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Synthesis of *exo*-Imidazolidin-2-one Dienes, Their Isomerization, and Selectivity in Diels−Alder Cycloadditions

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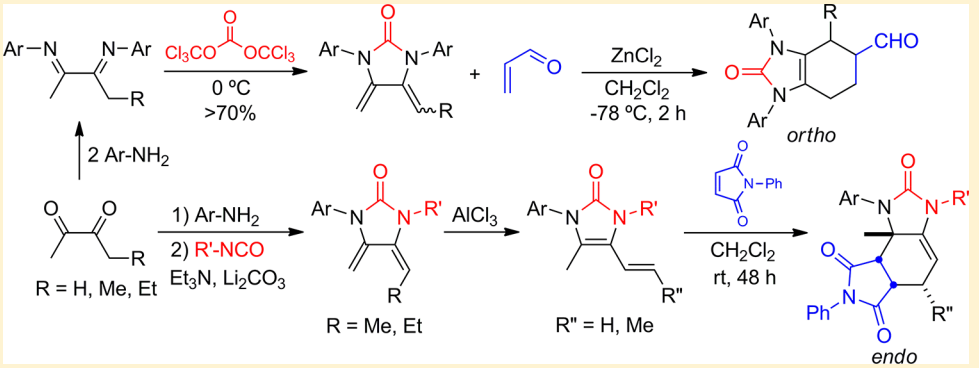
Supporting Information



ABSTRACT: An efficient and alternative synthesis of *exo*-imidazolidin-2-one dienes is described. A condensation reaction was carried out with bis-imino derivatives, diacetyl, and triphosgene, affording symmetrically *N*,*N*-disubstituted dienes. The use of alkyl methyl α-diketones led to the formation of nonsymmetrical dienes, which underwent isomerization to provide more stable *inner-outer*-ring dienes under Lewis acid conditions. Evaluation was made of the reactivity as well as regio- and stereoselectivity of these dienes in Diels−Alder reactions. They proved to be highly reactive and selective. DFT calculations of the transition states accounted for their behavior.

INTRODUCTION

Diels−Alder cycloaddition is a pericyclic reaction and one of the cornerstones of organic chemistry for the experimental and theoretical study of concerted reactions.[1] It is also a very useful methodological tool for designing the regio- and stereoselective synthesis of natural products containing six-membered rings.[2] Diels−Alder reactions are usually conducted through a synchronical, nonsynchronical, or diradicaloid concerted transition state,[1−3] or take place by coupling of two pseudoradical centers.[1f] However, there is evidence of nonpolar stepwise diradical[3b] and polar stepwise (zwitterionic) mechanisms.[4] The reactivity and stereochemical outcome of the process depend on diverse structural and electronic effects mainly due to the nature of the substituents on the diene and dienophile.[1,2,5]

Outer-ring *exo*-heterocyclic dienes have attracted much attention owing to the fact that heteroatoms enhance their reactivity in Diels−Alder additions.[6] Through this process, the heterocycle can be readily incorporated into the cyclohexene-fused polycyclic, increasing the synthetic versatility of the adducts. These attractive structural features are sometimes enhanced when the diene is partly integrated into the heterocycle as an *inner-outer*-ring diene, resulting in greater reactivity and selectivity.[6a,f,7] Nevertheless, both diene classes are relevant as potential synthons for the construction of polycyclic scaffolds and represent a huge theoretical challenge with respect to the evaluation of the substituent effects controlling either reactivity or regio- and stereoselectivity in Diels−Alder cycloadditions.[8]

Owing to our interest in designing novel outer-ring heterocyclic dienes,[9] we recently described the synthesis of *N*,*N*-disubstituted *exo*-2-imidazolidinone dienes **5**,[10] carried out through a base-assisted condensation/cyclization cascade

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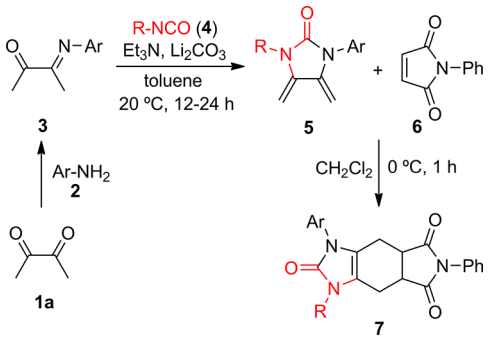
reaction of the monoimino diacetyl (**1a**) derivatives **3** with isocyanates **4** in the presence of a dehydrating agent (Scheme 1). These dienes proved to be highly reactive in Diels–Alder

Scheme 1. Synthesis of *exo*-2-Imidazolidinone Dienes 5 and Their Diels–Alder Reactions



additions with **6**, leading to the tricyclic adducts **7**, but showed only a modest regioselectivity with monosubstituted dienophiles.[10]

Due to the relevance of *exo*-heterocyclic dienes, the potential of dienes **5** for the synthesis of vicinal diamino compounds[11] and pharmacologically active benzimidazol-2-ones,[12] and the challenge in designing dienes such as **5** for highly regioselective [4 + 2] cycloadditions, we herein describe a novel and efficient approach for the preparation of dienes **5**. We also present the synthesis of new alkyl substituted dienes **12**–**15**, which proved to be reactive and regioselective in these reactions. The current endeavor led to the formation of novel *inner-outer*-heterocyclic dienes **16** and **17** through the thermal and acid-promoted isomerization of dienes **12**/**13**. The reactivity and selectivity of such dienes were experimentally evaluated, and a computational study was conducted to understand the factors involved in controlling the course of the [4 + 2] pathway.

RESULTS AND DISCUSSION

The novel synthesis of dienes **5a**–**e** was conceived based on a bis-condensation approach of α-bis-imino compounds **10a**–**e** with triphosgene (**9**), a safe and easy-to-handle synthetic equivalent of phosgene (Scheme 2).[13] Compounds **10a**–**e** can be produced from α-diketone **1a** by reacting it with 2 mol equiv of anilines **2a**–**e**.

Scheme 2. Synthesis of *exo*-Imidazolidin-2-one Dienes 5 and 12–15 from Imines 3, 8, 10, and 11 and Triphosgene (9) or Isocyanates 4

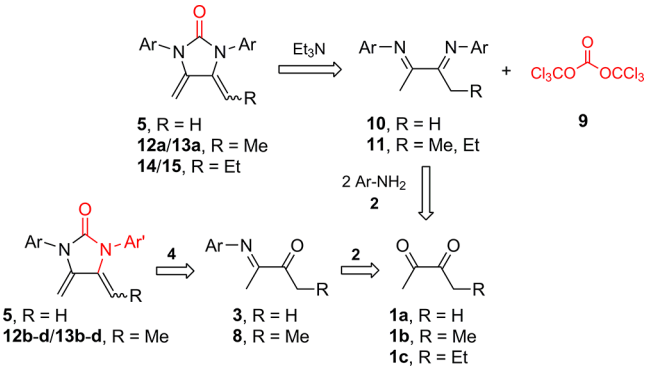
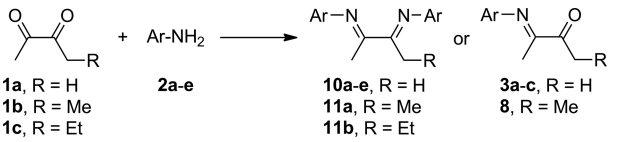


Table 1 summarizes the reaction conditions and yields in the preparation of α-bis-imino compounds **10a**–**e** and **11a** and **b**.

Table 1. Preparation of Imino Compounds 3a–c, 10a–e, 11a and b, and 8 by Condensation of α-Diketones 1a–c with Anilines 2a–e[a]



entry	1 (R)	2 (Ar)	catalyst (mol equiv)	solvent	t (h)	product (%)[b]
1	**1a** (H)	**2a** (C_6H_5)		MeOH	24.0	**10a** (78)
2	**1a** (H)	**2b** (C_6H_4-4-Me)		MeOH	24.0	**10b** (80)
3	**1a** (H)	**2c** (C_6H_4-4-OMe)		MeOH	24.0	**10c** (88)
4	**1a** (H)	**2d** (C_6H_4-4-Cl)		MeOH	24.0	**10d** (40)
5	**1a** (H)	**2e** (2-naphthyl)		MeOH	24.0	**10e** (86)
6	**1b** (Me)	**2c** (C_6H_4-4-OMe)	*p*-TsOH (0.20)	MeOH	24.0	**11a** (0)[c]
7	**1b** (Me)	**2c** (C_6H_4-4-OMe)	*p*-TsOH (0.05)	[d]	0.75	**11a** (30)
8	**1b** (Me)	**2c** (C_6H_4-4-OMe)	*p*-TsOH (0.10)	[d]	0.75	**11a** (55)
9	**1c** (Et)	**2c** (C_6H_4-4-OMe)	*p*-TsOH (0.20)	[d]	0.75	**11b** (50)
10	**1a** (H)	**2a** (C_6H_5)		MeOH	12.0	**3a** (80)[e]
11	**1a** (H)	**2c** (C_6H_4-4-OMe)		MeOH	12.0	**3b** (81)[e]
12	**1a** (H)	**2b** (C_6H_4-4-Me)		MeOH	24.0	**3c** (75)[e]
13	**1b** (Me)	**2c** (C_6H_4-4-OMe)		MeOH	24.0	**8** (59)

[a]Reaction conditions: for bis-imines **10a**–**e**: **1a** (1.0 mol equiv) and **2a**–**e** (2.0 mol equiv). For bis-imines **11a** and **b**: **1b** and **c** (1.0 mol equiv) and **2c** (2.0 mol equiv). For monoimines **3a**–**c**: **1a** (1.0 mol equiv) and **2** (1.0 mol equiv). For monoimine **8**: **1b** (1.0 mol equiv) and **2c** (1.0 mol equiv). All reactions were carried out at 25 °C. [b]After column chromatography. [c]Decomposition. [d]By the solvent-free mortar grinding method. [e]Ref 10.

The first series of *bis*-imines **10a**–**e** was obtained in moderate to high yields by treatment of diacetyl (**1a**) with an excess (2.0 mol equiv) of the corresponding anilines **2a**–**e** under mild conditions (entries 1–5).[14] Other methods have been used, including thermal conditions[15] and acid catalysis,[16] leading to lower yields or no reaction. The optimized conditions were also presently employed to try to introduce two different anilines, starting from the *mono*-imino α-diketone **3a** and reacting it with another aniline such as **2c**. However, the reaction was unsuccessful, generating a mixture of the starting compound **3a** and the symmetrically substituted *bis*-imine **10c** as the major product, along with aniline (**2a**) (through the decomposition of **3a**) and the unreacted starting *p*-anisidine (**2c**).

The endeavor to prepare the series of nonsymmetrical *bis*-imines **11a** and **b** was unsuccessful when starting from α-diketones **1b** and **c** and following the same methodology, or under acid (*p*-TsOH) catalyzed conditions (Table 1, entry 6). Despite the fact that similar conditions have been reported to provide *bis*-imines with diverse α-diketones and anilines,[16a,17] it was herein found that *bis*-imines other than **11a** and **b** were

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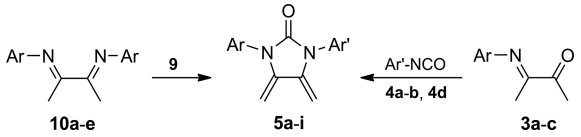
Table 2. Preparation of Dienes 5a–i by Reacting bis-Imines 10a–e and α-Iminoketones 3a–c with Triphosgene (9) and Isocyanates 4a and b and 4d, Respectively[a]



entry	imine	Ar	Ar′	4 or 9	T (°C)	t (h)	5 (%)[b]
1	**10a**	C_6H_5	C_6H_5	**9**	0	3	**5a** (81)
2	**10b**	C_6H_4-4-Me	C_6H_4-4-Me	**9**	0	3	**5b** (78)
3	**10c**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	0	3	**5c** (99)
4	**10d**	C_6H_4-4-Cl	C_6H_4-4-Cl	**9**	0	3	**5d** (85)
5	**10e**	2-naphthyl	2-naphthyl	**9**	0	3	**5e** (70)
6	**3a**	C_6H_5	C_6H_4-4-OMe	**4d**	20	24	**5f** (82)
7	**3b**	C_6H_4-4-OMe	C_6H_4-4-Cl	**4b**	20	24	**5g** (65)
8	**3a**	C_6H_5	C_6H_4-4-Cl	**4b**	20	24	**5h** (63)[c]
9	**3c**	C_6H_4-4-Me	C_6H_5	**4a**	20	24	**5i** (70)[c]

[a]Reaction conditions: for dienes **5a–e**: **10a–e** (1.0 mol equiv), **9** (1.5 mol equiv), and Et_3N (3.0 mol equiv) in toluene. For dienes **5f–i**: **3a–c** (1.0 mol equiv), **4a** and **b** and **4d** (3.0 mol equiv), Et_3N (2.0 mol equiv), and Li_2CO_3 (10.0 mol equiv) in toluene. [b]After column chromatography. [c]Ref 10.

either not formed or given in very low yields. Interestingly, by grinding **1b** and **c** and **2c** in a mortar under acid-catalyzed solvent-free mechanochemical conditions,[18] *bis*-imines **11a** and **b** were afforded in moderate yields (entries 7–9).

To obtain dienes **12b–d/13b–d** with two different aryl groups, we investigated the preparation of the corresponding monoimine **8** as the precursor for subsequent treatment with isocyanates **4**, adhering to our previously reported method.[10] In that study, the preparation of monoimine **8** (Ar = Ph) was attempted through a *p*-TsOH catalyzed procedure, but only a very low yield of the desired product was furnished. Better results were achieved with a catalyst-free reaction of **1b** and **2c** under mild reaction conditions (Table 1, entry 13).

After modifying solvents and reaction temperatures, we determined that the optimized method of synthesis of dienes **5a–e** involved the condensation of triphosgene (**9**) with bis-imines **10a–e** in the presence of Et_3N and in toluene as the solvent (0 °C, 3 h) (Table 2, entries 1–5). Although the yields were higher than those obtained by the previous methodology,[10] they were prone to drastically decrease with a rise in the reaction temperature and the maintenance of the dienes in solution (CH_2Cl_2) even at room temperature, observing polymerization. Despite the efficiency of this novel methodology, it was limited to the synthesis of symmetrically *N*-substituted dienes. For the preparation of the nonsymmetrically *N*-substituted dienes **5f–i**, the methodology that employs the reaction of α-iminoketones **3a–c** with the corresponding isocyanates **4a** and **b** and **4d** proved to be an efficient procedure (Table 2, entries 6–9). The structure of the novel compounds was established by spectrometric analyses, and that of the known diene **5a**[10] was verified by single crystal X-ray diffraction (Figure 1).[19] Unlike the *exo*-2-oxazolidinone dienes,[9] where the heterocycle is totally planar, diene **5a** adopts a slightly nonplanar conformation (C7–C5–C4–C6 dihedral angle: 14.5°; N1–C2–N3–C5 dihedral angle: 3.1°; C2–N1–C5–C4 dihedral angle: −7.7°, N1–C5–C4–N3 dihedral angle: 9.1°). However, in a similar manner as the *exo*-2-oxazolidinone dienes, the *N*-phenyl rings of **5a** assume a quasi-orthogonal conformation with respect to the plane of the heterocycle.

Upon treating bis-imine **11a** with **9** at 0 °C for 4 h, a diastereoisomeric mixture of (*E*/*Z*)-**12a**/**13a** (59/41) was

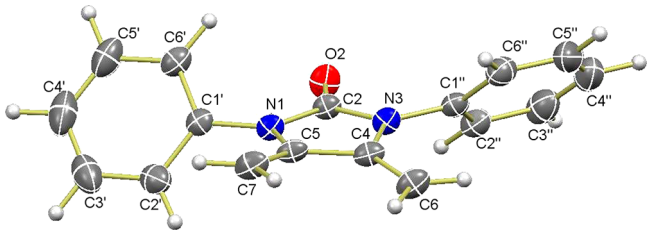


Figure 1. X-ray structure of **5a** (ellipsoids at the 30% probability level).

generated (Table 3, entry 1). The ratio was greatly improved by decreasing the reaction temperature to −10 °C, leading to the exclusive formation of (*E*)-**12a** in high yield (entry 2). Interestingly, increasing the reaction temperature to 20 °C afforded a single product which corresponded to the heterocyclic *inner-outer*-ring diene **16a** (entry 3).

With bis-imine **11b**, in contrast, the diastereoisomeric ratio of dienes (*E*/*Z*)-**14**/**15** did not improve significantly by modifying the reaction temperatures (Table 3, entries 4 and 5). Even after further reducing the temperature, the isomeric mixture ratio of (*E*/*Z*)-**14**/**15** was only a little better, being produced at a very low conversion rate and yield (<20%). However, carrying out the reaction at room temperature led to the isomerization of the diene to deliver the respective heterocyclic *inner-outer*-ring diene **17** as a single (*E*) isomer (entry 6).

Upon acidic treatment of diene **12a** with $AlCl_3$ in CH_2Cl_2 as the solvent at −78 °C for 30 min, heterocyclic *inner-outer*-ring diene **16a** was furnished in a slightly lower yield (70%) than that found by direct condensation of **11a** with **9** (Table 3, entries 3 and 10). Similarly, when a mixture of dienes **12c**/**13c** (57/43) was submitted under Lewis acid-assisted reaction conditions *inner-outer*-ring diene **16b** was provided in good yield (entry 11).

Unexpectedly, the reaction of **8** with isocyanates **4a–c** led to the corresponding dienes as diastereoisomeric mixtures of (*E*/*Z*)-**12b–d/13b–d**, without the formation of the isomerized heterocyclic *inner-outer*-ring dienes, even though the reactions took place at 20 °C (Table 3, entries 7–9). The absence in the reaction mixture of potentially acidic species such as **9** may be the cause of the inhibition of isomerization.

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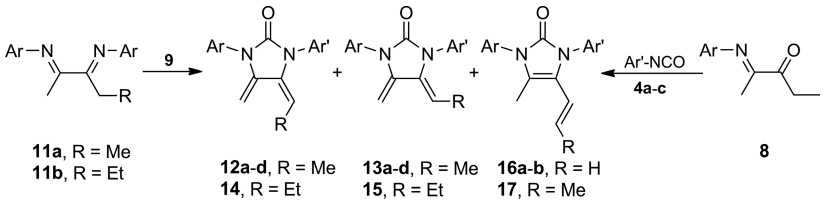
Table 3. Preparation of Dienes 12a, 12a–d/13a–d, 14/15, 16a and b, and 17 by Reacting bis-Imines 11a and b or α-Ketoimine 8 with Triphosgene (9) and Isocyanates 4a–c[a]



entry	imine	Ar	Ar′	6 or 9	T (°C)	t (h)	dienes[b] (%)[c]
1	**11a**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	0	4	**12a/13a** (59/41) (88)
2	**11a**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	−10	4	**12a** (88)
3	**11a**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	20	1	**16a** (75)
4	**11b**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	0	4	**14/15** (42/58) (78)
5	**11b**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	−10	4	**14/15** (64/36) (80)
6	**11b**	C_6H_4-4-OMe	C_6H_4-4-OMe	**9**	20	1	**17** (70)
7	**8**	C_6H_4-4-OMe	C_6H_5	**4a**	20	48	**12b/13b** (36/64) (40)
8	**8**	C_6H_4-4-OMe	C_6H_4-4-Cl	**4b**	20	48	**12c/13c** (57/43) (65)
9	**8**	C_6H_4-4-OMe	C_6H_4-4-Me	**4c**	20	48	**12d/13d** (68/32) (54)
10	**12a**[d]	C_6H_4-4-OMe	C_6H_4-4-OMe		−78	0.5	**16a** (70)
11	**12c/13c**[d]	C_6H_4-4-OMe	C_6H_4-4-Cl		−78	0.5	**16b** (78)

[a]Reaction conditions: For dienes **12a/13a**, **14/15**, **16a**, and **17**: **11a** and **b** (1.0 mol equiv), **9** (1.5 mol equiv), and Et_3N (3.0 mol equiv) in toluene. For dienes **12b–d/13b–d**: **8** (1.0 mol equiv), **4a–c** (2.5 mol equiv), Et_3N (3.0 mol equiv), and Li_2CO_3 (13.0 mol equiv) in toluene. [b]Ratios calculated by ^1H NMR of the crude mixtures. [c]After column chromatography. [d]For dienes **16a** and **b**: **12a** and **12c/13c** (57/43) (1.0 mol equiv) and $AlCl_3$ (0.27 mol equiv) in CH_2Cl_2.

The molecular geometries of dienes **12a**, **13a**, **14**, **15**, **16a**, and **17** were calculated at the B3LYP/6-31G**[20] level of DFT theory without symmetry constraints. As expected for both homologue series, compounds **16a** and **17** were the most stable dienes (Figure 2). Although the *s-cis* conformation was found to

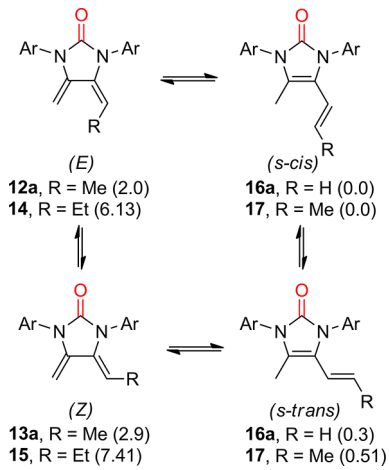


Figure 2. Calculated (B3LYP/6-31G**) relative energies (kcal/mol) of the optimized geometries of dienes **12a**, **13a**, **14**, **15**, **16a**, and **17** (Ar = C_6H_4-4-OMe).

be more stable than the *s-trans*, the energy difference between them was 0.51 kcal/mol. Among the (*E*/Z) diastereoisomeric dienes **12a/13a**, the former was more stable by 0.90 kcal/mol. The energy difference was greater for the most hindered ethyl substituted isomers **14/15** at 1.28 kcal/mol. This preference is presumably linked to the steric interaction of the alkyl group with the vicinal *N*-aryl ring, even when the latter adopts a noncoplanar conformation in relation to the plane of the heterocycle (Figure 1).

The reactivity and regioselectivity of these dienes was evaluated in Lewis acid-catalyzed Diels–Alder cycloadditions to acrolein (**18a**). In a previous study, diene **5h** was reacted with methyl vinyl ketone (**18b**) in the presence of $BF_3{\cdot}OEt_2$ as the catalyst at −78 °C to afford a (65/35) mixture of regioisomers.[10] This low regioselectivity supports the hypothesis that the electron density on the nitrogen atoms is almost unperturbed by the aryl rings owing to conformational restrictions, as shown by the X-ray diffraction structure of diene **5a** (Figure 1). Therefore, we investigated the regioselectivity of dienes **12a/13a** and **14/15** to assess the effect of the perturbation of the alkyl group on the polarization of the dienic moiety.

First, the reaction was carried out with the single isomer **12a** in the presence of **18a** and the same catalyst at a low temperature (−78 °C) for 2 h to furnish the four expected adducts **19a/20a/21a/22a** (Scheme 3). Although the diastereoisomeric ratio was estimated from the ^1H NMR spectrum of the crude mixture (Table 4, entry 1), the complexity of the signals did not allow for the assignment of the adduct structures. Hence, regioselectivity was unambiguously established by converting the adduct mixture into the aromatic *ortho/meta* isomers **23a/24a** (65/35) by DDQ-promoted aromatization (Scheme 3). This regioselectivity, similar to that found with the nonmethylated diene **5h**, was greatly improved by using $ZnCl_2$ as the catalyst under the same reaction conditions (entry 2). Additionally, the process resulted in a high *endo/exo* diastereoselectivity, generating the mixture of adducts **19a/20a** (83/17). The assignment of the stereochemistry was tentatively made in agreement with the *endo* preference predicted by calculations (vide infra).

Both regio- and stereoselectivity were similar to that found when the cycloaddition was carried out with the mixture of (*E*/*Z*) isomeric dienes **12a/13a** (Table 4, entry 3). This is rather surprising because it is well-known that the reactivity and selectivity of isomeric (*E*)- and (*Z*)-1-substituted dienes are

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Scheme 3. Diels–Alder Additions of Dienes 12a/13a and 14/15 to Acrolein (18a), Followed by Aromatization with DDQ to Afford the Regioisomeric Benzimidazol-2-ones 23a/24a and 27a/27b

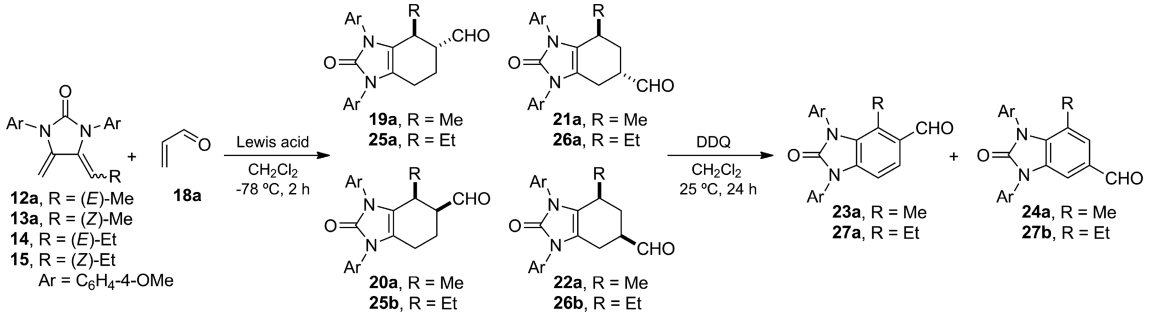
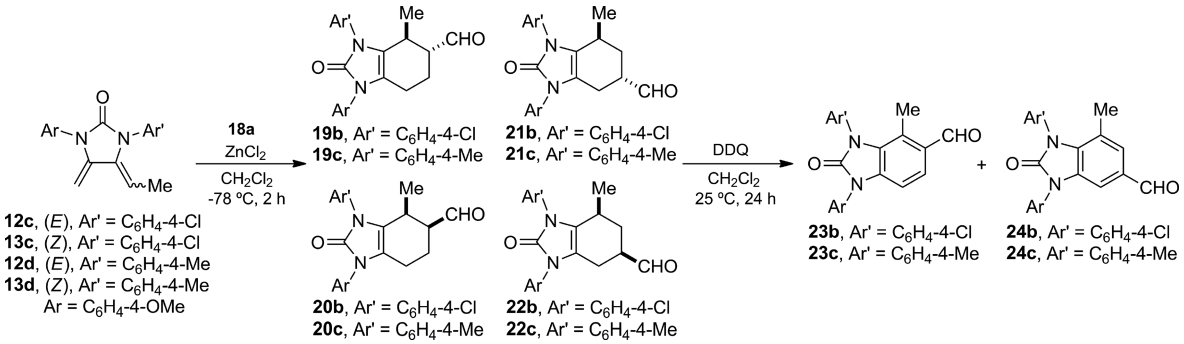


Table 4. Diels–Alder Cycloadditions of Dienes 12a/13a, 14/15, and 5h–i to Acrolein (18a)[a]

entry	dienes	catalyst	adducts *ortho endo/exo*[b]	adducts *meta endo/exo*[b]	yield (%)[c]	2-benzimidazoles[b] (%)[c]
1	**12a**	$BF_3{\cdot}OEt_2$	**19a/20a** (25/36)	**21a/22a** (14/25)	72	**23a/24a** (65/35) (81)
2	**12a**	$ZnCl_2$	**19a/20a** (83/17)	**21a/22a** (d)	74	**23a/24a** (98/2) (80)
3	**12a/13a** (59/41)	$ZnCl_2$	**19a/20a** (81/19)	**21a/22a** (d)	75	**23a/24a** (96/4) (80)
4	**14/15** (42/58)	$ZnCl_2$	**25a/25b** (57/43)	**26a/26b** (d)	95	**27a/27b** (91/9) (88)
5	**12c/13c** (57/43)	$ZnCl_2$	**19b/20b** (80/20)	**21b/22b** (d)	73	**23b/24b** (96/4) (82)
6	**12d/13d** (68/32)	$ZnCl_2$	**19c/20c** (69/31)	**21c/22c** (d)	60	**23c/24c** (92/8) (85)
7	**5h**	$ZnCl_2$	**28a** (60)[e]	**29a** (40)[e]	88	**30a/31a** (57/43)[e] (88)
8	**5i**	$ZnCl_2$	**28b** (53)[e]	**29b** (47)[e]	72	**30b/31b** (57/43)[e] (92)

[a]Reaction conditions: diene (1.0 mol equiv) and $ZnCl_2$ (0.27 mol equiv) or $BF_3{\cdot}OEt_2$ (0.27 mol equiv) in CH_2Cl_2 at −78 °C for 2 h. [b]Ratios calculated by ^1H NMR of the crude mixtures. [c]After column chromatography. [d]Not determined. [e]Regiochemistry could not be assigned.

Scheme 4. Diels–Alder Additions of Dienes 12c-d/13c-d to Acrolein (18a), Followed by Aromatization with DDQ to Afford the Regioisomeric Benzimidazol-2-ones 23b-c/24b-c



usually quite different.[21] Although the nonfavorable equilibrium (as shown in Figure 2) did not allow us to isolate (*Z*)-**13a** and observe its Diels–Alder selectivity, the use of the (*E*)-**12a**/(*Z*)-**13a** mixture revealed that a previous isomerization could have taken place before the cycloaddition, leading to the comparable selectivity. This idea may be supported by the result obtained from the mixture of the ethyl substituted (*E*/*Z*) isomeric dienes **14**/**15** (42/58). When this mixture was evaluated under similar reaction conditions, an analogous regioselectivity but a much lower *endo*/*exo* diastereoselectivity was observed (entry 4) in comparison with the reaction of **12a**/**13a** (59/41) (entry 3). Due to the higher isomerization energy (Figure 2), it is likely that the isomerization between dienes **14**/**15** is slower. This would lead to a different selectivity, at least concerning *endo*/*exo* selectivity.

In principle, if the processes are concerted or there is no isomerization of the diene in the course of the reaction, adducts **19a**, **21a**, **25a**, and **26a** are a consequence of the *endo* approach when the (*E*) isomeric dienes **12a** and **14** react with **18a**. Of course, these adducts are also the products of the *exo* approach in the additions to the (*Z*) isomeric dienes **13a** and **15**. Thus, isomers **20a**, **22a**, **25b**, and **26b** are the *exo* adducts when the (*E*) isomeric dienes **12a** and **14** react with **18a**, and the *endo* adducts in the event that they result from additions of **18a** to the (*Z*) isomeric dienes **13a** and **15**.

We also assessed the effect of having two different *N*- and *N*′-aryl rings in the methyl substituted dienes **12c-d**/**13c-d** during the cycloadditions with **18a**, maintaining the same $ZnCl_2$-catalyzed reaction conditions (Scheme 4; Table 4, entries 5 and 6). The reactivity and regioselectivity were comparable to those found in the assays with dienes **12a**/**13a** and **14**/**15** (entries 3 and 4). Adducts **19b** and **c** and **21b** and **c** would be considered as the *endo*-approach products when **18a** is reacted with the (*E*) isomeric dienes **12c** and **d**, or the *exo* adducts upon its reaction with the (*Z*) isomeric dienes **13c** and **d**. Likewise, adducts **20b** and **c** and **22b** and **c** would be considered as the *endo*-approach products when **18a** reacts with the (*Z*) isomeric dienes **13c** and **d**, or the *exo* adducts in the event that it reacts with the (*E*) isomeric dienes **12c** and **d**. After aromatization of the

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Scheme 5. Diels–Alder Cycloadditions of Dienes 5h and i to Acrolein (18a), Followed by Aromatization with DDQ to Afford the Regioisomeric Benzimidazol-2-ones 30a-b/31a-b

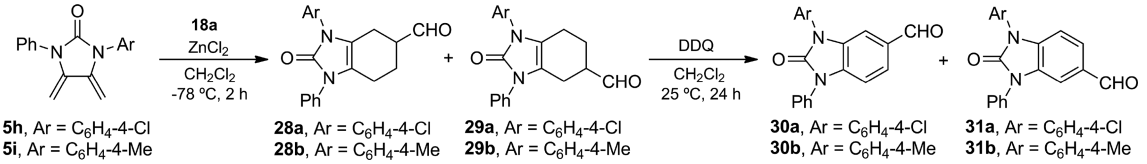
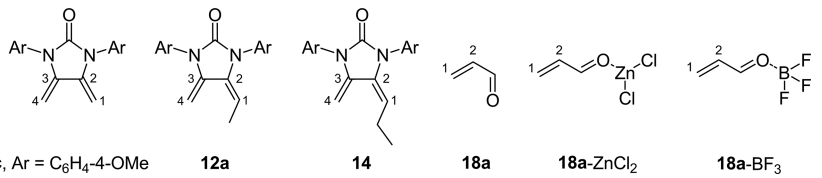


Table 5. Calculated [HF/6-31G(d,p)] Energy Gaps (eV) of the Frontier Molecular Orbitals for Dienes 5c, 12a, and 14 and Dienophiles 18a, 18a-$ZnCl_2$, and 18a-BF_3



addends	HOMO–LUMO[a]	LUMO–HOMO[a]	diff
5c-18a	10.2	13.7	3.5
5c-18a-$ZnCl_2$	8.4	14.7	6.3
5c-18a-BF_3	8.7	14.8	6.1
12a-18a	10.1	13.8	3.7
12a-18a-$ZnCl_2$	8.3	14.8	6.5
12a-18a-BF_3	8.6	14.9	6.3
14-18a	10.1	13.8	3.7
14-18a-$ZnCl_2$	8.3	14.8	6.5
14-18a-BF_3	8.6	14.9	6.3

[a] $HOMO_{diene}$–$LUMO_{dienophile}$ and $LUMO_{diene}$–$HOMO_{dienophile}$.

corresponding adducts **19b-c/20b-c/21b-c/22b-c**, mixtures of **23b-c/24b-c** were obtained.

Considering the catalytic efficiency of $ZnCl_2$ in all the previous cycloadditions, and the fact that the nonsubstituted diene **5h** was previously evaluated only with BF_3·OEt_2 as the catalyst,[10] we again explored the regioselectivity with the nonalkylated dienes **5h** and **i** in the presence of $ZnCl_2$ (Scheme 5). The reaction between these dienes and **18a** under conditions similar to those described in Schemes 3 and 4 gave inseparable mixtures of adducts **28a-b/29a-b** with low regioselectivity (Table 4, entries 7 and 8). Unfortunately, the series of aromatic benzimidazol-2-ones **30a-b/31a-b** was obtained as inseparable mixtures as well. Their ^{1}H NMR spectra showed overlapping signal patterns, which made it difficult to assign the regioisomeric preference by NOE experiments.

The aforementioned results not only confirm the low regioselectivity evidenced previously with BF_3·OEt_2 but also support the idea that the substituents in the aromatic rings attached to the nitrogen atoms do not produce a significant electronic perturbation capable of inducing polarization of the diene terminal carbon atoms. This is probably due to the inhibition of the conjugation between the electron lone pairs of the nitrogen atoms with the aryl rings, because the aryl rings are unable to adopt a planar conformation in relation to the plane of the heterocycle (Figure 1). Consequently, the electronic effects generated by the aryl substituents are mainly transmitted onto the dienic moiety as inductive effects,[22] which are expected to be weak owing to the distance separating the interacting centers. Therefore, the exocyclic diene moiety must be substituted, minimally with an alkyl group, to induce a regioselective approach to the dienophile. As shown herein, these dienes are both reactive and selective enough to facilitate a new strategy for the construction of *N*,*N*′-diarylbenzimidazol-2-ones efficiently (Schemes 3 and 4).

To rationalize the regioselectivity observed in the $ZnCl_2$-catalyzed Diels–Alder cycloadditions with the alkyl substituted dienes **12a/13a** and **14/15**, frontier molecular orbital (FMO) theory was used (Table S1).[23] The geometries of these dienes as well as that of acrolein (**18a**), acrolein-zinc chloride (**18a**-$ZnCl_2$) and acrolein-boron trifluoride (**18a**-BF_3) were calculated and optimized at the M06-2*X*/6-31+G(d,p) level of DFT theory without symmetry constraints. The energies and coefficients of the FMOs were calculated at the HF/6-31G(d,p) level. The most favorable normal electronic demand interaction ($HOMO_{diene}$–$LUMO_{dienophile}$) was established from the energy gaps (Table 5). For the alkyl substituted dienes **12a** and **14**, calculations gave energy gaps smaller than those for the nonsubstituted diene **5c**. These gaps were also much smaller when the LUMOs of the two catalyst complexes **18a**-$ZnCl_2$ and **18a**-BF_3 were compared to the LUMO of the noncomplexed dienophile **18a**. Hence, in terms of perturbation theory,[23] dienes **12a** and **14** should have reactivity higher than that of diene **5c** and also higher than that of the nonsymmetrical diene **5h**. Consequently, the regioselectivity of dienes **12a** and **14** should also be higher than that of dienes **5**.[24] Although a quantitative kinetic evaluation of the reactivity of dienes **12a** and **14** was not made, the higher regioselectivity would indicate a higher reactivity than that of dienes **5**.

The energy gap is smaller for the HOMOs of the dienes in relation to the LUMO of **18a**-$ZnCl_2$ than the LUMO of **18a**-BF_3. Nevertheless, the difference between these two gaps is not so great as to justify the large difference in reactivity found. Nor can this outcome be explained based on the coefficient differences for the $HOMO_{diene}$–$LUMO_{dienophile}$ interactions (Table S1). The HOMO coefficients of the dienes termini

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C1 and C4 are almost equal, and a nonregioselective interaction with the LUMO coefficients of dienophile **18a** should be expected. In addition, the LUMO coefficient differences (ΔC_i) for the complexed dienophiles **18a**-$ZnCl_2$ and **18a**-BF_3 are almost identical. Therefore, a lack of significant difference in regioselectivity would be expected between both complexed dienophiles, as was experimentally observed.

Because the evaluation of the electronic effects that control these cycloadditions appears to be beyond the scope of FMO theory,[1f] we decided to explore the geometries and energies of the possible transition states (TSs) and the associated minima along the reaction coordinates for their respective processes.[25] The geometries of the reactants, transition states, and products were optimized at the M06-2*X*/6-31+G(d,p) level of theory[26] with the Gaussian 09 program package.[27]

The reaction trajectory for the cycloaddition of **12a** with **18a** was found to be concerted, passing through a single TS (Table S3, Figure S1) but displaying a highly asynchronous geometry (Figures S2–S13). The TS energy for the *ortho-endo* approach turned out to be lower than that for the other possible approaches (*ortho-exo*, *meta-endo*, and *meta-exo*), the energies of which are similar to each other (Table S2). Unfortunately, the slow decomposition of dienes **12a**/**13a** under thermal conditions prevented an accurate evaluation of the selectivity of the reaction.

For the cycloaddition of **12a** with **18a**-$ZnCl_2$ and **18a**-BF_3, however, there were two TSs on the reaction coordinate before arriving to the corresponding adduct, with a minimum between these two TSs (Figures 3 and 5).[1c,25c−f] Hence, these reactions

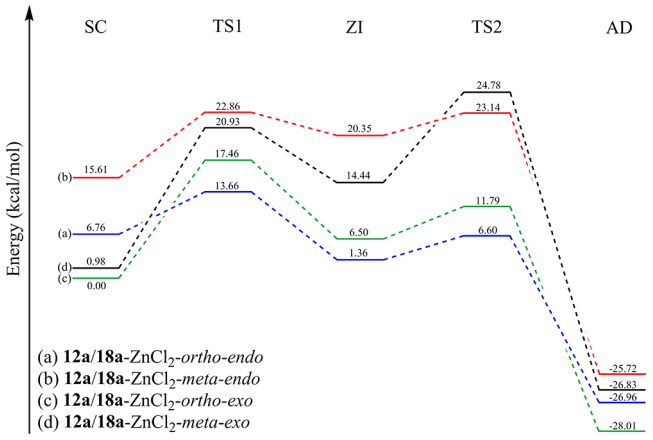

Figure 3. Calculated [M06-2*X*/6-31+G(d,p)] relative ZPE-corrected energies (kcal/mol) of the stationary points of the **12a**/**18a**-$ZnCl_2$ cycloadditions for the four possible approaches: *ortho-endo* (blue), *ortho-exo* (green), *meta-endo* (red), and *meta-exo* (black). SC = supramolecular complex; TS1 = transition state 1; zwitterionic intermediate (ZI); TS2 = transition state 2; AD = adduct.

do not proceed via a concerted pathway, rather through a two-step mechanism leading to the formation of a zwitterionic intermediate (ZI),[1f] probably as a result of the stabilizing effect of the strong coordination by the metal in the metal-complexed dienophile species.[1c] The M06-2*X*/6-31+G(d,p) level of theory was also used for the optimization of the geometries of each regioisomer and diastereoisomer in the cycloadditions. For example, for the $ZnCl_2$-catalyzed cycloaddition, four possible approaches exist: **12a**/**18a**-$ZnCl_2$-*ortho-endo*, **12a**/**18a**-$ZnCl_2$-*ortho-exo*, **12a**/**18a**-$ZnCl_2$-*meta-endo*, and **12a**/**18a**-$ZnCl_2$-*meta-exo*. The relative energies of the stationary points of these Diels–Alder reactions are given in Tables S2 and S4, and the geometries are described in Figure 4 and in the Supporting Information (Figures S14–S33).

The energy differences between the four cycloaddition approaches mentioned are illustrated in Figure 3. Both *ortho* approaches (*endo* and *exo*) are lower in energy than the *meta* approaches, showing different reaction coordinate patterns. For the *ortho* pathways (*endo* and *exo*), in each case the first TS (TS1) is reached from a stationary state as a supramolecular complex (SC)[8f] and corresponds to the rate-determining step. For the *meta* pathways, contrarily, in each case the second TS (TS2) determines the highest energy barrier. The ZIs follow the same energy stability trend between the *ortho* and *meta* approaches, the former having the most stable intermediates. It is noteworthy that, from the thermodynamics point of view, the ZI is reached through an exergonic process only for the *ortho-endo* approach, while the process is endergonic for the *ortho-exo* and both *meta* regioisomers.

Scheme 6 and Figure 4 illustrate the pathway, chemical structures, and geometries of SC, TS1, ZI, TS2, and the adduct (**19a**) for the most stable trajectory **12a**/**18a**-$ZnCl_2$-*ortho-endo*. The stationary points were further characterized with the aid of frequency calculations to verify that the TSs had a single imaginary frequency.

A correlation can be appreciated between the energy differences of the rate-determining TS1-*ortho* and TS2-*meta* transition states (*endo* = 9.48 kcal/mol; *exo* = 11.12 kcal/mol; Table S2) and the experimental selectivity of the **23a**/**24a** (98/2) mixture (Table 4, entry 2) in the corresponding *ortho* and *meta* approaches. Similarly, the energy difference between the *endo* and *exo* (3.80 kcal/mol) approaches for the *ortho* trajectory is significant, as it reflects the selectivity found experimentally (*endo*/*exo*, 83/17) (Table 4, entry 2). Although the experimental *endo*/*exo* ratio could not be determined for the *meta* trajectory, it is expected to be small due to the relatively low energy difference (1.64 kcal/mol) for TS2. This prediction is in agreement with the strong exergonic last step of the reaction coordinates for these *meta* regioisomers.[24]

Further examination of one diene, the geometric isomer (*Z*)-**13a**, in cycloaddition with **18a** would explain the fact that highly regioselective cycloadditions were observed for the mixtures of (*E*)-**12a**/(*Z*)-**13a** and **18a** (Table 4, entries 2 and 3). Thus, the calculation of (*Z*)-isomer **13a** and **18a**-$ZnCl_2$ showed the formation of zwitterionic species and the corresponding two transition states (Figures S63–S67) and indicated a preference for the *ortho* regioisomer, as for (*E*)-**12a**.

Both *ortho* and *meta* approaches have TS1 as the rate-determining TS for BF_3-catalyzed cycloadditions (Figures 5 and S34–S53), unlike those catalyzed by $ZnCl_2$. It is surprising that the calculated *ortho*/*meta* energies for the BF_3-catalyzed (Tables 2 and S5) process do not reflect the experimentally observed lack of regioselectivity (Table 4, entry 1). For example, the TS1 energy difference between the **12a**/**18a**-BF_3-*ortho-endo* and **12a**/**18a**-BF_3-*meta-endo* approach is 2.34 kcal/mol, which corresponds to a high *ortho*/*meta* ratio (~98/2) and is in contrast to the experimental ratio (65/35). However, the TS energy difference between the **12a**/**18a**-BF_3-*ortho-exo* and the *meta-exo* approach is very small (0.87 kcal/mol), which should provide an *ortho*/*meta* ratio close to one. There are probably other factors involved in the transition state that could explain the latter observations, such as electrostatic forces,[25a,28] enhancement of the charge-transfer configuration (polar interactions) between the diene and the dienophile in the

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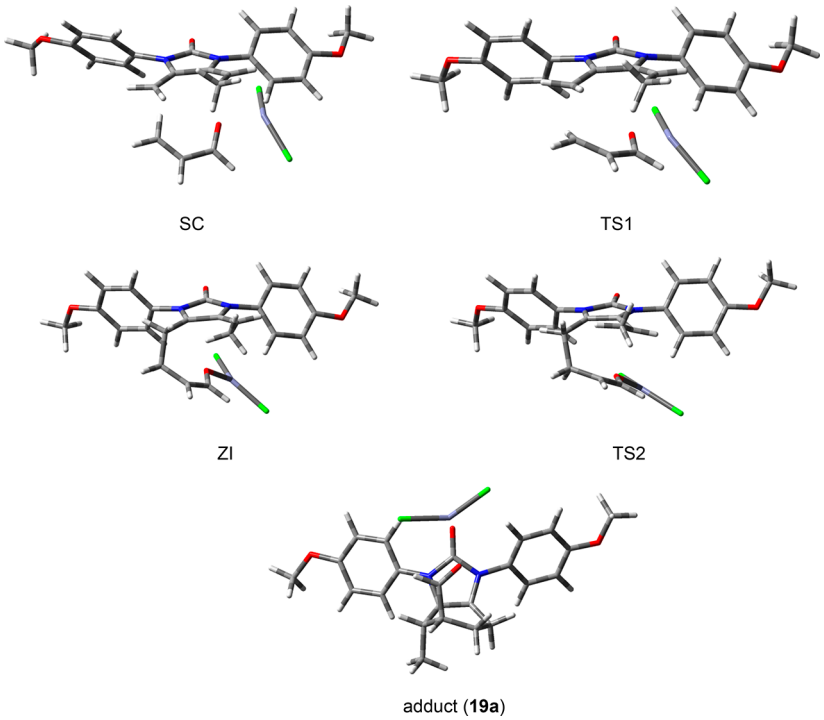
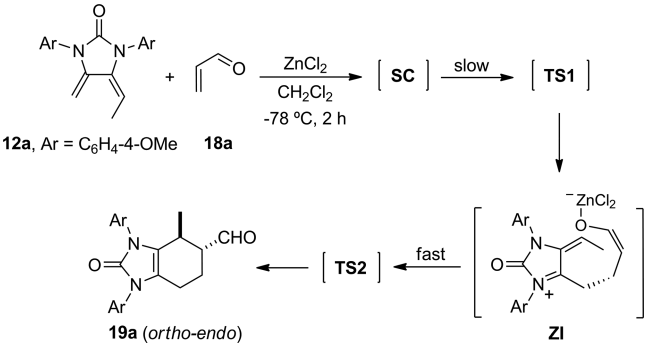


Figure 4. Calculated [M06-2*X*/6-31+G(d,p)] optimized geometries of the stationary points involved in the **12a**/**18a**-$ZnCl_2$ cycloaddition of the most stable *ortho-endo* approach.

Scheme 6. Diels–Alder Addition of Diene 12a to $ZnCl_2$-Complexed Acrolein (18a), Following the *ortho-endo* Approach to Yield Adduct 19a



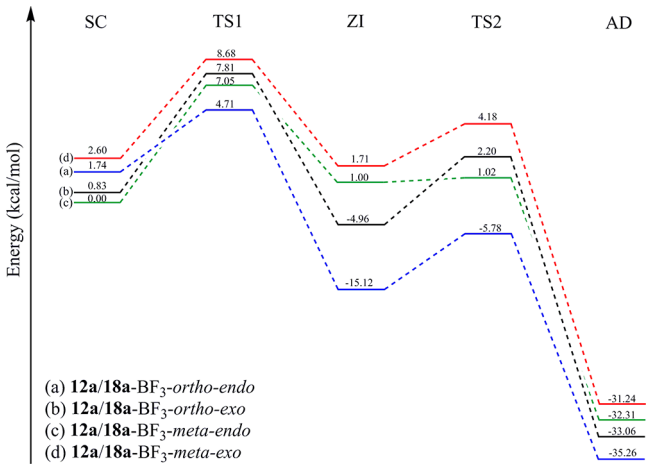


Figure 5. Calculated [M06-2*X*/6-31+G(d,p)] relative ZPE-corrected energies (kcal/mol) of the stationary points of **12a**/**18a**-BF_3 cycloadditions for the four possible approaches: *ortho-endo* (blue), *ortho-exo* (black), *meta-endo* (green), and *meta-exo* (red). SC = supramolecular complex; TS1 = transition state 1; zwitterionic intermediates (ZI); TS2 = transition state 2; AD = adduct.

presence of a stronger Lewis acid,[1c,24c,25b,c] the coordination interactions of BF_3 with the dienophile (**18a**) and the diene,[29] steric hindrance,[30] and/or the conformation of the dienophile at the TS,[8a] which would be capable of destabilizing the *ortho* regioisomer.

We also evaluated the reactivity of the *inner-outer*-ring dienes **16a** and **17** with *N*-phenylmaleimide (**6**) (Scheme 7). The cycloadditions took place at room temperature for 48 h to provide a high *endo* diastereoselectivity, which led to mixtures of the *endo*/*exo* (>98/2) adducts **32a-b**/**33a-b**. The stereochemistry of the major isomer was established by NOE experiments, revealing the spatial proximity and correlations between the protons of the Me-8b methyl group and the H-8a and H-5β protons.

These results suggest that dienes **16a** and **17** are less reactive than the exocyclic dienes **5**, which react with the same dienophile at 0 °C for 1 h.[10] This idea is also supported by the fact that all attempts to achieve the cycloaddition of compound **17** with acrolein (**18a**) under thermal and Lewis acid-catalyzed reaction conditions failed to give the corresponding adducts, resulting in decomposition of the reaction mixture. Interestingly, the energy of the HOMO is higher for diene **16a** than for **5c** (Table S1), implying a greater reactivity of the former. This inconsistency may be due to the presence of the *in* methyl group at C-5 in dienes **16a** and **17**, causing the depletion of reactivity due to steric hindrance, which takes place by not only perturbing the conformational *s-cis*/*s-trans* equilibrium (Figure 2) but also inhibiting the approach of the dienophile.[21,31] Such a destabilizing effect is possibly involved in the observed high *endo* diastereoselectivity as well, because the *in* methyl group would sterically inhibit the *exo* addition of the dienophile.[21c]

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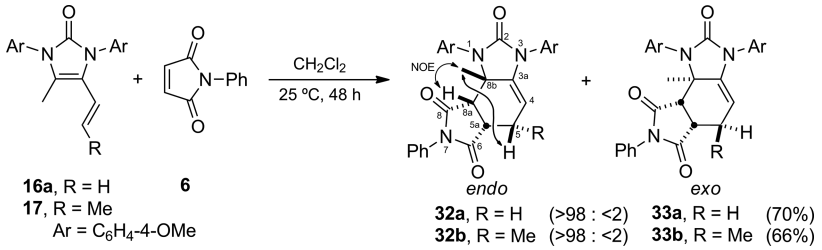
Scheme 7. Diels–Alder Cycloadditions of Dienes 16a and 17 to *N*-Phenylmaleimide (6)[a]



[a]Structure determination of the *endo* adduct **32a** by NOE correlations.

To assess the concertedness of the process, the M06-2*X*/6-31+G(d,p) calculation was made to determine the stationary points in the reaction coordinate for the cycloaddition of **16a** with **6**. This calculation indicated a single concerted TS and the absence of zwitterionic intermediates (Figures 6 and S54–S59). The TS was much more stable for the cycloaddition with the *endo* than the *exo* approach (a difference of 3.80 kcal/mol), which is in agreement with the observed experimental results.

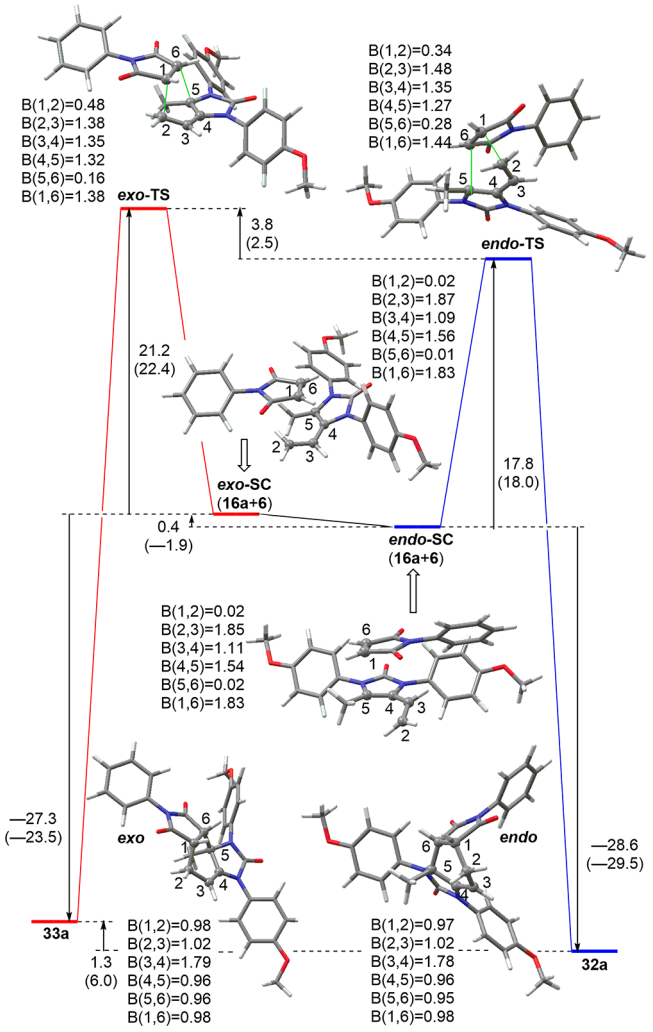


Figure 6. Calculated [M06-2*X*/6-31+G(d,p)] relative ZPE-corrected energies (kcal/mol) of the stationary points of the **16a**/**6** cycloadditions for the two possible approaches *endo* (blue) leading to **32a**, and *exo* (red) leading to **33a**. SC = supramolecular complex. Numbers in parentheses correspond to relative Gibbs energies (in kcal/mol) computed at 298 K. *B*(*A*,*B*) are the Wiberg bond indexes (in au) in the NBO basis between atoms *A* and *B*.

We computed the synchronicity[32] of the [4 + 2] cycloadditions between diene **16a** and maleimide (**6**) to yield the *endo* and *exo* cycloadducts **32a** and **33a**, respectively (details can be found in the Supporting Information). Wiberg analysis[33] yielded the relevant *B*(*A*,*B*) bond indexes for the supramolecular complexes, transition structures, and products **32a** or **33a**, in relation to the *endo* and *exo* reaction coordinates, respectively, within the NBO approximation (Figure 6).[34] Six sets of atom pairs (*A*,*B*) involved in the [4 + 2] cycloaddition were considered, namely: (1,2), (2,3), (3,4), (4,5), (5,6), and (1,6). Because the δB_{av} values for the *endo* and *exo* manifolds are 0.39 and 0.42, we concluded that both [4 + 2] cycloadditions occur via early transition structures, with the *endo* route taking place through an earlier saddle point than that associated with the *exo* reaction coordinate. According to the values of synchronicity (Sy) of the ***endo*-SC → *endo*-TS → 32a** and ***exo*-SC → *exo*-TS → 33a** [4 + 2] cycloadditions, both reactions are very synchronous: Sy(*endo*) = 0.97 and Sy(*exo*) = 0.98.

We also investigated the origins of the *endo* selectivity observed in this [4 + 2] cycloaddition. Obviously, the primary orbital interactions (POIs) responsible for the formation of the new C1–C2 and C5–C6 σ-bonds are essentially the same in both *exo* and *endo* transition structures. However, in the *endo*-TS, there are two stabilizing secondary orbital interactions (SOIs)[35] between the orbitals corresponding to the two C=C bonds of the diene and the two C=O bonds of the maleimide moiety. Natural bonding analysis (NBA) of the localized natural orbitals associated with the diene–dienophile interactions of *endo*-TS show two stabilizing π(C=C) → π*(C=O) interactions, the associated second-order perturbational energies of which represent a total stabilizing energy of ca. 4.8 kcal/mol (Figure 7). Because these SOIs are not possible in the *exo*-TS, the *endo* reaction coordinate is less energetic than the *exo* one, which is in agreement with the relative energies of both saddle points and the preference for the *endo* cycloadducts **32a** and **b** observed experimentally. This result is in line with similar SOI effects observed in [4 + 2] cycloadditions and other pericyclic reactions,[36] a topic that is still controversial.[8f,37]

In summary, the DFT calculations indicate that the nonassisted Diels–Alder reaction between diene **16a** and *N*-phenylmaleimide (**6**) occurs via early transition structures and that it is highly synchronous. The experimentally observed *endo* selectivity can be attributed to stabilizing secondary orbital interactions.

By determining the corresponding TS at the same level of theory as employed previously (Figures S60–S62), the cycloaddition of diene **5a** with **6** to afford adduct **7a** (Ar = R

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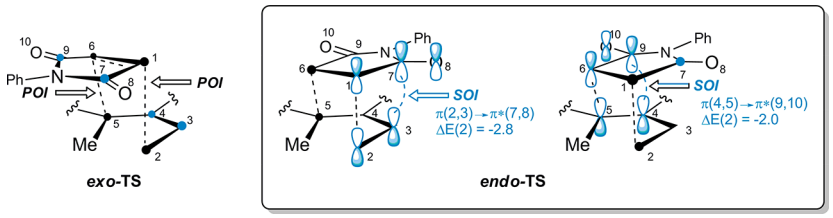

Figure 7. Second-order perturbational energies ($\Delta E(2)$, in kcal/mol) associated with two-electron interactions in the transition structure ***endo*-TS**. POIs in the **exo-TS** leading to the new σ-bonds are highlighted in black. SOIs that contribute to the lower energy of the ***endo*-TS** are highlighted in blue.

= Ph, Scheme 1)[10] was also found to be concerted. This supports the idea that the nonassisted Diels–Alder additions of the *N*,*N*-disubstituted *exo*-2-imidazolidinone dienes **5**, **12**/**13**, **14**–**16**, and **17** take place through a concerted process with symmetrically polarized dienophiles such as **6**, or even with monosubstituted alkenes such as **18a**. On the other hand, the highly polarized, coordinated **18a**-Lewis acid dienophiles prefer a nonconcerted cycloaddition through a zwitterionic intermediate, a reaction that takes place in a highly regioselective process (at least in the case of $ZnCl_2$).

CONCLUSIONS

A new and efficient method for preparing the symmetric *exo*-2-imidazolidinone dienes **5a**–**e** was developed, which was based on the reaction of α-bis-imines **10a**–**e** with triphosgene (**9**). Although this method is limited to symmetrically substituted α-bis-imines, the yields are better than those afforded by the previously reported method.[10] The same strategy was applied to generate the novel alkylated isomeric dienes (*E*/*Z*)-**12a**–**d**/**13a**–**d** and **14**/**15**, the selectivity of which was controlled by the reaction temperature. For example, the reaction at −10 °C gave diene **12a** exclusively, but at 0 °C or room temperature, either a mixture of (*E*/*Z*)-**12a**–**d**/**13a**–**d** was provided or the dienes underwent isomerization to the heterocyclic *inner-outer*-ring dienes **16a** and **b** and **17**. Dienes (*E*/*Z*)-**12**/**13** and **14**/**15** proved to be highly reactive and regioselective in Lewis acid-catalyzed Diels–Alder cycloadditions with acrolein (**18a**) to generate the corresponding *ortho* adducts as the major regioisomers. According to the stationary points determined for each of the reaction trajectories under study (M06-2*X*/6-31+G(d,P)), the selectivity was kinetically controlled, paralleling the stability of the zwitterionic intermediates when the dienophile was polarized by coordination with the catalyst ($ZnCl_2$). The alkyl group on the dienic moiety appears to have a significant effect on the electronic control of the process. In contrast, the course of the cycloaddition under nonassisted conditions maintained the expected concertedness for this pericyclic reaction, as shown by the Diels–Alder additions of diene **5a** and isomeric dienes **16a** and **17** with *N*-phenylmaleimide (**6**), and as supported by calculations of the corresponding transition states and minima. The reactions for the latter dienes were highly diastereoselective, producing only the *endo* adducts **32a** and **b**. Interestingly, these results evidence the advantage of Diels–Alder cycloadditions of such dienes as a novel and efficient synthetic strategy for the preparation of substituted benzimidazol-2-ones, which are important targets in the design of potential pharmacological agents

EXPERIMENTAL SECTION

General. Melting points were determined with a capillary melting point apparatus. ^{1}H (300, 400, or 500 MHz) and ^{13}C (75.4, 101, or 125 MHz) NMR spectra were recorded with TMS as internal standard. Assignment of the NMR signals was made by HMQC and HMBC 2D methods. Mass spectra (MS) and high-resolution mass spectra (HRMS) were obtained in a double-focusing (magnetic and electric) sector mass spectrometer operating in electron ionization (EI) (70 eV) mode. Analytical thin-layer chromatography was carried out using silica gel coated 0.25 plates, visualized by a long- and short-wavelength UV lamp. Flash column chromatography was performed over silica gel (230–400 mesh). All air moisture sensitive reactions were carried out under nitrogen in oven-dried glassware. MeOH and toluene were freshly distilled over sodium, and methylene chloride over calcium hydride, prior to use. Li_2CO_3 was dried overnight at 200 °C prior to use. Triethylamine was freshly distilled from NaOH. All other reagents were used without further purification. The known compounds **3a**–**c** and **5h** and **i** were prepared with the previously reported methods.[10]

*(E)-2-((4-Methoxyphenyl)imino)pentan-3-one (**8**).* A mixture of **1b** (0.50 mL, 5.0 mmol) and **2c** (0.615 g, 5.00 mmol) in MeOH (10 mL) was stirred at room temperature for 24 h. The reaction crude was concentrated under vacuum and purified by column chromatography over silica gel (20 g/g of crude, hexane) to furnish **8** (0.60 g, 59%) as a yellow oil. R_f 0.58 (hexane/EtOAc, 8/2); IR (film): ν_{max} 1698, 1635, 1604, 1504, 926, 841 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.14 (t, J = 7.5 Hz, 3H, CH_3CH_2), 2.02 (s, 3H, CH_3CO), 3.01 (q, J = 7.5 Hz, 2H, CH_3CH_2CO), 3.82 (s, 3H, CH_3O), 6.75–6.82 (m, 2H, H-2′), 6.88–6.95 (m, 2H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 7.9 (CH_3CH_2), 14.3 (CH_3CO), 29.8 (CH_3CH_2), 55.4 (CH_3O), 114.2 (C-3′), 121.1 (C-2′), 142.3 (C-1′), 157.1 (C-4′), 165.1 (C-2), 203.1 (C-3). HRMS (EI): m/z [M$^+$] Calcd for $C_{12}H_{15}NO_2$: 205.1103. Found: 205.1101.

*General Method for the Preparation of Bis-Imines **10a**–**e**. (E,E)-N,N′-Diphenylbutane-2,3-diimine (**10a**).* A mixture of **1a** (0.989 g, 11.50 mmol) and **2a** (2.14 g, 23.0 mmol) in MeOH (30 mL) was stirred at room temperature for 24 h. The crude mixture was filtered and washed with MeOH (3 × 10 mL) and then dried under vacuum to afford **10a** (2.1 g, 78%) as a yellow solid. R_f 0.72 (hexane/EtOAc, 8/2); mp 135–136 °C [Lit.[14] 137–139 °C]. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.15 (s, 6H, CH_3-1, CH_3-4), 6.75–6.83 (m, 4H, H-2′), 7.07–7.15 (m, 2H, H-4′), 7.33–7.41 (m, 4H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 15.4 ($2CH_3$), 118.7 (4C-2′), 132.8 (2C-4′), 129.0 (4C-3′), 150.9 (2C-1′), 168.3 (C-2, C-3).

*(E,E)-N,N′-bis(p-Tolylbutane)-2,3-diimine (**10b**).* The procedure for the preparation of **10a** was followed using a mixture of **1a** (0.989 g, 11.50 mmol) and **2b** (2.46 g, 23.0 mmol) in MeOH (30 mL) to generate **10b** (2.43 g, 80%) as a yellow solid. R_f 0.77 (hexane/EtOAc, 8/2); mp 108–109 °C [Lit.[18] 110.2–111.6 °C]. ^{1}H NMR (500 MHz, $CDCl_3$): δ 2.15 (s, 6H, $2CH_3$), 2.35 (s, 6H, 2Ar–CH_3), 6.68–6.71 (m, 4H, H-2′), 7.15–7.19 (m, 4H, H-3′). ^{13}C NMR (125 MHz, $CDCl_3$): δ 15.4 ($2CH_3$), 20.9 (2Ar–CH_3), 118.8 (4C-2′), 129.5 (4C-3′), 133.2 (2C-4′), 148.3 (2C-1′), 168.3 (C-2, C-3).

*(E,E)-N,N′-bis(4-Methoxyphenyl)butane-2,3-diimine (**10c**).* The procedure for the preparation of **10a** was followed using a mixture of **1a** (0.989 g, 11.50 mmol) and **2c** (2.83 g, 23.0 mmol) in MeOH (30 mL) to provide **10c** (3.0 g, 88%) as a yellow solid. R_f 0.50 (hexane/EtOAc, 8/2); mp 173–174 °C [Lit.[14] 185–186 °C; Lit.[15] 170 °C]. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.18 (s, 6H, $2CH_3$), 3.82 (s, 6H, $2CH_3O$), 6.73–6.80 (m, 4H, H-2′), 6.89–6.96 (m, 4H, H-3′). ^{13}C

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NMR (75.4 MHz, $CDCl_3$): δ 15.4 ($2CH_3$), 55.4 ($2CH_3O$), 114.2 (4C-3′), 120.6 (4C-2′), 144.0 (2C-1′), 156.3 (2C-4′), 168.5 (C-2, C-3).

*(E,E)-N,N′-Bis(4-chlorophenyl)butane-2,3-diimine (**10d**).* The procedure for the preparation of **10a** was followed using a mixture of **1a** (0.495 g, 5.75 mmol) and **2d** (1.47 g, 11.5 mmol) in MeOH (15 mL) to produce **10d** (0.70 g, 40%) as a yellow solid. R_f 0.77 (hexane/EtOAc, 8/2); mp 175−176 °C [Lit.[18] 172.4−173.8 °C]. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.13 (s, 6H, $2CH_3$), 6.69−6.75 (m, 4H, H-2′), 7.31−7.37 (m, 4H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 15.7 (C-1, C-4), 120.5 (4C-2′), 129.4 (4C-3′), 129.5 (2C-4′), 149.5 (2C-1′), 169.0 (C-2, C-3).

*(E,E)-N,N′-Di(naphthalen-2-yl)butane-2,3-diimine (**10e**).*[38] The procedure for the preparation of **10a** was followed using a mixture of **1a** (0.989 g, 11.50 mmol) and **2e** (3.29 g, 23.0 mmol) in MeOH (30 mL) to obtain **10e** (3.33 g, 86%) as a yellow solid. R_f 0.92 (hexane/EtOAc, 8/2); mp 183−185 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.25 (s, 6H, $2CH_3$), 7.05 (dd, *J* = 8.4, 2.1 Hz, 2H, H-3′), 7.19 (d, *J* = 2.1 Hz, 1H, H-1′), 7.42 (ddd, *J* = 8.4, 6.6, 1.2 Hz, 2H, H-6′), 7.49 (ddd, *J* = 8.4, 6.6, 1.2 Hz, 2H, H-7′), 7.82 (br d, *J* = 8.4 Hz, 2H, H-8′), 7.83 (br d, *J* = 8.4 Hz, 2H, H-5′), 7.87 (d, *J* = 8.4 Hz, 2H, H-4′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 15.7 (C-1, C-4), 114.7 (2C-1′), 120.0 (2C-3′), 124.7 (2C-6′), 126.4 (2C-7′), 127.4 (2C-8′), 127.8 (2C-5′), 128.9 (2C-4′), 130.7 (2C-4a′), 133.9 (2C-8a′), 148.6 (2C-2′), 168.7 (C-2, C-3).

*General Method for the Preparation of Nonsymmetric Bis-Imines **11a** and **b**. (E,E)-N,N′-Bis(4-methoxyphenyl)pentane-2,3-diimine (**11a**).* A mixture of **2c** (2.36 g, 19.2 mmol) and *p*-toluenesulfonic acid (0.18 g, 0.96 mmol) was ground in a mortar to obtain a fine homogeneous powder, then **1b** (0.96 g, 9.6 mmol) was added and ground for 40 min until the formation of a brown semisolid. MeOH (20 mL) was added; the crude mixture was filtered, and then the solid washed with cold MeOH (3 × 10 mL) to give **11a** (1.64 g, 55%) as a yellow solid; R_f 0.54 (hexane/EtOAc, 8/2); mp 84−85 °C. IR (film): ν_{max} 1636, 1504, 1466, 1456, 1033, 841 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.10 (t, *J* = 7.5 Hz, 3H, CH_3CH_2), 2.15 (s, 3H, H-1), 2.67 (q, *J* = 7.5 Hz, 2H, CH_3CH_2), 3.82 (s, 3H, CH_3O), 3.83 (s, 3H, CH_3O), 6.71−6.80 (m, 4H, H-2′, H-2″), 6.88−6.96 (m, 4H, H-3′, H-3″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 13.0 (CH_3CH_2), 15.8 (C-1), 21.6 (CH_3CH_2), 55.4 (CH_3O), 55.5 (CH_3O), 141.1 (C-3′ or C-3″), 114.2 (C-3″ or C-3′), 119.9 (C-2′ or C-2″), 120.5 (C-2″ or C-2′), 144.0 (2C-1′, C-1″), 156.1 (C-4′ or C-4″), 156.3 (C-4″ or C-4′), 167.2 (C-2), 173.3 (C-3). MS (70 eV): *m*/*z* 310 (M^+, 48), 309 (19), 295 (64), 162 (100), 148 (62), 134 (14), 77 (26). HRMS (EI): *m*/*z* [M^+] calcd for $C_{19}H_{22}N_2O_2$: 310.1681. Found: 310.1690.

*(E,E)-N,N′-Bis(4-methoxyphenyl)hexane-2,3-diimine (**11b**).* The procedure for the preparation of **11a** was followed using a mixture of **2c** (1.00 g, 8.2 mmol), *p*-toluenesulfonic acid (0.16 g, 0.82 mmol), and **1c** (0.467 g, 4.10 mmol) to give **11b** (0.67 g, 50%) as a yellow solid; R_f 0.86 (hexane/EtOAc, 7/3); mp 72−73 °C. IR (film): ν_{max} 1631, 1497, 1462, 1034, 842, 754 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.84 (t, *J* = 7.5 Hz, 3H, H-6), 1.55 (sext, *J* = 7.5 Hz, 2H, H-5), 2.15 (s, 3H, H-1), 2.60−2.68 (m, 2H, H-4), 3.82 (s, 6H, CH_3O), 6.70−6.81 (m, 4H, H-2′, H-2″), 6.88−6.96 (m, 4H, H-3′, H-3″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 14.3 (C-6), 15.7 (C-1), 21.6 (C-5), 30.1 (C-4), 55.3 (CH_3O) 55.4 (CH_3O), 114.0 (C-3′ or C-3″), 114.1 (C-3″ or C-3′), 119.9 (C-2′ or C-2″), 120.4 (C-2″ or C-2′), 144.0 (C-1′, C-1″), 156.0 (C-4′ or C-4″), 156.3 (C-4″ or C-4′), 167.5 (C-2), 172.3 (C-3). HRMS (EI): *m*/*z* [M^+] calcd for $C_{20}H_{24}N_2O_2$: 324.1838. Found: 324.1830.

*General Method for the Preparation of Imidazolidin-2-one Dienes **5a**−**e** from Bis-Imines. 4,5-Dimethylene-1,3-diphenylimidazolidin-2-one (**5a**).* After a mixture of **10a** (0.100 g, 0.42 mmol) in 25 mL of anhydrous toluene was stirred at 0 °C under N_2 atmosphere, Et_3N (0.127 g, 1.26 mmol) was added. Then, **9** (0.187 g, 0.63 mmol) dissolved in 5 mL of anhydrous toluene was added dropwise and stirred at 0 °C for 3 h. The crude mixture was washed with a 1.0 M aqueous solution of NaOH (3 × 20 mL); the organic layer was dried (Na_2SO_4), and the solvent removed under vacuum. The crude purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to furnish **5a** (0.090 g, 81%) as a white solid. R_f 0.51 (hexane/EtOAc, 8/2); mp 76−77 °C [Lit.[10] 75−76 °C]. IR (KBr): ν_{max} 1712, 1600, 1541, 1499, 1068, 756 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.37 (d, *J* = 2.4 Hz, 2H, H-6, H-7), 4.82 (d, *J* = 2.4 Hz, 2H, H-6, H-7), 7.34−7.45 (m, 6H, Ph-H), 7.46−7.52 (m, 4H, Ph-H). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 82.9 (C-6, C-7), 127.5 (C-2′), 127.9 (C-4′), 129.4 (C-3′), 134.2 (C-1′), 140.0 (C-4, C-5), 153.5 (C-2).

*4,5-Dimethylene-1,3-bis(4-tolyl)imidazolidin-2-one (**5b**).* The procedure for the preparation of **5a** was followed using a mixture of **10b** (0.200 g, 0.76 mmol), Et_3N (0.230 g, 2.28 mmol), and **9** (0.338 g, 1.14 mmol) in anhydrous toluene (40 mL) to provide **5b** (0.17 g, 78%) as a white solid. R_f 0.54 (hexane/EtOAc, 8/2); mp 118−120 °C [Lit.[10] 119−120 °C]. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.39 (s, 6H, Ar−CH_3), 4.30 (d, *J* = 2.3 Hz, 2H, H-6, H-7), 4.78 (d, *J* = 2.3 Hz, 2H, H-6, H-7), 7.27 (s, 8H, Ar−H). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 21.2 (Ar-CH_3), 82.6 (C-6, C-7), 127.4 (C-2′), 130.0 (C-3′), 131.6 (C-1′), 137.8 (C-4′), 140.3 (C-4, C-5), 153.7 (C-2).

*1,3-Bis(4-methoxyphenyl)-4,5-dimethyleneimidazolidin-2-one (**5c**).* The procedure for the preparation of **5a** was followed using a mixture of **10c** (0.201 g, 0.68 mmol), Et_3N (0.206 g, 2.04 mmol), and **9** (0.303 g, 1.02 mmol) in anhydrous toluene (40 mL) to afford **5c** (0.217 g, 99%) as a white solid. R_f 0.25 (hexane/EtOAc, 8/2); mp 161−162 °C [Lit.[10] 160−161 °C]. ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.83 (s, 6H, CH_3O), 4.26 (d, *J* = 2.1 Hz, 2H, H-6, H-7), 4.77 (d, *J* = 2.1 Hz, 2H, H-6, H-7), 6.95−7.02 (m, 4H, H-3′), 7.25−7.33 (m, 4H, H-2′). ^{13}C NMR (125 MHz, $CDCl_3$): δ 55.4 (CH_3O), 82.6 (C-6, C-7), 114.7 (C-3′), 126.8 (C-1′), 128.9 (C-2′), 140.6 (C-4, C-5), 154.0 (C-2), 159.1 (C-4′).

*1,3-Bis(4-chlorophenyl)-4,5-dimethyleneimidazolidin-2-one (**5d**).* The procedure for the preparation of **5a** was followed using a mixture of **10d** (0.100 g, 0.33 mmol), Et_3N (0.100 g, 0.99 mmol) and **9** (0.149 g, 0.5 mmol) in anhydrous toluene (25 mL) to generate **5d** (0.093 g, 85%) as a white solid. R_f 0.54 (hexane/EtOAc, 8/2); mp 164−165 °C [Lit.[10] 162−163 °C]. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.36 (d, *J* = 2.5 Hz, 2H, H-6, H-7), 4.84 (d, *J* = 2.5 Hz, 2H, H-6, H-7), 7.32−7.37 (m, 4H, H-2′), 7.44−7.49 (m, 4H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 83.5 (C-6, C-7), 128.8 (C-3′), 129.7 (C-2′), 132.6 (C-4′), 133.8 (C-1′), 139.5 (C-4, C-5), 153.1 (C-2).

*4,5-Dimethylene-1,3-di(naphthalen-2-yl)imidazolidin-2-one (**5e**).* The procedure for the preparation of **5a** was followed using a mixture of **10e** (0.10 g, 0.3 mmol), Et_3N (0.091 g, 0.90 mmol) and **9** (0.134 g, 0.45 mmol) in anhydrous CH_2Cl_2 (25 mL) to produce **5e** (0.076 g, 70%) as a white solid. R_f 0.62 (hexane/EtOAc, 7/3); mp 169−170 °C. IR (film): ν_{max} 1698, 1626, 1599, 1508, 1472, 856, 812 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.45 (d, *J* = 2.1 Hz, 2H, CH_2═), 4.89 (d, *J* = 2.1 Hz, 2H, CH_2═), 7.51−7.57 (m, 6H, ArH′), 7.86−7.92 (m, 4H, ArH′), 7.94 (br s, 2H, H-1′), 7.96 (d, *J* = 8.4 Hz, 2H, H-4′). ^{13}C NMR (101 MHz, $CDCl_3$): δ 83.2 ($2CH_2$═), 125.1 (2C-3′), 126.5 (2ArH′), 126.6 (2ArH′), 126.6 (2ArH′), 127.8 (2ArH′), 128.0 (2ArH′), 129.4 (2C-4′), 131.7 (2C-8a′), 132.6 (2C-4a′), 133.7 (2C-2′), 140.2 (C-4, C-5), 153.8 (C-2). MS (70 eV): *m*/*z* 362 (M^+, 64), 361 (45), 228 (88), 193 (100), 169 (50), 167 (70), 143 (62), 115 (30), 75 (32). HRMS (EI): *m*/*z* [M^+] calcd for $C_{25}H_{18}N_2O$: 362.1419. Found: 362.1435.

*1-(4-Methoxyphenyl)-4,5-dimethylene-3-phenylimidazolidin-2-one (**5f**).* A mixture of **3a** (0.659 g, 6.53 mmol), Et_3N (0.932 g, 7.83 mmol), and Li_2CO_3 (1.93 g, 26.1 mmol) in anhydrous toluene (60 mL) was stirred at 20 °C under N_2 atmosphere for 90 min in the dark. Subsequently, **4d** (0.932 g, 7.83 mmol) dissolved in anhydrous toluene (15 mL) was added dropwise, and the mixture stirred at room temperature for 24 h. The crude mixture was filtered over Celite/silica gel (1/1) and washed with CH_2Cl_2 (3 × 20 mL). The solvent was removed under vacuum, and the reaction crude purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to give **5f** (0.62 g, 82%) as a white solid. R_f 0.22 (hexane/EtOAc, 8/2); mp 168−169 °C. IR (KBr): ν_{max} 1718, 1631, 1514, 1037, 843, 754 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.84 (s, 3H, CH_3O), 4.27 (d, *J* = 2.7 Hz, 1H, H-7), 4.35 (d, *J* = 2.7 Hz, 1H, H-6), 4.78 (d, *J* = 2.7 Hz, 1H, H-7), 4.80 (d, *J* = 2.7 Hz, 1H, H-6), 6.97−7.02 (m, 2H, H-3′), 7.28−7.33 (m, 2H, H-2′), 7.33−7.43 (m,

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3H, H-2″, H-4″), 7.45−7.52 (m, 2H, H-3″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 55.5 (CH_3O), 82.6 (C-6 or C-7), 82.8 (C-7 or C-6), 114.7 (C-3′), 126.8 (C-1′), 127.5 (C-2″), 127.8 (C-4″), 128.9 (C-2′), 129.4 (C-3″), 134.3 (C-1″), 140.0 (C-4 or C-5), 140.5 (C-5 or C-4), 153.7 (C-2), 159.0 (C-4′). HRMS (EI): *m/z* [M^+] calcd for $C_{18}H_{16}N_2O_2$: 292.1212. Found: 292.1210.

*1-(4-Chlorophenyl)-3-(4-methoxyphenyl)-4,5-dimethyleneimidazolidin-2-one (**5g**).* The procedure for the preparation of **5f** was followed using a mixture of **3b** (0.300 g, 1.57 mmol), Et_3N (0.40 g, 3.96 mmol), Li_2CO_3 (1.16 g, 15.7 mmol), and **4b** (0.72 g, 4.70 mmol) to obtain **5g** (0.33 g, 65%) as a white solid. R_f 0.52 (hexane/EtOAc, 8/2); mp 180−181 °C. IR (film): ν_{max} 1714, 1631, 1514, 1038, 823 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.83 (s, 3H, CH_3O), 4.27 (d, *J* = 2.4 Hz, 1H, H-6), 4.34 (d, *J* = 2.6 Hz, 1H, H-7), 4.79 (d, *J* = 2.4 Hz, 1H, H-6), 4.82 (d, *J* = 2.6 Hz, 1H, H-7), 6.96−7.03 (m, 2H, H-3″), 7.26−7.32 (m, 2H, H-2″), 7.32−7.38 (m, 2H, H-2′), 7.41−7.48 (m, 2H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 55.5 (CH_3O), 82.9 (C-7), 83.1 (C-6), 114.8 (C-3″), 126.5 (C-1″), 128.8 (C-2′), 128.9 (C-2″), 129.6 (C-3′), 132.8 (C-1′), 133.5 (C-4′), 139.7 (C-5), 140.3 (C-4), 159.1 (C-2), 159.2 (C-4″). HRMS (EI): *m/z* [M^+] calcd for $C_{18}H_{15}N_2O_2Cl$: 326.0822. Found: 326.0818.

*(E)-4-Ethylidene-1,3-bis(4-methoxyphenyl)-5-(methylene)-imidazolidin-2-one (**12a**) and (Z)-4-Ethylidene-1,3-bis(4-methoxyphenyl)-5-methyleneimidazolidin-2-one (**13a**).* Method A: To a stirring solution of **11a** (0.100 g, 0.32 mmol) in anhydrous toluene (60 mL) at 0 °C under N_2 atmosphere, Et_3N (0.097 g, 0.96 mmol) was added, and then **9** (0.143 g, 0.48 mmol) in anhydrous toluene (5 mL) was added dropwise. The reaction mixture was stirred at 0 °C for 4 h. The crude was dissolved in CH_2Cl_2 (50 mL) and washed with NaOH 1 M (3 × 50 mL). The organic layer was dried (Na_2SO_4), concentrated under vacuum, and purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to provide a mixture of **12a**/**13a** (59/41) (0.095 g, 88%) as a white solid.

Method B: To a stirring solution of **11a** (0.100 g, 0.32 mmol) in anhydrous toluene (60 mL) at −10 °C under N_2 atmosphere, Et_3N (0.097 g, 0.96 mmol) was added, and then **9** (0.143 g, 0.48 mmol) in anhydrous toluene (5 mL) was added dropwise. The reaction mixture was stirred at −10 °C for 4 h. The crude was dissolved in CH_2Cl_2 (50 mL) and washed with a 1.0 M aqueous solution of NaOH (3 × 50 mL). The organic layer was dried (Na_2SO_4), concentrated under vacuum, and purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to deliver **12a** (0.095 g, 88%) as a white solid. R_f 0.53 (hexane/EtOAc, 1/1); mp 144−145 °C. IR (KBr): ν_{max} 1730, 1608, 1512, 1031, 830 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.85 (d, *J* = 7.8 Hz, 3H, CH_3C═), 3.83 (s, 3H, CH_3O), 3.84 (s, 3H, CH_3O), 4.45 (d, *J* = 2.1 Hz, 1H, CH_2═), 4.60 (d, *J* = 2.1 Hz, 1H, CH_2═), 5.00 (q, *J* = 7.8 Hz, 1H, CH═), 6.94−7.03 (m, 4H, H-3′, H-3″), 7.22−7.33 (m, 4H, H-2′, H-2″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 13.0 (CH_3C═), 55.4 (CH_3O), 87.8 (CH_2═), 100.0 (CH═), 114.70 (C-3′ or C-3″), 114.75 (C-3″ or C-3′), 126.8 (C-1′ or C-1″), 126.9 (C-1″ or C-1′), 129.4 (C-2′ or C-2″), 129.7 (C-2″ or C-2′), 134.5 (C-4), 140.9 (C-5), 153.8 (C-2), 159.00 (C-4′ or C-4″), 159.05 (C-4″ or C-4′). Signals attributed to minor isomer **13a**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.24 (d, *J* = 7.5 Hz, CH_3C═), 3.82 (s, CH_3O), 4.04 (d, *J* = 2.1 Hz, CH_2═), 4.54 (d, *J* = 2.1 Hz, CH_2═), 5.31 (q, *J* = 7.5 Hz, CH═). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 11.7 (CH_3CH), 79.2 (CH_2═), 96.0 (CH═), 114.1 (C-3′ or C-3″), 114.6 (C-3″ or C-3′), 127.1 (C-1′ or C-1″), 129.0 (C-2′ or C-2″), 129.1 (C-1″ or C-1′), 129.6 (C-2″ or C-2′), 132.4 (C-4), 142.0 (C-5), 155.1 (C-2), 158.9 (C-4′ or C-4″), 159.0 (C-4″ or C-4′). MS (70 eV): *m/z* 336 (M^+, 4), 231 (12), 100 (100), 72 (54). Anal. Calcd for $C_{20}H_{20}N_2O_3$: C, 71.41; H, 5.99; N, 8.33. Found: C, 71.39; H, 5.99; N, 8.38.

*1,3-Bis(4-methoxyphenyl)-4-methyl-5-vinyl-1,3-dihydro-2H-imidazol-2-one (**16a**).* Method A: The procedure for the preparation of **12a**/**13a** was followed using a mixture of **11a** (0.300 g, 0.97 mmol), Et_3N (0.294 g, 2.91 mmol), and **9** (0.431 g, 1.45 mmol) in anhydrous toluene (60 mL) stirred at 20 °C for 1 h to give **16a** (0.244 g, 75%) as a brown solid.

Method B: To a stirring solution of **12a** (0.050 g, 0.97 mmol) in anhydrous CH_2Cl_2 (5 mL) at −78 °C under N_2 atmosphere, $AlCl_3$ (1 M in diethyl ether) (0.005 g, 0.04 mmol) was added dropwise, and the mixture was stirred for 30 min. Then, it was washed with an aqueous saturated solution of Na_2CO_3 (3 × 10 mL); the organic layer was dried (Na_2SO_4), and the solvent concentrated under vacuum. The crude was purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to obtain **16a** (0.035 g, 70%) as a brown solid. R_f 0.11 (hexane/EtOAc, 1/1); mp 166−167 °C. IR (film): ν_{max} 1698, 1512, 1031, 831 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.06 (s, 3H, CH_3-C4), 3.829 (s, 3H, CH_3O), 3.834 (s, 3H, CH_3O), 4.85 (dd, *J* = 17.7, 0.6 Hz, 1H, CH_2═), 5.01 (dd, *J* = 12.0, 0.6 Hz, 1H, CH_2═), 6.22 (dd, *J* = 17.7, 12.0 Hz, 1H, CH═), 6.92−7.01 (m, 4H, H-3′, H-3″), 7.23−7.32 (m, 4H, H-2′, H-2″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 10.5 (CH_3−C4), 55.4 (CH_3O), 55.5 (CH_3O), 113.4 (CH_2═), 114.2 (C-3′ or C-3″), 114.4 (C-3″ or C-3′), 118.1 (C-5), 118.9 (C-4), 123.3 (CH═), 127.5 (C-1′ or C-1″), 128.4 (C-1′ or C-1″), 128.90 (C-2′ or C-2″), 128.92 (C-2′ or C-2″), 152.6 (C-2), 158.8 (C-4′ or C-4″), 159.0 (C-4″ or C-4′). HRMS (EI): *m/z* [M^+] calcd for $C_{20}H_{20}N_2O_3$: 336.1474. Found: 336.1482.

*(E)-1,3-Bis(4-methoxyphenyl)-4-(methylene)-5-propylideneimidazolidin-2-one (**14**) and (Z)-1,3-Bis(4-methoxyphenyl)-4-methylene-5-propylideneimidazolidin-2-one (**15**).* Following method A for the preparation of **12a**/**13a**, a mixture of **11b** (0.100 g, 0.31 mmol), Et_3N (0.094 g, 0.93 mmol), and **9** (0.101 g, 0.34 mmol) in anhydrous toluene (60 mL) was stirred at 0 °C for 4 h to produce a mixture of **14**/**15** (42/58) (0.085 g, 78%) as a white oil; R_f 0.57 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1682, 1509, 1027, 830 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.82 (t, *J* = 7.5 Hz, 3H, CH_3CH_2), 1.50−1.63 (m, 2H, CH_3CH_2), 3.84 (s, 6H, CH_3O), 4.05 (d, *J* = 2.4 Hz, 1H, CH_2═), 4.57 (d, *J* = 2.4 Hz, 1H, CH_2═), 5.18 (t, *J* = 7.5 Hz, 1H, CH═), 6.91−7.02 (m, 4H, H-3′, H-3″), 7.23−7.32 (m, 4H, H-2′, H-2″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 14.4 (CH_3CH_2), 19.1 (CH_3CH_2), 55.4 ($2CH_3O$), 79.3 (CH_2═), 103.7 (CH═), 114.1 (C-3′ or C-3″), 114.5 (C-3″ or C-3′), 127.1 (C-1′ or C-1″), 128.9 (C-2′ or C-3″), 129.2 (C-1″ or C-1′), 129.4 (C-2″ or C-2′), 131.1 (C-4), 142.0 (C-5), 153.8 (C-2), 158.8 (C-4′ or C-4″), 159.0 (C-4″ or C-4′). Signals attributed to the minor isomer **14**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.06 (t, *J* = 7.5 Hz, CH_3CH_2), 2.22−2.35 (m, 2H, CH_3CH_2), 3.83 (s, CH_3O), 4.43 (d, *J* = 1.8 Hz, CH_2═), 4.59 (d, *J* = 1.8 Hz, CH_2═), 4.84 (t, *J* = 6.9 Hz, CH═). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 14.1 (CH_3CH_2), 20.8 (CH_3CH_2), 87.6 (CH_2═), 108.1 (CH═), 114.65 (C-3′ or C-3″), 114.68 (C-3″ or C-3′), 126.7 (C-1′ or C-1″), 126.8 (C-1″ or C-1′), 129.3 (C-2′ or C-2″), 129.7 (C-2″ or C-2′), 132.2 (C-4), 140.7 (C-5), 153.8 (C-2), 158.9 (C-4′, C-4″). HRMS (EI): *m/z* [M^+] calcd for $C_{21}H_{22}N_2O_3$: 350.1631. Found: 350.1632.

*(E)-1,3-Bis(4-methoxyphenyl)-4-methyl-5-(prop-1-en-1-yl)-1,3-dihydro-2H-imidazol-2-one (**17**).* Following method A for the preparation of **16a**, a mixture of **11b** (0.200 g, 0.62 mmol), Et_3N (0.188 g, 1.86 mmol), and **9** (0.220 g, 0.74 mmol) in anhydrous toluene (60 mL) was stirred at 20 °C for 1 h to give **17** (0.152 g, 70%) as a brown solid. R_f 0.22 (hexane/EtOAc, 8/2); mp 132−133 °C. IR (film): ν_{max} 1697, 1512, 1030, 831 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.73 (dd, *J* = 6.6, 1.2 Hz, 3H, CH_3CH═), 2.02 (s, 3H, CH_3-C4), 3.82 (s, 3H, CH_3O), 3.83 (s, 3H, CH_3O), 5.46 (dq, *J* = 16.0, 6.6 Hz, 1H, CH_3CH═), 5.86 (dd, *J* = 16.0, 1.5 Hz, 1H, CH═), 6.91−7.00 (m, 4H, H-3′, H-3″), 7.23−7.31 (m, 4H, H-2′, H-2″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 10.5 (CH_3−C4), 19.0 (CH_3CH═), 55.3 (CH_3O), 55.4 (CH_3O), 114.1 (C-3′ or C-3″), 114.3 (C-3″ or C-3′), 116.7 (C-4), 117.7 (CH═), 118.1 (C-5), 126.7 (CH_3CH═), 127.6 (C-1′ or C-1″), 128.4 (C-1″ or C-1′), 128.81 (C-2′ or C-2″), 128.83 (C-2″ or C-2′), 152.4 (C-2), 158.6 (C-4′ or C-4″), 158.9 (C-4″ or C-4′). HRMS (EI): *m/z* [M^+] calcd for $C_{21}H_{22}N_2O_3$: 350.1631. Found: 350.1633.

*General Method for the Preparation of Imidazolidin-2-one Dienes **12b**−**d** and **13b**−**d**. (E)-4-Ethylidene-1-(4-methoxyphenyl)-5-methylene-3-phenyl-5-imidazolidin-2-one (**12b**) and (Z)-4-Ethylidene-1-(4-methoxyphenyl)-5-methylene-3-phenylimidazolidin-2-one (**13b**).* To a stirring mixture of **8** (0.500 g, 2.44 mmol), Li_2CO_3 (2.34 g, 31.7 mmol), and Et_3N (0.739 g, 7.32 mmol) in anhydrous

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toluene (40 mL) at room temperature under N_2 atmosphere was added **4a** (0.726 g, 6.10 mmol), and the reaction mixture was stirred for 48 h. The crude was filtered over Celite and washed with CH_2Cl_2 (2 × 25 mL), concentrated under vacuum, and purified by column chromatography over silica gel treated with Et_3N (10% w/w) (10 g/g of crude, hexane/EtOAc, 9/1) to give a mixture of **12b**/**13b** (36/64) (0.30 g, 40%) as a white solid. R_f 0.55 (hexane/EtOAc, 7/3); mp 129−130 °C. IR (film): ν_{max} 1734, 1648, 1515, 1031, 754, 695 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.23 (d, J = 7.8 Hz, 3H, CH_3CH=), 3.82 (s, 3H, CH_3O), 4.07 (d, J = 2.7 Hz, 1H, CH_2=), 4.57 (d, J = 2.7 Hz, 1H, CH_2=), 5.35 (q, J = 7.8 Hz, 1H, CH=), 6.92−7.02 (m, 2H, H-3′), 7.25−7.31 (m, 2H, H-2′), 7.34−7.48 (m, 5H, H-2″, H-3″, H-4″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 12.2 (CH_3CH), 55.4 (CH_3O), 79.4 (CH_2=), 96.5 (CH_3CH=), 114.6 (C-3′), 127.1 (C-1′), 127.7 (C-4″), 128.2 (C-2″), 128.8 (C-2′ or C-3″), 129.0 (C-3″ or C-2′), 132.2 (C-4), 136.5 (C-1″), 142.0 (C-5), 154.9 (C-2), 159.0 (C-4′). Signals attributed to the minor isomer **12b**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.85 (d, J = 7.5 Hz, CH_3CH), 4.47 (d, J = 2.1 Hz, CH_2=), 4.63 (d, J = 2.1 Hz, CH_2=), 5.07 (q, J = 7.5 Hz, CH_3CH). HRMS (EI): m/z [M^+] calcd for $C_{19}H_{18}N_2O_2$: 306.1368. Found: 306.1357.

*(E)-1-(4-Chlorophenyl)-5-ethylidene-3-(4-methoxyphenyl)-4-(methylene)imidazolidin-2-one (**12c**) and (Z)-1-(4-Chlorophenyl)-5-ethylidene-3-(4-methoxyphenyl)-4-(methylene)imidazolidin-2-one (**13c**).* The procedure for the preparation of **12b**/**13b** was followed using a mixture of **8** (0.187 g, 0.91 mmol), Li_2CO_3 (0.96 g, 13.0 mmol), Et_3N (0.303 g, 3.00 mmol), and **4b** (0.383 g, 2.50 mmol) in anhydrous toluene (60 mL) to afford a mixture of **12c**/**13c** (57/43) (0.22 g, 65%) as a white solid: R_f 0.58 (hexane/EtOAc, 7/3); mp 135−139 °C. IR (film): ν_{max} 1732, 1514, 1494, 1090, 829 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.86 (d, J = 7.8 Hz, 3H, CH_3CH), 3.84 (s, 3H, CH_3O), 4.48 (d, J = 2.1 Hz, 1H, CH_2=), 4.64 (d, J = 2.1 Hz, 1H, CH_2=), 5.08 (q, J = 7.8 Hz, 1H, CH_3CH), 6.94−7.03 (m, 2H, H-3″), 7.23−7.36 (m, 4H, H-2′, H-2″), 7.39−7.48 (m, 2H, H-3′). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 13.0 (CH_3CH), 55.5 (CH_3O), 88.5 (CH_2=), 100.3 (CH_3CH), 114.8 (C-3″), 126.4 (C-1″), 129.4 (C-2″), 129.7 (C-2′, C-3′), 132.9 (C-1′), 133.5 (C-4′), 133.8 (C-4), 140.6 (C-5), 153.4 (C-2), 159.2 (C-4″). Signals attributed to the minor isomer **13c**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.28 (d, J = 7.8 Hz, CH_3CH), 3.83 (s, CH_3O), 4.07 (d, J = 2.4 Hz, CH_2=), 4.58 (d, J = 2.4 Hz, CH_2=), 5.37 (q, J = 7.8 Hz, CH_3CH). HRMS (EI): m/z [M^+] calcd for $C_{19}H_{17}ClN_2O_2$: 340.0979. Found: 340.0974.

*(E)-4-Ethylidene-1-(4-methoxyphenyl)-5-methylene-3-(p-tolyl)-imidazolidin-2-one (**12d**) and (Z)-4-Ethylidene-1-(4-methoxyphenyl)-5-methylene-3-(p-tolyl)imidazolidin-2-one (**13d**).* The procedure for the preparation of **12b**/**13b** was followed using a mixture of **8** (0.495 g, 2.41 mmol), Li_2CO_3 (2.32 g, 31.3 mmol), Et_3N (0.730 g, 7.23 mmol), and **4c** (0.802 g, 6.03 mmol) in anhydrous toluene (60 mL) to give a mixture of **12d**/**13d** (68/32) (0.417 g, 54%) as a white solid. R_f 0.75 (hexane/EtOAc, 7/3); mp 94−97 °C. IR (film): ν_{max} 1730, 1513, 1032, 825, 749 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.85 (d, J = 7.8 Hz, 3H, CH_3CH), 2.38 (s, 3H, CH_3Ar), 3.82 (s, 3H, CH_3O), 4.46 (d, J = 2.4 Hz, 1H, CH_2=), 4.60 (d, J = 2.4 Hz, 1H, CH_2=), 5.04 (q, J = 7.8 Hz, 1H, CH_3CH), 6.93−7.02 (m, 2H, H-3′), 7.19−7.32 (m, 6H, H-2′, H-2″, H-3″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 13.0 (CH_3CH), 21.1 ($ArCH_3$), 55.38 (CH_3O), 87.8 (CH_2=), 100.0 (CH_3CH), 114.7 (C-3′), 126.7 (C-1′), 128.2 (C-2′), 129.4 (C-2″), 130.1 (C-3″), 131.6 (C-1″), 134.3 (C-4), 137.8 (C-4″), 140.9 (C-5), 153.6 (C-2), 159.0 (C-4′). Signals attributed to the minor isomer **13d**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.23 (d, J = 7.8 Hz, CH_3CH), 3.81 (s, CH_3O), 4.05 (d, J = 2.1 Hz, CH_2=), 4.55 (d, J = 2.1 Hz, CH_2=), 5.32 (q, J = 7.8 Hz, CH_3CH), 6.93−7.02 (m, 2H, H-2′), 7.20−7.32 (m, 6H, H-2″, H-3′, H-3″). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 12.0 (CH_3CH), 22.6 ($ArCH_3$), 55.4 (CH_3O), 79.2 (CH_2=), 96.2 (CH_3CH), 114.6 (C-3′), 127.1 (C-1′), 128.1 (C-2′), 129.0 (C-2″), 129.5 (C-3″), 132.2 (C-1″), 133.8 (C-4), 137.6 (C-4″), 142.0 (C-5), 155.0 (C-2), 158.9 (C-4′). HRMS (EI): m/z [M^+] calcd for $C_{20}H_{20}N_2O_2$: 320.1525. Found: 320.1510.

*1-(4-Chlorophenyl)-3-(4-methoxyphenyl)-4-methyl-5-vinyl-1,3-dihydro-2H-imidazol-2-one (**16b**).* Following method B for the preparation of **16a**, a mixture of **12c**/**13c** (57/43) (0.050 g, 0.15 mmol) and $AlCl_3$ (1 M in diethyl ether) (0.005 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) at −78 °C under N_2 atmosphere was stirred for 30 min to produce **16b** (0.041 g, 78%) as a white solid; R_f 0.46 (hexane/EtOAc, 1/1); mp 116−118 °C. IR (film): ν_{max} 1700, 1515, 1495, 1401, 1250, 830 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 2.05 (s, 3H, CH_3−C4), 3.83 (s, 3H, CH_3O), 4.90 (d, J = 17.8, 1H, CH_2=), 5.09 (d, J = 11.8, 1H, CH_2=), 6.22 (dd, J = 17.8, 11.8 Hz, 1H, CH=), 6.95−7.00 (m, 2H, H-3″), 7.24−7.28 (m, 2H, H-2″), 7.33−7.36 (m, 2H, H-3′), 7.40−7.43 (m, 2H, H-2′). ^{13}C NMR (101 MHz, $CDCl_3$): δ 10.5 (CH_3−C4), 55.5 (CH_3O), 114.2 (CH_2=), 114.5 (C-3″), 117.6 (C-4), 119.7 (C-5), 123.1 (CH=), 127.1 (C-1″), 128.6 (C-3′), 128.9 (C-2″), 129.1 (C-2′), 133.0 (C-1′), 134.1 (C-4′), 152.2 (C-2), 159.2 (C-4″). HRMS (EI): m/z [M^+] calcd for $C_{19}H_{17}ClN_2O_2$: 340.0979. Found: 340.0977.

General Method for the Diels−Alder Cycloaddition of Imidazolidin-2-ones. (4R,5S*)-1,3-Bis(4-methoxyphenyl)-4-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**19a**), (4R*,5R*)-1,3-Bis(4-methoxyphenyl)-4-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**20a**), (5R*,7R*)-1,3-Bis(4-methoxyphenyl)-7-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**21a**), and (5R*,7S*)-1,3-Bis(4-methoxyphenyl)-7-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**22a**).* Method A: To a solution of **12a** (0.050 g, 0.15 mmol) in anhydrous CH_2Cl_2 (5 mL), at −78 °C and under N_2 atmosphere, **18a** (0.025 g, 0.45 mmol) and $ZnCl_2$ (1 M in diethyl ether) (0.005 g, 0.04 mmol) were added dropwise. The reaction mixture was stirred at the same temperature for 2 h and then washed with an aqueous saturated solution of Na_2CO_3 (3 × 10 mL). The organic layer was dried (Na_2SO_4) and concentrated under vacuum to generate a mixture with a 98/2 *ortho*/*meta* ratio and the corresponding *endo*/*exo* ratios of **19a**/**20a** (83/17)/**21a**/**22a** (0.043 g, 74%) as a yellow oil.

Method B: To a mixture of **12a** (0.050 g, 0.15 mmol) in anhydrous CH_2Cl_2 (5 mL) at −78 °C under N_2 atmosphere, **18a** (0.025 g, 0.45 mmol) and $BF_3{\cdot}OEt_2$ (0.0057 g, 0.04 mmol) were added dropwise, followed by stirring at the same temperature for 2 h. The reaction crude was washed with an aqueous saturated solution of Na_2CO_3 (3 × 10 mL), and then the organic layer was dried (Na_2SO_4) and concentrated under vacuum to give a mixture with a 65/35 *ortho*/*meta* ratio and the corresponding *endo*/*exo* ratios of **19a**/**20a** (25/36)/**21a**/**22a** (14/25) (0.042 g, 72%) as a yellow oil.

Data of the mixture of **19a**/**20a** (83/17): R_f 0.16 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1698, 1513, 1407, 1030, 832 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 0.79 (d, J = 7.0 Hz, 3H, CH_3-C4), 1.77−1.89 (m, 1H, H-6), 2.13−2.20 (m, 1H, H-6), 2.29−2.37 (m, 1H, H-7), 2.37−2.46 (m, 1H, H-7), 2.82 (ddd, J = 12.5, 5.0 Hz, 1H, H-5), 3.24−3.32 (m, 1H, H-4), 3.82 (s, 3H, CH_3O), 3.83 (s, 3H, CH_3O), 6.90−7.00 (m, 4H, H-3′, H-3″), 7.27−7.32 (m, 4H, H-2′, H-2″), 9.74 (s, 1H, CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 15.3 (CH_3−C4), 17.4 (C-6), 20.4 (C-7), 25.9 (C-4), 50.9 (C-5), 55.4 (CH_3O), 114.3 (C-3′ or C-3″), 114.6 (C-3′ or C-3″), 117.1 (C-7a), 121.1 (C-3a), 127.7 (C-2′ or C-2″), 127.8 (C-1′ or C-1″), 128.5 (C-2′ or C-2″), 129.3 (C-1′ or C-1″), 152.8 (C-2), 158.6 (C-4′ or C-4″), 159.0 (C-4′ or C-4″), 202.8 (CHO). Signals attributed to the minor stereoisomer **20a**: ^1H NMR (500 MHz, $CDCl_3$): δ 0.85 (d, J = 6.5 Hz, CH_3-C4), 3.82 (s, CH_3O), 3.88 (s, CH_3O), 6.84−6.88 (m, H-3′, H-3a), 7.15−7.25 (m, H-2′, H-2″), 9.70 (s, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 17.1 (CH_3−C4), 17.8 (C-6), 21.7 (C-7), 23.5 (C-4), 55.36 (CH_3O), 55.38 (CH_3O), 113.9 (C3′ or C3″), 127.6, 128.3, 129.6, 130.4, 130.9, 152.5 (C-2), 159.1, 159.3, 202.0 (CHO). HRMS (EI) m/z [M^+] calcd for $C_{23}H_{24}N_2O_4$: 392.1736. Found: 392.1723.

(4R,5S*)-4-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**25a**), (4R*,5R*)-4-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**25b**), (5R*,7R*)-7-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**26a**), and (5R*,7S*)-7-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo-[d]imidazole-5-carbaldehyde (**26b**).* The procedure for the preparation of **19a**/**20a** was followed using a mixture of **14**/**15** (42/58) (0.050 g, 0.14 mmol), **18a** (0.020 g, 0.36 mmol), and $ZnCl_2$ (1.0 M in

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diethyl ether) (0.0054 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) to deliver a mixture with a 91/9 *ortho*/*meta* ratio and the corresponding *endo*/*exo* ratios of **25a**/**25b** (57/43)/**26a**/**26b** (0.055 g, 95%) as a yellow oil. R_f 0.18 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1698, 1512, 1408, 1030, 831 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 0.69 (t, J = 7.5 Hz, 3H, CH_3CH_2), 1.20−1.35 (m, 2H, CH_3CH_2), 2.16−2.27 (m, 2H, H-6, H-7), 2.32−2.40 (m, 1H, H-7), 2.60−2.65 (m, 1H, H-5), 3.02−3.07 (m, 1H, H-4), 3.81 (s, 3H, CH_3O), 3.84 (s, 3H, CH_3O), 6.91−7.00 (m, 4H, H-3′, H-3″), 7.23−7.29 (m, 2H, H-2′ or H-2″), 7.30−7.34 (m, 2H, H-2″ or H-2′), 9.74 (s, 1H, CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 11.3 (CH_3CH_2), 18.4 (C-6), 19.0 (C-7), 25.1 (CH_3CH_2), 31.9 (C-4), 48.3 (C-5), 55.4 (CH_3O), 55.5 (CH_3O), 114.3 (C-3′ or C-3″), 114.6 (C-3″ or C-3′), 117.3 (C-7a), 119.2 (C-3a), 127.7 (C-2′ or C-2″), 128.1 (C-1′ or C-1″), 128.3 (C-2″ or C-2′), 152.9 (C-2), 158.6 (C-4′ or C-4″), 158.8 (C-4″ or C-4′), 203.0 (CHO). Signals attributed to the minor stereoisomer **25b**: ^1H NMR (500 MHz, $CDCl_3$): δ 0.88 (t, J = 6.5 Hz, CH_3CH_2), 9.71 (s, 1H, CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 14.1 (CH_3CH_2), 22.7 (CH_3CH_2), 29.7 (C-4). HRMS (EI): m/z [M^+] calcd for $C_{24}H_{26}N_2O_4$: 406.1893. Found: 406.1884.

(4R,5S*)-3-(4-Chlorophenyl)-1-(4-methoxyphenyl)-4-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**19b**), (4S*,5S*)-3-(4-Chlorophenyl)-1-(4-methoxyphenyl)-4-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**20b**), (5R*,7R*)-1-(4-Chlorophenyl)-3-(4-methoxyphenyl)-7-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**21b**), and (5R*,7S*)-1-(4-Chlorophenyl)-3-(4-methoxyphenyl)-7-methyl-2-oxo-2,3,4,5,6,7-hexahydro-1H-benzo[d]-imidazole-5-carbaldehyde (**22b**).* The procedure for the preparation of **19a**/**20a** was followed using a mixture of **12c**/**13c** (57/43) (0.051 g, 0.15 mmol), **18a** (0.021 g, 0.37 mmol), and $ZnCl_2$ (1 M in diethyl ether) (0.0054 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) to produce a mixture with a 96/4 *ortho*/*meta* ratio and the corresponding *endo*/*exo* ratios of **19b**/**20b** (80/20)/**21b**/**22b** (0.043 g, 73%) as a yellow oil. R_f 0.36 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1700, 1661, 1514, 1090, 830 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 0.76 (d, J = 6.9 Hz, 3H, CH_3-C4), 1.73−1.90 (m, 1H, H-6), 2.13−2.24 (m, 1H, H-6), 2.25−2.50 (m, 2H, H-7), 2.84 (ddd, J = 12.6, 4.8, 2.4 Hz, 1H, H-5), 3.20−3.37 (m, 1H, H-4), 3.80 (s, 3H, CH_3O), 6.85−7.03 (m, 2H, H-3′), 7.14−7.50 (m, 6H, ArH), 9.73 (s, 1H, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 15.2 (CH_3-4), 17.2 (C-6), 20.2 (C-7), 25.8 (C-4), 50.7 (C-5), 55.4 (CH_3O), 114.4 (C-3′), 118.4 (C-7a), 121.0 (C-3a), 127.4 (C-1′), 127.8 (C-2′), 128.4 (C-2″ or C-3″), 129.6 (C-3″ or C-2″), 132.9 (C-4″), 133.7 (C-1″), 152.4 (C-2), 158.9 (C-4′), 202.5 (CHO). Signals attributed to the minor isomer **20b**: ^{13}C NMR (74.5 MHz, $CDCl_3$): δ 53.4, 114.5, 121.9, 126.8, 129.7. HRMS (EI): m/z [M^+] calcd for $C_{22}H_{21}ClN_2O_3$: 396.1241. Found: 396.1239.

(4R,5S*)-1-(4-Methoxyphenyl)-4-methyl-2-oxo-3-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**19c**), (4R*,5R*)-1-(4-Methoxyphenyl)-4-methyl-2-oxo-3-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**20c**), (5R*,7R*)-3-(4-Methoxyphenyl)-7-methyl-2-oxo-1-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**21c**), and (5R*,7S*)-3-(4-Methoxyphenyl)-7-methyl-2-oxo-1-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**22c**).* The procedure for the preparation of **19a**/**20a** was followed using a mixture of **12d**/**13d** (68/32) (0.050 g, 0.16 mmol), **18a** (0.022 g, 0.39 mmol), and $ZnCl_2$ (1 M in diethyl ether) (0.0054 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) to give a mixture with a 92/8 *ortho*/*meta* ratio and the corresponding *endo*/*exo* ratios of **19c**/**20c** (69/31)/**21c**/**22c** (0.035 g, 60%) as a yellow oil. R_f 0.33 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1699, 1513, 1030, 824 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 0.77 (d, J = 6.6 Hz, 3H, CH_3-C4), 1.74−1.91 (m, 1H, H-6), 2.14−2.25 (m, 1H, H-6), 2.39 (s, 3H, ArCH_3), 2.50−2.71 (m, 2H, H-7), 2.84 (ddd, J = 12.3, 5.1, 2.4 Hz, 1H, H-5), 3.20−3.40 (m, 1H, H-4), 3.82 (s, 3H, CH_3O), 6.91−7.02 (m, 2H, H-3′), 7.08−7.40 (m, 6H, ArH), 9.74 (s, 1H, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 15.3 (CH_3−C4), 17.4 (C-6), 20.4 (C-7), 21.1 (ArCH_3), 25.9 (C-4), 50.9 (C-5), 55.4 (CH_3O), 114.3 (C-3′), 120.6 (C-7a), 120.9 (C-3a), 126.9 (C-2′), 127.2 (C-1′), 127.6 (C-2″), 129.4 (C-1″), 130.0 (C-3″), 137.6 (C-4″), 153.9 (C-2), 158.5 (C-4′), 202.9 (CHO). Signals attributed to the minor isomer **20c**: ^1H NMR (300 MHz, $CDCl_3$): δ 0.88 (d, J = 6.9 Hz, CH_3-C4). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 114.4, 126.8, 128.9, 129.3, 129.8, 131.9, 132.4, 132.8. HRMS (EI): m/z [M^+] calcd for $C_{23}H_{24}N_2O_3$: 376.1787. Found: 376.1782.

*General Method for the Aromatization of Adducts **19**−**22**. 1,3-Bis(4-methoxyphenyl)-4-methyl-2-oxo-2,3-dihydro-1H-benzo[d]-imidazole-5-carbaldehyde (**23a**) and 1,3-Bis(4-methoxyphenyl)-7-methyl-2-oxo-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**24a**).* Method A: To a mixture of **19a**/**20a** (83/17)/**21a**/**22a** (0.044 g, 0.11 mmol) was added DDQ (0.064 g, 0.28 mmol) in CH_2Cl_2 (5 mL), followed by stirring at room temperature for 24 h. The crude was filtered over Celite and silica gel to afford a mixture of **23a**/**24a** (98/2) (0.035 g, 80%) as a brown solid.

Method B: The procedure for the preparation of **23a**/**24a** was followed using a mixture of **19a**/**20a** (25/36)/**21a**/**22a** (14/25) (0.044 g, 0.11 mmol), then adding DDQ (0.064 g, 0.28 mmol) in CH_2Cl_2 (5 mL) to furnish a mixture of **23a**/**24a** (65/35) (0.037 g, 81%) as a brown solid.

Data of **23a**/**24a** (98/2): R_f 0.69 (hexane/EtOAc, 1/1); mp 86−88 °C. IR (film): ν_{max} 1723, 1684, 1512, 1027, 831 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 2.24 (s, 3H, CH_3-C4), 3.87 (s, 3H, CH_3O), 3.88 (s, 3H, CH_3O), 7.00 (d, J = 8.3 Hz, 1H, H-7), 7.02−7.08 (m, 4H, H-3′, H-3″), 7.35−7.38 (m, 2H, H-2′ or H-2″), 7.43−7.46 (m, 2H, H-2′ or H-2″), 7.60 (d, J = 8.3 Hz, 1H, H-6), 10.16 (s, 1H, CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 13.4 (CH_3−C4), 55.5 (CH_3O), 55.6 (CH_3O), 106.4 (C-7), 114.6 (C-3′ or C-3″), 114.9 (C-3″ or C-3′), 123.3 (C-4), 126.3 (C-1′ or C-1″), 127.9 (C-2′ or C-2″), 128.3 (C-6), 128.6 (C-3a or C-1′), 128.7 (C-1′ or C-3a), 129.7 (C-5), 129.9 (C-2″ or C-2′), 134.8 (C-7a), 154.2 (C-2), 159.5 (C-4′ or C-4″), 159.9 (C-4″ or C-4′), 191.8 (CHO). Signals attributed to the minor regioisomer **24a**: ^1H NMR (500 MHz, $CDCl_3$): δ 1.97 (s, CH_3−C7), 9.86 (s CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 18.1 (CH_3−C7), 106.6 (C-7), 114.5 (C-3′ or C-3″), 115.0 (C-3″ or C-3′), 120.3 (C-6), 127.8 (C-2′ or C-2″), 128.8 (C-1′ or C-1″), 129.2 (C-5), 130.3 (C-2′ or C-2″), 133.0 (C-7a), 154.0 (C-2), 159.4 (C-4′ or C-4″), 160.1 (C-4″ or C-4′), 191.2 (CHO). HRMS (EI): m/z [M^+] calcd for $C_{23}H_{20}N_2O_4$: 388.1423. Found: 388.1404.

*4-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3-dihydro-1H-benzo-[d]imidazole-5-carbaldehyde (**27a**) and 7-Ethyl-1,3-bis(4-methoxyphenyl)-2-oxo-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**27b**).* Following method A for the preparation of **23a**/**24a**, a mixture of **25a**/**25b** (57/43)/**26a**/**26b** (0.053 g, 0.13 mmol) and DDQ (0.075 g, 0.33 mmol) in CH_2Cl_2 (5 mL) provided a mixture of **27a**/**27b** (91/9) (0.045 g, 88%) as a brown solid. R_f 0.66 (hexane/EtOAc, 1/1); mp 68−71 °C. IR (film): ν_{max} 1720, 1678, 1509, 1025, 803 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 0.95 (t, J = 7.5 Hz, 3H, CH_3CH_2), 2.74 (q, J = 7.5 Hz, 2H, CH_3CH_2), 3.87 (s, 3H, CH_3O), 3.89 (s, 3H, CH_3O), 7.01 (d, J = 8.3 Hz, 1H, H-7), 7.02−7.10 (m, 4H, H-3′, H-3″), 7.37−7.48 (m, 4H, H-2′, H-2″), 7.65 (d, J = 8.3 Hz, 1H, H-6), 10.16 (s, 1H, CHO). ^{13}C NMR (125 MHz, $CDCl_3$): δ 16.2 (CH_3CH_2), 18.2 (CH_3CH_2), 55.53 (CH_3O), 55.55 (CH_3O), 106.6 (C-7), 114.8 (C-3′ or C-3″), 114.9 (C-3″ or C-3′), 126.2 (C-1′, C-1″), 127.9 (C-2′ or C-2″), 128.0 (C-6), 128.4 (C-5 or C-3a), 128.7 (C-3a or C-5), 130.0 (C-2″ or C-2′), 130.2 (C-4), 135.0 (C-7a), 154.3 (C-2), 159.4 (C-4′ or C-4″), 160.1 (C-4″ or C-4′), 191.3 (CHO). Signals attributed to the minor regioisomer **27b**. ^1H NMR (500 MHz, $CDCl_3$): δ 1.26 (t, J = 7.5 Hz, CH_3CH_2), 2.32 (q, J = 7.5 Hz, CH_3CH_2), 9.87 (s, 1H, CHO). HRMS (EI): m/z [M^+] calcd for $C_{24}H_{22}N_2O_4$: 402.1580. Found: 402.1579.

*3-(4-Chlorophenyl)-1-(4-methoxyphenyl)-4-methyl-2-oxo-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**23b**) and 1-(4-Chlorophenyl)-3-(4-methoxyphenyl)-7-methyl-2-oxo-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**24b**).* Following method A for the preparation of **23a**/**24a**, a mixture of **19b**/**20b** (80/20)/**21b**/**22b** (0.044 g, 0.11 mmol) and DDQ (0.064 g, 0.28 mmol) in CH_2Cl_2 (5 mL) generated a mixture of **23b**/**24b** (96/4) (0.036 g, 82%) as a brown solid. R_f 0.77 (hexane/EtOAc, 1/1); mp 88−90 °C. IR (film): ν_{max} 1719, 1683, 1596, 1515, 1090, 830 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 2.25 (s, 3H, CH_3-C4), 3.87 (s, 3H, CH_3O), 7.00 (d, J = 8.3 Hz, 1H, H-7), 7.03−7.08 (m, 2H, H-3′), 7.39−7.45 (m, 4H, H-2′, H-2″), 7.49−7.53 (m, 2H, H-3″), 7.62 (d, J = 8.3 Hz, 1H, H-6), 10.15 (s,

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1H, CHO). ^{13}C NMR (101 MHz, $CDCl_3$): δ 14.0 (CH_3−C4), 55.5 (CH_3O), 106.6 (C-7), 115.0 (C-3′), 123.2 (C-4), 125.9 (C-1′), 127.9 (C-2′ or C-2″), 128.1 (C-3a), 128.9 (C-6), 129.6 (C-3″), 129.8 (C-2″), 129.9 (C-5), 134.5 (C-4″), 134.8 (C-1″ or C-7a), 134.9 (C-7a or C-1″), 153.8 (C-2), 159.5 (C-4′), 191.7 (CHO). Signals attributed to the minor regioisomer **24b**: ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.23 (s, CH_3-C7), 3.88 (s, CH_3O), 9.87 (s, CHO). ^{13}C NMR (101 MHz, $CDCl_3$): δ 14.2 (CH_3−C7), 60.5 (CH_3O), 114.7 (C-3′), 121.9 (Ar), 127.7 (C-2′), 129.0 (ArH), 149.9 (C-2), 157.9 (C-4′), 191.79 (CHO). HRMS (EI): m/z [M^+] calcd for $C_{22}H_{17}ClN_2O_3$: 392.0928. Found: 392.0939.

*1-(4-Methoxyphenyl)-4-methyl-2-oxo-3-(p-tolyl)-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**23c**) and 3-(4-Methoxyphenyl)-7-methyl-2-oxo-1-(p-tolyl)-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**24c**).* Following method A for the preparation of **23a**/**24a** and with a mixture of **19c**/**20c** (69/31)/**21c**/**22c** (0.036 g, 0.10 mmol) and DDQ (0.055 g, 0.24 mmol) in CH_2Cl_2 (5 mL), a mixture of **23c**/**24c** (92/8) (0.03 g, 85%) was obtained as a brown solid. R_f 0.58 (hexane/EtOAc, 1/1); mp 82−85 °C. IR (film): ν_{max} 1720, 1685, 1594, 1026, 802 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.23 (s, 3H, CH_3-C4), 2.45 (s, 3H, ArCH_3), 3.87 (s, 3H, CH_3O), 7.01 (d, J = 8.4 Hz, 1H, H-7), 7.02−7.10 (m, 2H, H-3′), 7.31−7.36 (m, 4H, H-2″, H-3″), 7.40−7.47 (m, 2H, H-2′), 7.61 (d, J = 8.4 Hz, 1H, H-6), 10.16 (s, 1H, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 13.6 (CH_3−C4), 21.3 (ArCH_3), 55.5 (CH_3O), 106.4 (C-7), 114.9 (C-3′), 120.6 (C-4), 126.1 (C-1′), 127.9 (C-2′), 128.4 (C-2″, C-6), 128.6 (C-3a), 129.7 (C-5), 130.0 (C-3″), 133.2 (C-1″), 134.8 (C-7a), 139.1 (C-4″), 154.1 (C-2), 159.4 (C-4′), 191.9 (CHO). Signals attributed to the minor regioisomer **24c**. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.94 (s, CH_3-C7), 2.36 (s, ArCH_3), 9.86 (s, CHO). ^{13}C NMR (75.4 MHz $CDCl_3$): δ 123.4, 124.5, 129.0, 130.5, 137.1. HRMS (EI): m/z [M^+] calcd for $C_{23}H_{20}N_2O_3$: 372.1474. Found: 372.1463.

*3-(4-Chlorophenyl)-2-oxo-1-phenyl-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**28a**) and 1-(4-Chlorophenyl)-2-oxo-3-phenyl-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**29a**).* Following method A for the preparation of **19a**/**20a**, a mixture of **5h** (0.050 g, 0.17 mmol), **18a** (0.024 g, 0.42 mmol), and $ZnCl_2$ (1 M in diethyl ether) (0.0054 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) produced a mixture of **28a**/**29a** (60:40) (0.053 g, 88%) as a yellow oil; R_f 0.36 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1702, 1666, 1090, 838, 749 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.84−1.99 (m, 2H, CH_2), 2.16−2.28 (m, 2H, CH_2), 2.30−2.46 (m, 5H, CH_2), 2.51−2.58 (m, 2H, CH_2), 2.62−2.80 (m, 3H, CHCHO, CH_2), 7.29−7.49 (m, 18H, ArH), 9.74 (s, 2H, CHO). ^{13}C NMR (101 MHz, $CDCl_3$) δ 19.9 ($2CH_2$), 20.8 ($2CH_2$), 22.0 ($2CH_2$), 46.02 (CHCHO), 46.04 (CHCHO), 115.5 (C-3a or C-7a), 116.3 (C-7a or C-3a), 117.0 (C-3a′ or C-7a′), 117.9 (C-7a′ or C-3a′), 126.25 (2ArH), 126.34 (2ArH), 127.4 (ArH), 127.5 (ArH), 127.5 (2ArH), 129.2 (2ArH), 129.29 (ArH), 129.32 (ArH), 129.4 (2ArH), 132.9 (Ar), 133.0 (Ar), 133.27 (Ar), 133.34 (Ar), 134.5 (Ar), 134.6 (Ar), 152.0 (C-2), 202.03 (CHO), 202.10 (CHO). HRMS (EI) m/z [M^+] calcd for $C_{20}H_{17}ClN_2O_2$: 352.0979. Found: 352.0973.

*2-Oxo-1-phenyl-3-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]-imidazole-5-carbaldehyde (**28b**) and 2-Oxo-3-phenyl-1-(p-tolyl)-2,3,4,5,6,7-hexahydro-1H-benzo[d]imidazole-5-carbaldehyde (**29b**).* Following method A for the preparation of **19a**/**20a**, a mixture of **5i** (0.050 g, 0.17 mmol), **18a** (0.024 g, 0.42 mmol) and $ZnCl_2$ (1 M in diethyl ether) (0.0054 g, 0.04 mmol) in anhydrous CH_2Cl_2 (5 mL) afforded a mixture of **28b**/**29b** (53:47) (0.041 g, 72%) as a yellow oil; R_f 0.40 (hexane/EtOAc, 1/1). IR (film): ν_{max} 1702, 1665, 1516, 1188, 747 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.84−1.95 (m, 2H, CH_2), 2.16−2.25 (m, 2H, CH_2), 2.36 (s, 3H, ArCH_3), 2.37 (s, 3H, ArCH_3), 2.38−2.47 (m, 4H, CH_2), 2.47−2.58 (m, 2H, CH_2), 2.58−2.67 (m, 2H, CH_2), 2.67−2.80 (m, 3H, CHCHO, CH_2), 7.20−7.48 (m, 18H, ArH), 9.71 (s, 2H, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 19.8 (CH_2), 19.9 (CH_2), 20.7 (CH_2), 20.8 (CH_2), 21.02 (ArCH_3), 21.03 (ArCH_3), 22.1 (CH_2), 22.2 (CH_2), 45.96 (CHCHO), 46.01 (CHCHO), 115.4 (C-3a or C-7a), 115.9 (C-3a′ or C-7a′), 117.1 (C-7a or C-3a), 117.5 (C-7a′ or C-3a′), 126.0 (2ArH), 126.1 (2ArH), 126.15 (2ArH), 126.19 (2ArH), 127.1 (ArH), 127.2 (ArH), 129.0 (2ArH), 129.1 (2ArH), 129.6 (2ArH), 129.8 (2ArH), 131.9 (Ar), 132.0 (Ar), 134.7 (Ar), 134.8 (Ar), 137.1 (Ar), 137.2 (Ar), 152.1 (C-2), 202.36 (CHO), 202.38 (CHO). HRMS (EI) m/z [M^+] calcd for $C_{21}H_{20}N_2O_2$: 332.1525. Found: 332.1523.

*3-(4-Chlorophenyl)-2-oxo-1-phenyl-2,3-dihydro-1H-benzo[d]-imidazole-5-carbaldehyde (**30a**). and 1-(4-Chlorophenyl)-2-oxo-3-phenyl-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**31a**).* Following method A for the preparation of **23a**/**24a**, a mixture of **28a**/**29a** (59/41) (0.050 g, 0.14 mmol) and DDQ (0.079 g, 0.35 mmol) in CH_2Cl_2 (5 mL) furnished a regioisomer mixture of **30a**/**31a** (57/43) (0.043 g, 88%) as a brown solid. R_f 0.90 (hexane/EtOAc, 1/1); mp 114−117 °C. IR (film): ν_{max} 1727, 1687, 1594, 1095, 804, 757 cm^{-1}. Signals attributed to the major regioisomer **30a**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.23 (d, J = 7.8 Hz, 1H, H-7), 7.44−7.52 (m, 1H, H-4′), 7.52−7.61 (m, 8H, ArH), 7.63−7.70 (m, 2H, H-4, H-6), 9.92 (s, 1H, CHO). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 108.2 (C-4), 108.9 (C-7), 126.2 (2ArH), 127.1 (Ar), 127.3 (2ArH), 128.6 (Ar), 129.8 (2ArH), 130.0 (2ArH), 131.4 (Ar), 132.2 (Ar), 133.4 (Ar), 134.6 (Ar), 152.4 (C-2), 190.89 (CHO). Signals attributed to the minor regioisomer **31a**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.22 (br d, J = 8.1 Hz, H-7). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 108.56 (C-4 or C-7), 108.61 (C-7 or C-4), 126.1 (2ArH), 126.9 (Ar), 127.4 (2ArH), 128.5 (Ar), 129.8 (2ArH), 131.5 (Ar), 132.1 (Ar), 133.5 (Ar), 134.0 (Ar), 190.94 (CHO). HRMS (EI) m/z [M^+] calcd for $C_{20}H_{13}ClN_2O_2$: 348.0666. Found: 348.0668.

*2-Oxo-1-phenyl-3-(p-tolyl)-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**30b**) and 2-Oxo-3-phenyl-1-(p-tolyl)-2,3-dihydro-1H-benzo[d]imidazole-5-carbaldehyde (**31b**).* Following Method A for the preparation of **23a**/**24a**, a mixture of **28b**/**29b** (52/48) (0.035 g, 0.11 mmol) and DDQ (0.059 g, 0.26 mmol) in CH_2Cl_2 (5 mL) provided a mixture of **30b**/**31b** (57/43) (0.032 g, 92%) as a brown solid. R_f 0.87 (hexane/EtOAc, 1/1); mp 124−128 °C. IR (film): ν_{max} 1725, 1686, 1595, 1519, 1111, 805 cm^{-1}. Signals attributed to the major regioisomer **30b**: ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.45 (s, 3H, ArCH_3), 7.18−7.27 (m, 1H, H-7), 7.34−7.42 (m, 2H, H-3″), 7.43−7.50 (m, 3H, H-4′, H-2″), 7.54−7.61 (m, 4H, H-2′, H-3′), 7.61−7.69 (m, 2H, H-4, H-6), 9.92 (s, 1H, CHO). ^{13}C NMR (101 MHz, $CDCl_3$): δ 21.23 (ArCH_3), 108.4 (C-4), 108.68 (C-7), 126.12 (C-2′), 126.13 (C-2″), 126.9 (C-6), 128.3 (C-4′), 129.7 (C-3′), 130.2 (C-1″), 130.36 (C-3″), 130.92 (C-3a), 131.25 (C-5), 133.73 (C-1′), 134.90 (C-7a), 138.6 (C-4″), 152.7 (C-2), 191.1 (CHO). Signals attributed to the minor regioisomer **31b**: ^{13}C NMR (101 MHz, $CDCl_3$): δ 21.22 (ArCH_3), 108.5 (C-4), 108.67 (C-7), 126.04 (C-2″), 126.2 (C-2′), 126.7 (C-6), 128.4 (C-4″), 129.5 (C-3″), 130.40 (C-3′), 130.94 (C-3a), 131.34 (C-5), 133.70 (C-1″), 134.6 (C-7a), 138.5 (C-4′), 150.0 (C-2). HRMS (EI) m/z [M^+] calcd for $C_{21}H_{16}N_2O_2$: 328.1212. Found: 328.1206.

*General Method for the Preparation of **32** and **33**. (5aR*,8aR*,8bR*)-1,3-Bis(4-methoxyphenyl)-8b-methyl-7-phenyl-1,3,5,5a,8a,8b-hexahydroimidazo[4,5-e]isoindole-2,6,8(7H)-trione (**32a**) and (5aS*,8aS*,8bR*)-1,3-Bis(4-methoxyphenyl)-8b-methyl-7-phenyl-1,3,5,5a,8a,8b-hexahydroimidazo[4,5-e]isoindole-2,6,8(7H)-trione (**33a**).* A mixture of **16a** (0.100 g, 0.31 mmol) and **6** (0.054 g, 0.31 mmol) in anhydrous CH_2Cl_2 (5 mL) was stirred at room temperature for 48 h. Then, the crude was concentrated under vacuum and purified by column chromatography over silica gel (10 g/g of crude, hexane/EtOAc, 1/1) to generate a mixture of **32a**/**33a** (99/1) (0.107 g, 70%) as a white solid. R_f 0.43 (hexane/EtOAc, 7/3); mp 130−132 °C. IR (film): ν_{max} 1711, 1675, 1510, 1030, 829 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.47 (s, 3H, CH_3-C8b), 2.70−2.80 (m, 2H, H-5), 3.22−3.27 (m, 1H, H-5a), 3.48 (d, J = 5.0 Hz, 1H, H-8a), 3.81 (s, 6H, $2CH_3O$), 4.74−4.78 (m, 1H, H-4), 6.90−6.97 (m, 4H, H-3′, H-3″), 7.18−7.24 (m, 4H, H-2′, H-2″), 7.37−7.41 (m, 1H, H-4‴), 7.43−7.47 (m, 2H, H-3‴), 7.55−7.59 (m, 2H, H-2‴). ^{13}C NMR (125 MHz, $CDCl_3$): δ 20.9 (CH_3−C8b), 24.5 (C-5), 38.2 (C-5a), 48.5 (C-8a), 55.4 (CH_3O), 55.5 (CH_3O), 61.2 (C-8b), 88.2 (C-4), 114.4 (C-3′ or C-3″), 114.6 (C-3″ or C-3′), 126.4 (C-2′ or C-2″), 127.6 (C-1″ or C-1′), 128.0 (C-2″ or C-2′), 128.4 (C-1′ or C-1″), 128.7 (C-4‴), 129.1 (C-3‴), 130.5 (C-2‴), 131.7 (C-1‴), 143.7 (C-3a), 155.7 (C-2), 158.7 (C-4′ or C-4″), 158.8 (C-4″ or C-4′), 173.7 (C-8), 178.1 (C-6). HRMS (EI): m/z [M^+] calcd for $C_{30}H_{27}N_3O_5$: 509.1951. Found: 509.1945.

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(5R,5aR*,8aR*,8bR*)-1,3-Bis(4-methoxyphenyl)-5,8b-dimethyl-7-phenyl-1,3,5,5a,8a,8b-hexahydroimidazo[4,5-e]isoindole-2,6,8(7H)-trione (**32b**) and (5R*,5aS*,8aS*,8bR*)-1,3-Bis(4-methoxyphenyl)-5,8b-dimethyl-7-phenyl-1,3,5,5a,8a,8b-hexahydroimidazo[4,5-e]isoindole-2,6,8(7H)-trione (**33b**).* Following the procedure for **32a**/**33a**, a mixture of **17** (0.100 g, 0.29 mmol) and **6** (0.05 g, 0.29 mmol) in anhydrous CH_2Cl_2 (5 mL) delivered a mixture of **32b**/**33b** (99/1) (0.099 g, 66%) as a white solid. R_f 0.48 (hexane/EtOAc, 8/2); mp 120−122 °C. IR (film): ν_{max} 1711, 1672, 1510, 1030, 832, 749 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.22 (d, J = 6.9 Hz, 3H, CH_3-C5), 1.48 (s, 3H, CH_3-C8b), 3.03−3.18 (m, 2H, H-5, H-5a), 3.48 (d, J = 7.2 Hz, 1H, H-8a), 3.79 (s, 1H, CH_3O), 3.80 (s, 1H, CH_3O), 4.46 (d, J = 2.7 Hz, 1H, H-4), 6.89−6.97 (m, 4H, H-3′, H-3″), 7.17−7.26 (m, 4H, H-2′, H-2″), 7.34−7.40 (m, 1H, H-4‴), 7.40−7.47 (m, 2H, H-3‴), 7.47−7.55 (m, 2H, H-2‴). ^{13}C NMR (75.4 MHz, $CDCl_3$): δ 18.9 (CH_3−C5), 20.2 (CH_3−C8b), 28.2 (C-5 or C-5a), 43.0 (C-5a or C-5), 49.4 (C-8a), 55.4 ($2CH_3O$), 61.0 (C-8b), 94.8 (C-4), 114.4 (C-3′ or C-3″), 114.6 (C-3″ or C-3′), 126.3 (C-2′ or C-2″), 127.5 (C-1′ or C-1″), 127.9 (C-1″ or C-1′), 128.1 (C-2″ or C-2′), 128.6 (C-4‴), 129.0 (C-3‴), 130.7 (C-2‴), 131.5 (C-1‴), 143.5 (C-3a), 155.7 (C-2), 158.6 (C-4′ or C-4″), 158.9 (C-4″ or C-4′), 173.6 (C-8), 174.7 (C-6). HRMS (EI): m/z [M^+] calcd for $C_{31}H_{29}N_3O_5$: 523.2107. Found: 523.2118.

Single-Crystal X-ray Crystallography. Diene **5a** was obtained as colorless crystals and crystallized on a mixture of hexane/EtOAc (9/1), which were mounted on glass fibers. Crystallographic measurements were performed by utilizing an area-detector with Mo Kα radiation (λ = 71073 Å; graphite monochromator) at room temperature. Unit cell parameters were obtained from a least-squares refinement. Intensities were corrected for Lorentz and polarization effects. No absorption correction was applied. Anisotropic temperature factors were introduced for all non-hydrogen atoms. Hydrogen atoms were placed in idealized positions, and their atomic coordinates refined employing unit weights. After being solved using SHELX-97,[39] the structure was visualized and plotted with the MERCURY program package.[40] Data from **5a**: (CCDC **1503136**) Formula: $C_{17}H_{14}N_2O$; molecular weight: 262.30; cryst. syst.: monoclinic; space group: P1 21/n 1; unit cell parameters: a, 7.4517(3), b, 7.8084(4), c, 23.7466(13) (Å); α, 90°, β, 89.969(4)°, γ, 90°; temp. (K): 292(2); Z: 4; no. of reflections collected: 7475; no. of independent reflections: 4180; no. of reflections observed: 2715; data collection range: 2.75 < 2θ < 32.57°; R: 0.0615; GOF: 1.081.

Theoretical Calculations. All ab initio and DFT calculations were carried out using the Gaussian 09 program package.[27] Optimizations of the stationary points were initially made at the HF/6-31G(d,p) level of theory. The optimized geometries were used as starting points for further optimizations at the M06-2X/6-31+G(d,p) level of theory. For all optimizations, the OPT = TIGHT optimization option was employed. For all DFT calculations, the INT(GRID = ULTRAFINE) option was used. The TSs were located using the QST2, QST3 or TS optimization options. Additional confirmation of the nature of the TSs was obtained by IRC analyses for all the reaction coordinates under study, except for the cycloadditions with dienes **16a** and **17**. All stationary points were characterized by frequency calculations. All minima (starting materials, zwitterionic intermediates and adducts) showed only real vibrational frequencies, while the TSs each displayed a single negative eigenvalue of the Hessian matrix. Through visual inspection of the normal mode associated with the imaginary vibrational frequency, it was confirmed that the TSs corresponded to motion along the reaction coordinate. The synchronicities were obtained by taking the DFT geometries and wave functions of supramolecular complexes, transition states, and products along each of the reaction coordinates under study, and using each as input for the NBO 5.0 program[34] after conversion to the appropriate format. The Wiberg bond indexes[33] for the bonds of interest for each stationary point were taken from the output and used to calculate the synchronicities as described elsewhere[32] and in the Supporting Information.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.7b02344.

Appendix 1: frontier molecular orbitals [HF/6-31G-(d,p)] of the optimized geometries of dienes **5c**, **12a**, and **14** and dienophiles **18a**, **18a**-$ZnCl_2$, and **18a**-BF_3; Appendix 2: relative zero point-corrected energies of the supramolecular complexes, TSs (TS1 and TS2), zwitterionic intermediates, and adducts located in the potential surfaces of the Diels−Alder reactions of diene **12a** and dienophiles **18a**, **18a**-$ZnCl_2$, and **18a**-BF_3; Appendix 3: Calculation (NBO) of synchronicities of the Diels−Alder cycloadditions of diene **16a** and maleimide (**6**); Appendix 4: Copies of the ^1H NMR and ^{13}C NMR spectra of all new compounds; Appendix 5: X-ray crystallographic structure of **5a**; Appendix 6: M06-2X/6-31+G(d,p) relative ZPE-corrected energies (kcal/mol) of the stationary points of the nonassisted Diels−Alder cycloadditions of **12a**/**18a**; Appendix 7: calculation [M06-2X/6-31+G(d,p)] of Z-matrices of the optimized geometries of supramolecular complexes, transition states, and adducts; Appendix 8: geometrical parameters, bond distances (Å) of the transition states (TS1 and TS2) and zwitterionic intermediates, located at the potential surfaces of the Diels−Alder reactions of diene **12a** and dienophiles **18a**, **18a**-$ZnCl_2$, and **18a**-BF_3 (PDF)

Crystallographic information for **5a** (CIF)

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Notes

The authors declare no competing financial interest.

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