.59−2.79 (2H, m), 2.90 (1H, s), 3.43 (1H, s), 4.06−4.17 (1H, m), 5.74−5.78 (1H, m), 6.12−6.16 (1H, m), 7.11−7.40 (5H, m).

2-(3′-Methylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3-phenyl-*l*-menthopyrazole (10b): IR ($CHCl_3$) 3063, 1721, 1571, 1369, 1324.

Anal. Calcd for $C_{26}H_{32}N_2O$: C, 80.37; H, 8.3; N, 7.21. Found: C, 80.54; H, 8.46; N, 7.17.

(1′*R*,2′*S*,3′*R*,4′*S*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.6 Hz), 0.93 (3H, d, J = 6.8 Hz), 1.10 (3H, d, J = 7.0 Hz), 1.16 (3H, d, J = 7.0 Hz), 1.28−1.32 (2H, m), 1.42−1.61 (2H, m), 1.70−1.74 (1H, m), 1.82−2.01 (3H, m), 2.48 (1H, s), 2.59−2.80 (2H, m), 3.39 (1H, s), 3.59−3.68 (1H, m), 5.94−5.98 (1H, m), 6.26−6.31 (1H, m), 7.20−7.40 (5H, m); ^{13}C NMR δ 18.0 (CH_3), 19.6 (CH_3), 20.0 (CH_3), 22.6 (CH_2), 26.9 (CH), 29.4 (CH), 31.9 (CH_2), 36.4 (CH), 41.0 (CH), 46.5 (CH), 47.9 (CH), 49.1 (CH_2), 51.8 (CH), 127.1 (C), 127.5 (CH), 128.7 (CH), 131.8 (CH), 132.6 (C), 138.4 (CH), 155.0 (C), 173.6 (C).

(1′*S*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.6 Hz), 0.86 (3H, d, J = 6.6 Hz), 1.08 (3H, d, J = 6.8 Hz), 1.16 (3H, d, J = 7.0 Hz), 1.28−1.32 (2H, m), 1.42−1.61 (2H, m), 1.70−1.74 (1H, m), 1.82−2.01 (3H, m), 2.48 (1H, s), 2.59−2.80 (2H, m), 3.39 (1H, s), 3.59−3.68 (1H, m), 5.73−5.76 (1H, m), 6.15−6.19 (1H, m), 7.20−7.40 (5H, m).

(1′*S*,2′*S*,3′*R*,4′*S*)-Isomer: ^{1}H NMR δ 0.68 (3H, d, J = 6.8 Hz), 0.94 (3H, d, J = 7.0 Hz), 1.00 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 7.0 Hz), 1.15−1.36 (2H, m), 1.40−1.70 (1H, m), 1.76−2.01 (2H, m), 2.26−2.48 (2H, m), 2.50−2.82 (3H, m), 2.69 (1H, s), 2.95 (1H, s), 2.95−3.07 (1H, m), 6.15−6.19 (1H, m), 6.28−6.33 (1H, m), 7.03−7.42 (5H, m).

(1′*R*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.8 Hz), 0.89 (3H, d, J = 6.8 Hz), 0.97 (3H, d, J = 6.8 Hz), 1.08 (3H, d, J = 6.8 Hz), 1.15−1.36 (2H, m), 1.40−1.70 (1H, m), 1.76−2.01 (2H, m), 2.26−2.48 (2H, m), 2.50−2.82 (3H, m), 2.69 (1H, s), 2.95 (1H, s), 2.95−3.07 (1H, m), 6.15−6.19 (1H, m), 6.27−6.31 (1H, m), 7.03−7.42 (5H, m).

2-(3′-Phenylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3-phenyl-*l*-menthopyrazole (10c): IR ($CHCl_3$) 3063, 1719, 1602, 1581, 1368, 1334.

Anal. Calcd for $C_{31}H_{34}N_2O$: C, 82.63; H, 7.61; N, 6.22. Found: C, 82.56; H, 7.56; N, 6.19.

(1′*R*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.68 (3H, d, J = 6.6 Hz), 0.95 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 7.0 Hz), 1.19−1.31 (1H, m), 1.40−1.68 (2H, m), 1.76−2.00 (3H, m), 2.31−2.52 (1H, m), 2.55−2.65 (1H, m), 2.69−2.79 (1H, m) 3.02 (1H, s), 3.25−3.30 (1H, m), 3.57 (1H, s), 4.22−4.27 (1H, m), 5.86−5.90 (1H, m), 6.36−6.40 (1H, m), 7.11−7.38 (10H, m); ^{13}C NMR δ 17.9 (CH_3), 19.8 (CH_3), 20.0 (CH_3), 22.3 (CH_2), 26.9 (CH), 29.4 (CH), 31.7 (CH_2), 40.8 (CH), 46.1 (CH), 47.6 (CH), 48.6 (CH), 48.7 (CH_2), 51.6 (CH), 125.5 (C), 127.3 (CH), 127.3 (CH), 127.5 (CH), 127.5 (CH), 127.7 (CH), 128.0 (CH), 128.7 (C), 128.9 (CH), 132.6 (C), 139.1 (CH), 144.1 (C), 155.2 (C), 172.7 (C).

(1′*S*,2′*S*,3′*R*,4′*S*)-Isomer: ^{1}H NMR δ 0.68 (3H, d, J = 6.6 Hz), 0.95 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 7.0 Hz), 1.19−1.31 (1H, m), 1.40−1.68 (2H, m), 1.76−2.00 (3H, m), 2.31−2.52 (1H, m), 2.55−2.65 (1H, m), 2.69−2.79 (1H, m) 3.02 (1H, s), 3.25−3.30 (1H, m), 3.63 (1H, s), 4.35−4.39 (1H, m), 6.05−6.10 (1H, m), 6.44−6.48 (1H, m), 7.11−7.38 (10H, m).

(1′*S*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.66 (3H, d, J = 6.6 Hz), 1.00 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 6.8 Hz), 1.14−1.29 (1H, m), 1.38−1.59 (2H, m), 1.76−1.97 (2H, m), 2.17−2.36 (1H, m), 2.51−2.58 (1H, m), 2.61−2.77 (1H, m), 3.10 (1H, s), 3.15 (1H, s), 3.90 (1H, br s), 6.03−6.07 (1H, m), 6.41−6.45 (1H, m), 7.15−7.39 (10H, m).

2-(3′-Ethoxycarbonylbicyclo[2.2.1]hept-5′-ene-2′-carbonyl)-3-phenyl-*l*-menthopyrazole (10d): IR ($CHCl_3$) 3064, 1720, 1581, 1332, 1321.

Anal. Calcd for $C_{28}H_{34}N_2O_3$: C, 75.31; H, 7.67; N, 6.27. Found: C, 75.16; H, 7.55; N, 6.22.

(1′*R*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.67 (3H, d, J = 6.8 Hz), 0.91 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 6.8 Hz), 1.23 (3H, t, J = 7.1 Hz), 1.16−1.31 (1H, m), 1.39−1.67 (2H, m), 1.76−2.01 (3H, m), 2.37−2.53 (1H, m), 2.61−2.82 (3H, m), 3.12 (1H, s), 3.56 (1H, s), 4.01−4.25 (2H, m), 4.45−4.49 (1H, m), 6.08−6.12 (1H, m), 6.26−6.30 (1H, m), 7.18−7.39 (5H, m); ^{13}C NMR δ 13.8 (CH_3), 17.6 (CH_3), 19.6 (CH_3), 20.1 (CH_3), 21.9 (CH_2), 26.9 (CH), 29.2 (CH), 31.7 (CH_2), 40.9 (CH), 46.5 (CH), 46.8 (CH), 47.0 (CH), 47.4 (CH), 49.0 (CH_2), 60.2 (CH_2), 125.4 (C), 127.5 (CH), 127.7 (CH), 128.7 (C), 128.8 (CH), 134.7 (CH), 136.8 (C), 137.3 (CH), 155.4 (C), 171.9 (C), 174.4 (C).

(1′*S*,2′*R*,3′*S*,4′*R*)-Isomer: ^{1}H NMR δ 0.69 (3H, d, J = 6.6 Hz), 0.91 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 6.8 Hz), 1.27 (3H, t, J = 7.2 Hz), 1.21−1.32 (1H, m), 1.40−1.67 (2H, m), 1.77−2.01 (3H, m), 2.34−2.52 (1H, m), 2.59−2.82 (3H, m), 3.22 (1H, s), 3.30 (1H, s), 3.44−3.52 (1H, m), 3.89−3.98 (1H, m), 3.99−4.24 (2H, m), 6.09−6.14 (1H, m), 6.36−6.40 (1H, m), 7.19−7.41 (5H, m).

(1′*S*)-2-(3′-Cyclohexenecarbonyl)-3-phenyl-*l*-menthopyrazole (11a): IR ($CHCl_3$) 3029, 1713, 1556, 1459; ^{1}H NMR δ 0.69 (3H, d, J = 6.6 Hz), 0.95 (3H, d, J = 6.8 Hz), 1.08 (3H, d, J = 7.0 Hz), 1.14−1.33 (1H, m), 1.43−1.73 (2H, m), 1.82−2.23 (5H, m), 2.30−2.47 (3H, m), 2.57−2.81 (2H, m), 3.83−3.98 (1H, m), 5.75 (2H, AB, J = 4.0 Hz), 7.24−7.44 (5H, m); ^{13}C NMR δ 17.7 (CH_3), 19.3 (CH_3), 20.2 (CH_3), 20.3 (CH_2), 24.0 (CH_2), 24.7 (CH_2), 26.6 (CH), 27.0 (CH), 29.7 (CH_2), 31.2 (CH_2), 38.9 (CH), 39.3 (CH), 125.0 (C), 126.3 (CH), 127.1 (CH), 127.2 (CH), 127.2 (CH), 128.1 (CH), 128.8 (C), 132.5 (C), 146.0 (C), 180.3 (C).

Anal. Calcd for $C_{24}H_{30}N_2O$: C, 79.52; H, 8.34; N, 7.73. Found: C, 79.54; H, 8.29; N, 7.48.

(1′*R*,2′*R*)-2-(6′-Ethoxycarbonyl-3′-cyclohexenecarbonyl)-3-phenyl-*l*-menthopyrazole (11d): IR ($CHCl_3$) 3030, 1724, 1581, 1368, 1321; ^{1}H NMR δ 0.70 (3H, d, J = 6.6 Hz), 0.95 (3H, d, J = 6.6 Hz), 1.05−1.12 (6H, m), 1.16−1.33 (2H, m), 1.43−1.60 (1H, m), 1.79−2.00 (2H, m), 2.13−2.33 (2H, m), 2.39−2.56 (1H, m), 2.59−2.80 (3H, m), 2.88−3.02 (1H, m), 3.90−4.32 (3H, m), 5.71 (2H, AB, J = 1.6 Hz), 7.09−7.38 (5H, m); ^{13}C NMR δ 13.5 (CH_3), 18.0 (CH_3), 19.7 (CH_3), 20.0 (CH_3), 22.5 (CH_2), 26.9 (CH), 27.6 (CH_2), 28.5 (CH_2), 29.4 (CH), 31.7 (CH_2), 40.2 (CH), 40.5 (CH), 40.9 (CH), 59.9 (CH_2), 124.5 (CH), 125.0 (C), 125.7 (C), 127.4 (CH), 127.6 (CH), 128.8 (CH), 132.3 (C), 140.4 (C), 155.5 (C), 174.3 (C), 174.6 (C).

Anal. Calcd for $C_{27}H_{34}N_2O_3$: C, 74.62; H, 7.89; N, 6.45. Found: C, 74.60; H, 7.92; N, 6.51.

(1′*S*)-2-(3′,4′-Dimethyl-3′-cyclohexenecarbonyl)-3-phenyl-*l*-menthopyrazole (11e): IR ($CHCl_3$) 1709, 1458, 1560, 1458; ^{1}H NMR: δ 0.68 (3H, d, J = 6.8 Hz), 0.94 (3H, d, J = 6.8 Hz), 1.07 (3H, d, J = 7.0 Hz), 1.21−1.43 (1H, m), 1.48−1.69 (2H, m), 1.62 (6H, s), 1.82−2.47 (8H, m), 2.57−2.81 (2H, m), 3.80−3.96 (1H, m), 7.26−7.41 (5H, m); ^{13}C NMR δ 18.4 (CH_3), 18.5 (CH_3), 18.6 (CH_2), 19.3 (CH_3), 20.3 (CH_3), 20.7 (CH_3), 25.4 (CH), 26.7 (CH_2), 30.7 (CH), 30.8 (CH_2), 33.6 (CH_2), 33.9 (CH_2), 37.6

(CH), 39.4 (CH), 123.8 (C), 124.2 (C), 124.8 (C), 127.2 (CH), 128.1 (CH), 128.1 (CH), 133.2 (C), 145.4 (C), 151.5 (C), 176.9 (C).

Anal. Calcd for $C_{26}H_{34}N_2O$: C, 79.96; H, 8.77; N, 7.17. Found: C, 79.84; H, 8.79; N, 6.99.

(1′*S*)-2-(4′-Methyl-3′-cyclohexenecarbonyl)-3-phenyl-*l*-menthopyrazole (11f): IR ($CHCl_3$) 3022, 1716, 1560, 1210; ^{1}H NMR δ 0.69 (3H, d, J = 6.8 Hz), 0.95 (3H, d, J = 6.8 Hz), 1.08 (3H, d, J = 6.8 Hz), 1.16−1.33 (1H, m), 1.43−1.76 (2H, m), 1.67 (3H, m), 1.82−2.15 (5H, m), 2.32−2.48 (3H, m), 2.60−2.81 (2H, m), 3.77−3.91 (1H, m), 5.42 (1H, s), 7.24−7.39 (5H, m); ^{13}C NMR δ 17.7 (CH_3), 19.3 (CH_3), 20.2 (CH_3), 20.4 (CH_2), 21.4 (CH_3), 23.0 (CH_2), 25.0 (CH_2), 26.6 (CH), 28.8 (CH), 29.7 (CH_2), 31.2 (CH_2), 38.8 (CH), 39.3 (CH), 119.0 (C), 127.1 (CH), 127.2 (CH), 127.4 (CH), 128.1 (CH), 133.4 (C), 144.0 (C), 146.0 (C), 80.5 (C).

Anal. Calcd for $C_{25}H_{32}N_2O$: C, 79.74; H, 8.57; N, 7.44. Found: C, 79.41; H, 8.28; N, 7.12.

(1′*R*,6′*R*)-2-(3′,4′-Dimethyl-6′-ethoxycarbonyl-3′-cyclohexenecarbonyl)-3-phenyl-*l*-menthopyrazole (11g): IR ($CHCl_3$) 3029, 1724, 1210; ^{1}H NMR δ 0.70 (3H, d, J = 6.8 Hz), 0.94 (3H, d, J = 6.8 Hz), 1.09 (3H, d, J = 6.8 Hz), 1.09 (3H, t, J = 7.2 Hz), 1.19−1.33 (2H, m), 1.64 (6H, s), 1.84−2.03 (2H, m), 2.03−2.35 (3H, m), 2.37−2.52 (2H, m), 2.57−2.98 (3H, m), 3.90−4.30 (3H, m), 7.24−7.39 (5H, m); ^{13}C NMR δ 13.5 (CH_3), 18.0 (CH_3), 18.2 (CH_3), 19.7 (CH_3), 20.0 (CH_3), 22.4 (CH_2), 26.8 (CH_2), 29.3 (CH_2), 31.7 (CH_2), 33.7 (CH), 34.6 (CH), 40.9 (CH), 41.2 (CH), 59.8 (CH_2), 123.5 (C), 123.9 (C), 125.6 (C), 127.4 (CH), 127.6 (CH), 128.0 (C), 128.7 (C), 132.4 (C), 155.4 (C), 174.3 (C), 174.8 (C).

Anal. Calcd for $C_{29}H_{38}N_2O_3$: C, 75.29; H, 8.28; N, 6.06. Found: C, 75.07; H, 8.48; N, 5.88.

Benzyl (1′*R*,2′*S*,4′*S*)-Bicyclo[2.2.1]hept-5-ene-2-carboxylate. The mixture of (1′*R*,2′*S*,4′*S*)-**10a** (395 mg, 1.0 mmol), benzyl alcohol (0.33 mL, 3.1 mmol), and BF_3·OEt_2 (0.27 mL, 2.1 mmol) in THF (4 mL) was heated for 18 h at 60 °C, and the reaction mixture was worked up as usual. Benzyl (1*R*,2*S*,4*S*)-bicyclo[2.2.1]hept-5-ene-2-carboxylate was purified by silica gel column chromatography with hexanes−ethyl acetate mixture: yield 75%; ^{1}H NMR δ 1.23−1.28 (1H, m), 1.38−1.51 (2H, m), 1.84−1.97 (1H, m), 2.89−2.90 (1H, m), 2.95−3.04 (1H, m), 3.22−3.23 (1H, m), 5.06 (2H, AB-q, J = 12.6 Hz), 5.87 (1H, d−d, J = 5.6, 2.8 Hz), 6.18 (1H, d−d, J = 5.6, 3.0 Hz), 7.34 (5H, s); $[\alpha]^{19}_D$ −106.1° (*c* 1.79, $CHCl_3$) [ref[17] $[\alpha]_D$ −129° (*c* 1.39, $CHCl_3$)].

Methyl (1*S*)-3-Cyclohexenecarboxylate. The Diels−Alder adduct ((***S*)-11a**) (530 mg, 1.7 mmol) was treated with BF_3·OEt_2 (0.43 mL, 3.4 mmol) in methanol (3.4 mL) at 60 °C for 17 h with stirring. Methyl (1*S*)-3-cyclohexenecarboxylate was purified by silica gel column chromatography with benzene: yield 70%; ^{1}H NMR δ 1.60−1.78 (1H, m), 1.96−2.00 (1H, m), 2.00−2.12 (2H, m), 2.23−2.26 (2H, m), 2.49−2.60 (1H, m), 3.69 (3H, s), 5.68 (2H, s), 7.38 (5H, s); $[\alpha]^{19}_D$ −68.4° (*c* 1.60, $CHCl_3$) [ref[18] $[\alpha]^{25}_D$ −86.3°(*c* 1.0, $CHCl_3$)].

PM3 Calculation of the Structures and the Transition States. All geometries of starting mixture and the products were optimized with use of the PM3 method by Spartan v.4.1.1. software package on an SGI indigo^2 computer. The temporary geometries of the transition states were set by the extension of the bond length of the products and then calculated by gradient norm minimization.

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