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SYNTHESIS OF 2-ARYLBENZOTHIAZOLES AND IMIDAZOLES USING SCANDIUM TRIFLATE AS A CATALYST FOR BOTH A RING CLOSING AND AN OXIDATION STEPS

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Abstract – 2-Aminobenzenethiol and an aryl aldehyde were allowed to react to give a 2-arylbenzothiazole in good yield in the presence of a catalytic amount of scandium triflate $Sc(OTf)_3$. The detailed study showed that $Sc(OTf)_3$ catalyzed two steps, that is, the formation of a thiazoline ring and the oxidation of the thiazoline to a thiazole ring. This is the first example that scandium(III) ion catalyzed oxidation of an organic compound using molecular oxygen as an oxidant. The reaction was applied to *o*-phenylenediamine and an aryl aldehyde to give corresponding 2-arylbenzimidazole in moderate to good yields depending upon the structure of aldehyde.

INTRODUCTION

2-Substituted benzothiazole[1] and benzimidazole[2] derivatives are of industrial, biological, and medicinal interest, thus the methods for preparing these compounds have been extensively studied.[3] Although condensation of 2-aminobenzenethiol or *o*-phenylenediamine with an appropriate carboxylic acid provides the most direct synthetic route to the 2-substituted benzothiazoles or imidazoles, respectively, these processes usually require vigorous reaction conditions.[4] Thus, there have been several papers which report alternative methods. In the cases of benzothiazoles, there is an only study that adopted 2-aminobenzenethiol and an aldehyde as starting material for 2-substituted benzothiazole in DMSO solvent.[5] Although DMSO was supposed to act as an oxidant in the reaction, the scope and the

mechanism remain unclear. On the other hand, several methods for the synthesis of benzimidazoles have been recently reported which involve palladium-catalyzed carbonylation reaction of an *o*-phenylenediamine followed by cyclodehydration,[6] palladium-catalyzed intramolecular *N*-arylation reaction of (*o*-bromophenyl)amidines,[7] and rhodium-catalyzed hydroformylation of *N*-alkenyl-phenylenediamines.[8] However, there are seldom studies in which the syntheses of both heterocycles are carried out in the same reaction system.

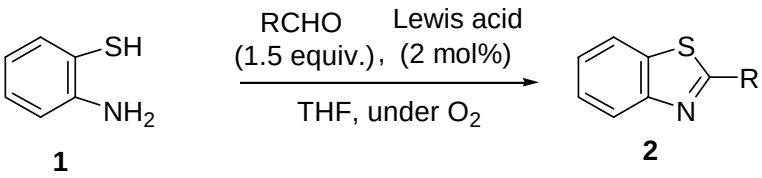
In the course of our study for the application of lanthanide and related rare earth metal triflates as a catalyst of the synthesis of azaaromatic compounds, 2-aminobenzenethiol and an aryl aldehyde were found to react to give a 2-arylbenzothiazole in good yield in the presence of a catalytic amount of scandium triflate $Sc(OTf)_3$. In addition, the same reaction procedure was applied to *o*-phenylenediamine to give benzimidazole derivatives. The reaction was found to proceed *via* scandium (III) catalyzed oxidation step. This paper describes these results in detail.[9]

RESULTS AND DISCUSSION

It is well known that lanthanide and related rare earth metal triflates function as Lewis acid catalysts even in the presence of water,[10] and there are several works which applied these acids to the synthesis of aza compounds.[11] We supposed that the property of these Lewis acids was suitable for the construction of azaaromatics whose syntheses involve an initial formation of an imine from carbonyl and amino groups, since the process was inevitably accompanied by generation of an equimolar amount of water.

As the first attempt, 2-aminobenzenethiol (**1**) and an aldehyde were allowed to react at room temperature in the presence of a catalytic amount of $Sc(OTf)_3$ under O_2 to give corresponding benzothiazole (**2)** in excellent yield (Scheme 1 and Table 1, entry 1).

Although the corresponding imine was formed even in the absence of the Lewis acid, the reaction did not proceed to the next step. That is, by the ^{1}H-NMR spectrum, formation of the corresponding imine was observed (y. 75%) accompanied by a small amount of **2**, and 2-arylbenzothiazoline was not identified in this reaction. (Table 1, entry 2). Thus, it was suggested that $Sc(OTf)_3$ was a catalyst for



1 **2** **Scheme 1**

Table 1 The Reaction of 2-Aminobenzenethiol with Aryl Aldehyde in the Presence of Lewis Acid

entry	R	product	Lewis acid (2.0 mol%)	time (h)	yield of **2** (%)
1	Ph	**2a**	$Sc(OTf)_3$	2	98
2	Ph	**2a**	-	2	9
3	Ph	**2a**	$Yb(OTf)_3$	2	89
4	Ph	**2a**	$Sn(OTf)_2$	2	84
5	Ph	**2a**	$Cu(OTf)_2$	2	13
6	*p*-Me-C_6H_4	**2b**	$Sc(OTf)_3$	2	99
7	*p*-Cl-C_6H_4	**2c**	$Sc(OTf)_3$	2	99
8	2-naphthyl	**2d**	$Sc(OTf)_3$	3	97
9	*p*-MeO-C_6H_4	**2e**	$Sc(OTf)_3$	2	97

the cyclization process which afforded 2-arylbenzothiazoline. Although other Lewis acids than $Sc(OTf)_3$ were used as catalysts, it was shown that $Sc(OTf)_3$ was superior to the other metal triflate (Table 1, entries 3-5). The reaction system was applied to other aldehydes, and it was shown that various aryl aldehydes afforded good yields of 2-arylbenzothiazoles (entries 6-9). In addition, the reaction was found to hardly proceed under Ar, thus molecular oxygen was suggested to react as an oxidant which transformed the benzothiazoline formed *in situ* to the product.

In the present reaction, 2-arylbenzothiazoline was supposed to be an intermediate because the signals of it were observed in the ^{1}H-NMR spectrum of the reaction mixture when the reaction time was shortened. In order to investigate the oxidation step of 2-arylbenzothiazoline to 2-arylbenzothiazole, 2-phenylbenzothiazoline (**3**) was synthesized according to the reported method.[12] The isolated compound **(3)** was allowed to react with O_2 in the presence or absence of $Sc(OTf)_3$, and the results are shown in Table 2.

The data shown in Table 2 suggested that a catalytic amount of $Sc(OTf)_3$ was necessary for the oxidation of **3** to **2a**. In the absence of $Sc(OTf)_3$ or oxygen, the reaction seldom proceeded (Table 2, entries 1 and

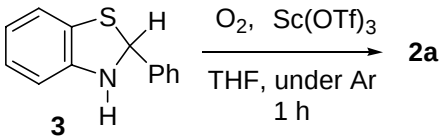


Table 2 Oxidation of 2-Phenylbenzothiazoline (**3**) with O_2 in the Presence of Scandium Triflate

entry	$Sc(OTf)_3$ (mol %)	O_2 (equiv)	yield of **2a** (%)
1	0	excess	9
2	1	excess	48
3	2	excess	95
4	2	0	6
5	2	0.1	14

4). In addition, the limited amount of oxygen afforded only corresponding amount of **2a** (entry 5). These results shown in Table 1 and Table 2 revealed that $Sc(OTf)_3$ catalyzed both the cyclization step and the oxidation step which employed molecular oxygen as an oxidant.

In order to confirm the above assumption, the effects of $Sc(OTf)_3$ and O_2 on the progress of the reaction were investigated, and the results are summarized in Table 3. In the absence of $Sc(OTf)_3$, the reaction

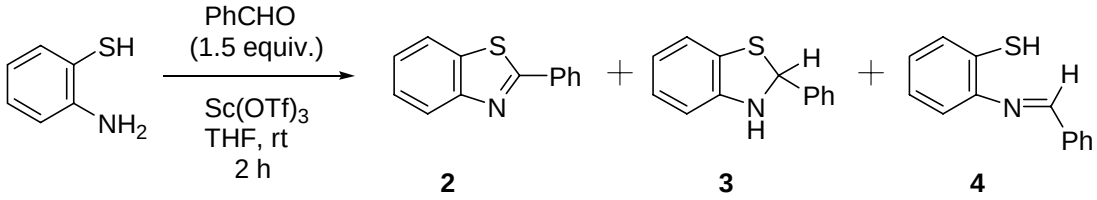
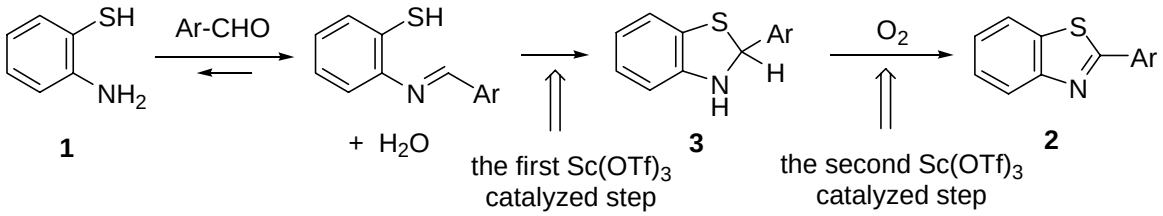


Table 3 The Yields of Various Products in the Presence and Absence of the Catalyst or O_2

entry	O_2	amount of $Sc(OTf)_3$ (mol%)	yield of **2** (%)	yield of **3** (%)	yield of **4** (%)
1	(+)	0	9	0	75
2	(-)	2	21	76	0
3	(+)	2	98	0	0

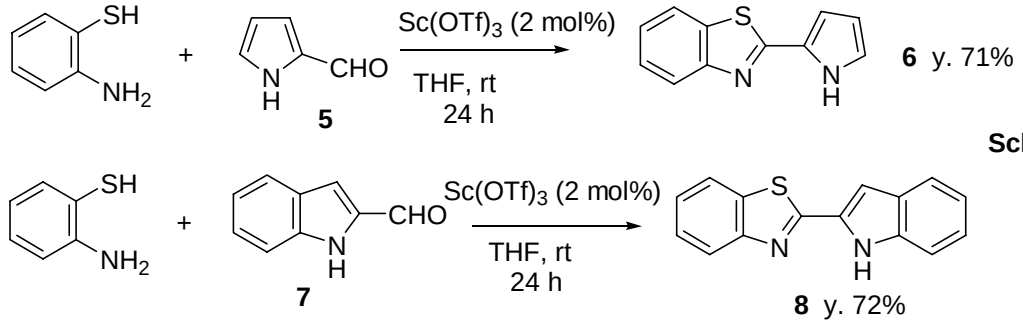
ceased to proceed at the formation of the corresponding imine (**4)**, therefore the further reaction was shown to be catalyzed by the Lewis acid (entry 1). Without O_2 in the presence of $Sc(OTf)_3$, the reaction proceeded to the formation of benzothiazoline (**3)**, thus the cyclization step was catalyzed by $Sc(OTf)_3$ (entry 2). Accordingly, the present reaction is the first example in which $Sc(OTf)_3$ catalyzes

two consecutive steps. In particular, the second step is the first example where the Lewis acid catalyzes the oxidation using molecular oxygen (Scheme 2).



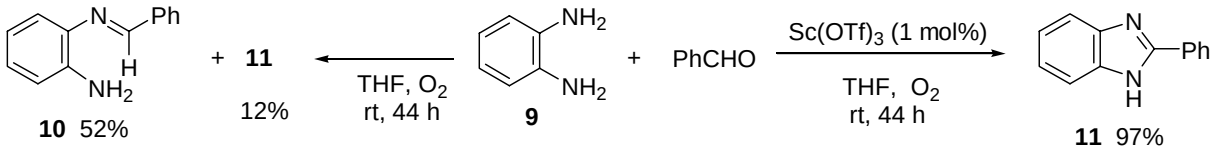
Scheme 2

In addition to the mechanistic interest, the reaction seems to be of use because the oxidation step adopts quite mild conditions. Thus, the reaction was applied to the aldehydes which are sensitive toward the oxidative reagents, and the reaction proceeded smoothly to give the corresponding thiazole derivatives in good yields (Scheme 3).



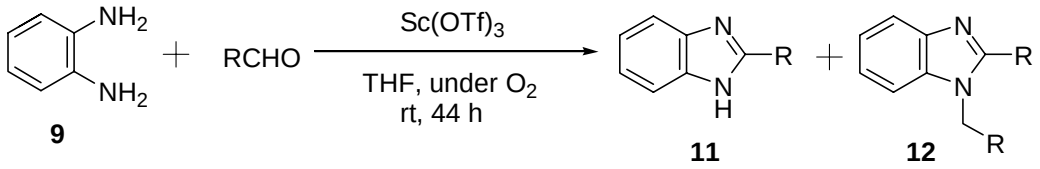
Scheme 3

The above results prompted us to investigate the application of the present reaction toward the other heterocycles, and it was found that benzimidazoles were synthesized by the method. When *o*-phenylenediamine (**9**) was allowed to react with benzaldehyde in THF in air, the corresponding imine (**10)** was obtained in 52% accompanied by 12% of 2-phenylbenzimidazole (**11)** (Scheme 4). The addition of $Sc(OTf)_3$ in the system resulted in quantitative formation of **11**.



Scheme 4

The results indicated that the reaction system found for benzothiazoles was also applicable to a construction of benzimidazole ring. Thus, we investigated the reaction of *o*-phenylenediamine and various aldehydes in the presence of the Lewis acid, and the data are summarized in Table 4 (Scheme 5).



Scheme 5

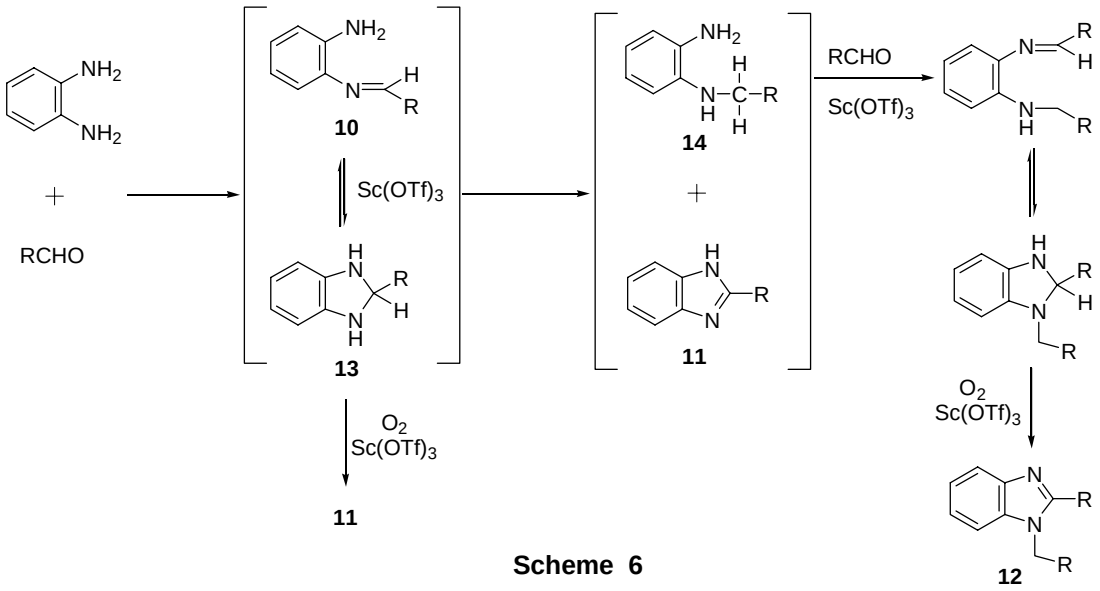
Table 4 Reaction of *o*-Phenylenediamine with an Aldehyde in the Presence of $Sc(OTf)_3$ under O_2

entry	R	conc. of the substrate(M)	$Sc(OTf)_3$ (mol%)	aldehyde (equiv.)	yield of **11** (%)	yield of **12** (%)
1	Ph	0.35	1.0	1.0	97 (**11a**)	1 (**12a**)
2	*p*-Cl-C_6H_4	0.35	1.0	1.0	37 (**11b**)	6 (**12b**)
3	*p*-Cl-C_6H_4	0.35	10	1.5	63 (**11b**)	35 (**12b**)
4	*p*-Cl-C_6H_4	0.002	10	1.5	95 (**11b**)	3 (**12b**)
5	1-naphthyl	0.35	1.0	1.0	43 (**11c**)	9 (**12c**)
6	1-naphthyl	0.01	10	1.5	53 (**11c**)	31 (**12c**)
7	1-naphthyl	0.002	10	1.5	82 (**11c**)	12 (**12c**)
8	*p*-Me-C_6H_4	0.35	1.0	1.0	37 (**11d**)	19 (**12d**)
9	*p*-Me-C_6H_4	0.01	10	1.5	55 (**11d**)	35 (**12d**)
10	*p*-Me-C_6H_4	0.002	10	1.5	72 (**11d**)	23 (**12d**)
11	*p*-Br-C_6H_4	0.002	10	1.5	95 (**11e**)	-
12*	H	0.002	10	1.5	57 (**11f**)	41 (**12f**)
13**	CH_3	0.002	10	1.5	52 (**11g**)	42 (**12g**)
14	$(CH_3)_3C$	0.002	10	1.5	98 (**11h**)	0

* 37% aq. HCHO was used. ** 90% CH_3CHO was used.

To our disappointment, however, the yields of **11** were moderate to low (entries 2, 5, and 8) under the standard conditions used for entry 1, and the side products (**12)** derived through the reaction of **9** with two equivalents of the aldehyde were obtained in every case. In order to improve the reaction yields, we scrutinized the reaction conditions, and found that dilution of the reaction medium improved the reaction yields considerably (entries 2-4, 5-7, and 8-10). In the cases of aliphatic aldehydes, bulkiness affected the reaction yields as shown in entries 12 to 14. That is, by using formaldehyde and acetaldehyde, formation of **12** was inevitable even under the high dilution conditions (entries 12 and 13). By using 2,2-dimethylpropanal, however, the desired product (**11)** was obtained in a high yield (entry 14).

Although conclusive experimental supports for the reaction mechanism have not been obtained yet, the plausible one is as follows. The reaction of *o*-phenylenediamine with an aldehyde is supposed to give an imine (**10)**. The imine is cyclized to corresponding benzimidazoline (**13)** under the influence of $Sc(OTf)_3$, and a subsequent oxidation of **13** catalyzed by the same Lewis acid affords the benzimidazole (**11)**. Different from the reaction of aminobenzenethiol, however, a side product *N*-alkyl-*o*-phenylenediamine (**14)** was formed in a considerable yield especially when the reaction rate was slow.[13] We speculated that the compound (**14)** was obtained from the redox reaction between the imine (**10)** and benzimidazoline (**13)** catalyzed by $Sc(OTf)_3$ to afford **14** and **11**.[14] The reaction of **14** and aldehyde, and succeeding ring closure and oxidation give **12**. When the redox reaction of **10** and **13** resulted in the formation of the side product(s), dilution might be effective for preventing this side reaction to form **11**. Thus, the results shown in Table 4 (entries 2-4, 5-7, and 8-10) support the present mechanism.



Scheme 6

In this paper, we described that the reaction of 2-aminobenzenethiol with an aryl aldehyde was accelerated by $Sc(OTf)_3$ to give a ring closing product, and succeeding aromatization was also carried out by participation of $Sc(OTf)_3$ as a catalyst to give 2-arylbenzothiazole in a good yield. In addition, the reaction was applied to *o*-phenylenediamine and aldehyde to give corresponding 2-substituted

benzimidazoles when the concentration of the substrate was sufficiently low. This type of ring closing-oxidation reaction is a ubiquitous process for the synthesis of heterocycles, thus the present reaction system is thought to be a new, general synthetic method for various heteroaromatics. Moreover, the reaction is the first example that $Sc(OTf)_3$ plays a catalytic role on the oxidation reaction by molecular oxygen. The application to synthesis of other heterocycles is now under investigation.

EXPERIMENTAL

Unless otherwise specified, materials were purchased from commercial suppliers and used without further purification. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ at 500 and 125 MHz, respectively, using tetramethylsilane as a standard. All melting points are uncorrected.

Reaction of 2-aminobenzenethiol with an aldehyde in the presence of scandium triflate (Table 1): the typical procedure; 2-Aminobenzenethiol (25 mg, 0.2 mmol) was dissolved in THF (2 mL), and O_2 was introduced to the reaction vessel. Then benzaldehyde (30μL, 0.3 mmol) and $Sc(OTf)_3$ (2 mg, 0.004 mmol) were added, and the mixture was allowed to react at rt for 2 h. Thereafter, ethyl acetate (12 mL) was added, and the organic layer was washed with 5% aq. Na_2CO_3 (2 mL) and brine (2 mL), dried over $MgSO_4$, and evaporated off. The residue was chromatographed on silica gel (CH_2Cl_2) to give 2-phenylbenzothiazole (41 mg, 0.19 mmol).

2-Phenylbenzothiazole (2a). oil; ^1H NMR ($CDCl_3$) δ: 7.39 (1H, td, *J*=7.2, 1.2 Hz), 7.48-7.52 (4H, m), 7.91 (1H, ddd, *J*= 8.0, 1.6, 0.8 Hz), 8.10-8.12 (3H, m). The ^1H NMR spectrum of this compound was identical with that of the commercial compound.

2-(4-Methylphenyl)benzothiazole (2b). mp 81-82°C (lit.,[15] 83-85°C). ^1H NMR ($CDCl_3$) δ: 2.40 (3H, s), 7.28 (2H, d, *J*=7.9 Hz), 7.35 (1H, t, *J*=7.5 Hz), 7.47 (1H, t, *J*=7.6 Hz), 7.87 (1H, d, *J*=7.9 Hz), 7.97 (2H, d, *J*=8.1 Hz), 8.05 (1H, d, *J*=8.2 Hz). ^{13}C NMR ($CDCl_3$) δ: 21.5, 121.6, 123.0, 125.1, 126.3, 127.5, 129.7, 130.8, 134.9, 141.5, 154.0, 168.3.

2-(4-Chlorophenyl)benzothiazole (2c). mp 114-116°C (lit.,[16] 116°C). ^1H NMR ($CDCl_3$) δ: 7.40 (1H, t, *J*=7.6 Hz), 7.47 (2H, d, *J*=8.4 Hz), 7.50 (1H, t, *J*=7.7 Hz), 7.90 (1H, d, *J*=8.1 Hz), 8.03 (2H, d, *J*=8.4 Hz),

8.07 (1H, d, *J*=8.2 Hz). ^{13}C NMR ($CDCl_3$) δ: 121.5, 123.1, 125.3, 126.3, 128.6, 129.1, 132.0, 134.9, 136.9, 153.9, 166.4. FAB-MS: 246 $(M+H)^+$.

2-(2-Naphthyl)benzothiazole (2d). mp 140.5-141.5°C (EtOH/H_2O). ^{1}H NMR ($CDCl_3$) δ: 7.41 (1H, t, *J*=7.6 Hz), 7.51-7.59 (3H, m), 7.88-7.91 (1H, m), 7.93-7.99 (3H, m), 8.12 (1H, d, *J*=8.2 Hz), 8.22 (1H, d, *J*=8.5 Hz), 8.58 (1H, s). ^{13}C NMR ($CDCl_3$) δ: 121.7, 123.2, 124.4, 125.3, 126.5, 126.9, 127.5, 127.7, 127.9, 128.9, 130.9, 133.2, 134.6, 135.0, 154.0, 168.2. FAB-MS: 262 $(M+H)^+$. Anal. Calcd for $C_{17}H_{11}NS$: C, 78.13; H, 4.24; N, 5.36. Found: C, 77.97; H, 4.11; N, 5.31.

2-(4-Methoxyphenyl)benzothiazole (2e). mp 121.5-122.0°C (EtOH/H_2O). ^{1}H NMR ($CDCl_3$) δ: 3.88 (3H, s), 7.00 (2H, d, *J*=8.8 Hz), 7.35 (1H, t, *J*=7.6 Hz), 7.47 (1H, t, *J*=7.7 Hz), 7.87 (1H, d, *J*=7.7 Hz), 8.02-8.05 (3H, m). ^{13}C NMR ($CDCl_3$) δ: 55.4, 114.2, 121.3, 122.7, 124.6, 126.0, 126.3, 128.9, 134.7, 154.0, 161.7, 167.6. FAB-MS: 242 $(M+H)^+$. Anal. Calcd for $C_{14}H_{11}NOS$: C, 69.68; H, 4.59; N, 5.80. Found: C, 69.50; H, 4.44; N, 5.69.

Oxidation of 2-phenylbenzothiazoline (3) with O_2 in the presence of $Sc(OTf)_3$.

a) In the case of the reaction using an excess amount of O_2.

2-Phenylbenzothiazoline (43 mg, 0.2 mmol) was dissolved in THF (2 mL), and O_2 was introduced to the reaction vessel. Then $Sc(OTf)_3$ (2 mg, 0.004 mmol) was added, and the mixture was allowed to react at rt for 1 h under O_2. Thereafter, ethyl acetate (12 mL) was added, and the organic layer was washed with 5% aq. Na_2CO_3 (2 mL) and brine (2 mL), and dried over $MgSO_4$. Then the solvent was evaporated off, and the product was analyzed by ^{1}H NMR spectrum using mesitylene as an internal standard.

b) In the case of reaction using a limited amount of O_2.

2-Phenylbenzothiazoline (43 mg, 0.2 mmol) was placed in a two-necked flask (vol. *ca*. 42 mL) and THF (2 mL) was added. After the solution was bubbled with Ar gas for 20 min, $Sc(OTf)_3$ (2 mg, 0.004 mmol) was added under Ar atmosphere, and the flask was sealed with a septum rubber and a stopcock. Then, 8 mL of Ar was added through the septum rubber to raise an inner pressure to *ca*.1.2 atm. Into the flask was added 450μL of O_2 (0.1 equiv), and the reaction mixture was allowed to react for 1 h.

After the addition of ethyl acetate (12 mL), the organic layer was washed with 5% aq. Na_2CO_3 (2 mL) and brine (2 mL), and dried over $MgSO_4$. After the solvent was evaporated off, the product was analyzed by ^1H NMR spectrum using mesitylene as an internal standard.

2-(1*H*-Pyrrol-2-yl)benzothiazole (6). To a THF (5 mL) solution of pyrrole-2-carboxaldehyde (95 mg, 1.0 mmol) were added 2-aminobenzenethiole (53μL, 0.5 mmol) and $Sc(OTf)_3$ (5 mg, 0.01 mmol), and the mixture was allowed to react for 24 h at rt under O_2. Then ethyl acetate (20 mL) was added, and the organic layer was washed with 5% aq. Na_2CO_3 (4 mL) and brine (2 mL), dried over $MgSO_4$, and evaporated off. The residue was chromatographed on silica gel (hexane:AcOEt=2:1) to give **6** (71 mg, 71%). mp 167-168 °C (AcOEt/hexane). ^1H NMR ($CDCl_3$) δ: 6.32 (1H, m), 6.87 (1H, m), 6.95 (1H, m), 7.23 (1H, t, *J*=7.6 Hz), 7.43 (1H, t, *J*=7.6 Hz), 7.83 (1H, d, *J*=7.4 Hz), 7.89(1H, d, *J*=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 110.7, 112.6, 121.5, 121.8, 122.2, 124.5, 126.3, 133.8, 153.3, 160.4. Anal. Calcd for $C_{11}H_8N_2S$: C, 65.97; H, 4.03; N, 13.99. Found: C, 65.86; H, 3.80; N, 13.89.

2-(1*H*-Indol-3-yl)benzothiazole (8). To a THF (5 mL) solution of indole-3-carboxaldehyde (43 mg, 0.3 mmol) was added 2-aminobenzenethiol (21μL, 0.2 mmol) and $Sc(OTf)_3$ (2 mg, 0.004 mmol), and the mixture were allowed to react for 24 h at rt under O_2. Then ethyl acetate (12 mL) was added, and the organic layer was washed with 5% aq. Na_2CO_3 (2 mL) and brine (2 mL), dried over $MgSO_4$, and evaporated off. The residue was chromatographed on silica gel (hexane:AcOEt=2:1) to give **8** (36 mg, 72%). mp 168-169 °C (AcOEt/hexane). ^1H NMR ($CDCl_3$) δ: 7.26-7.36 (3H, m), 7.42 (1H, d, *J*=8.0 Hz), 7.45 (1H, t, *J*=8.3 Hz), 7.88 (1H, d, *J*=8.0 Hz), 7.99 (1H, d, *J*=2.9 Hz), 8.04 (1H, d, *J*=8.6 Hz), 8.42 (1H, d, *J*=7.5 Hz), 9.06 (1H, br s). ^{13}C NMR ($CDCl_3$) δ: 111.8, 112.2, 121.0, 121.3, 121.9, 122.0, 123.5, 124.4, 124.9, 126.2, 126.8, 133.5, 136.5, 153.1, 163.1. Anal. Calcd for $C_{15}H_{10}N_2S$: C, 71.97; H, 4.03; N, 11.19. Found: C, 71.83; H, 3.77; N, 11.14.

Reaction of *o*-phenylenediamine with an aldehyde in the presence of scandium triflate under O_2 (Table 4): the typical procedure; a) In the case of the reaction in 0.35 M solution; to a THF (1.5 mL)

solution of *o*-phenylenediamine **(**56 mg, 0.52 mmol) were added $Sc(OTf)_3$ (3 mg, 0.006 mmol) and benzaldehyde (55μL, 0.54 mmol), and the mixture was allowed to react for 44 h at rt under O_2. Then ethyl acetate (15 mL) was added, and the organic layer was washed with 5% aq. Na_2CO_3 (2 mL) and brine (2 mL), dried over $MgSO_4$, and evaporated off. The residue was chromatographed on silica gel (CH_2Cl_2:ether=4:1) to give **11a** (98 mg, 97%). b) In the case of the reaction in 0.002 M solution; to a THF (100 mL) solution of *o*-phenylenediamine (22 mg, 0.2 mmol) were added $Sc(OTf)_3$ (10 mg, 0.02 mmol) and *p*-chlorobenzaldehyde (42 mg, 0.3 mmol), and the mixture was allowed to react for 44 h at rt under O_2. Then the solvent was evaporated off, and ethyl acetate (30 mL) was added. The organic layer was washed with 5% aq. Na_2CO_3 (6 mL) and brine (2 mL), dried over $MgSO_4$, and evaporated off. The residue was chromatographed on silica gel (AcOEt:hexane=1:1) to give **11b** (43 mg, 95%).

2-Phenylbenzimidazole (11a). oil; ^{1}H NMR ($CDCl_3$) δ: 7.28 (2H, dd, *J*=6.0, 3.2 Hz), 7.46-7.51 (3H, m), 7.65 (2H, dd, *J*=6.0, 3.2 Hz), 8.05-8.08 (2H, m). The ^{1}H NMR spectrum of this compound was identical with that of the commercial compound.

2-(4-Chlorophenyl)benzimidazole (11b). ^{1}H NMR (DMSO-d_6) δ: 7.21-7.23 (2H, m), 7.59-7.65 (2H, m), 7.63 (2H, d, *J*= 8.6 Hz), 8.19 (2H, d, *J*=8.4 Hz). The ^{1}H NMR spectrum of this compound was identical with the reported one.[17]

2-(1-Naphthyl)benzimidazole (11c). mp 272-274°C (lit.,[18] 284°C). ^{1}H NMR (DMSO- d_6) δ: 7.23-7.28 (2H, m), 7.59-7.70 (5H, m), 8.00-8.05 (2H, m), 8.09 (1H, d, *J*=8.2 Hz), 9.10 (1H, d, *J*=8.2 Hz).

2-(4-Methylphenyl)benzimidazole (11d). mp 277-279°C (lit.,[19] 275-276°C). ^{1}H NMR (DMSO- d_6) δ: 2.37 (3H, s), 7.15-7.24 (2H, m), 7.35 (2H, d, *J*=8.2 Hz), 7.56 (2H, brs), 8.05 (2H, d, *J*=8.1 Hz).

2-(4-Bromophenyl)benzimidazole (11e). mp 291-294°C (lit.,[20] 296-298°C). ^{1}H NMR (DMSO-d_6) δ: 7.25-7.29 (2H, m), 7.60-7.62 (2H, m), 7.71 (2H, d, *J*=8.8 Hz), 7.99 (2H, d, *J*=8.8 Hz).

Benzimidazole (11f). oil; ^{1}H NMR (MeOH-d_4) δ: 7.25 (2H, dd, *J*=6.0, 2.8 Hz), 7.63 (2H, dd, *J*=6.0, 3.2 Hz), 8.02 (1H, s). The ^{1}H NMR spectrum of this compound was identical with that of commercial compound.

2-Methylbenzimidazole (11g). oil; ^{1}H NMR ($CDCl_3$) δ: 2.63 (3H, s), 6.80 (1H, br s), 7.20 (2H, dd,

J=6.1, 3.1 Hz), 7.54 (2H, dd, *J*=6.1, 3.1 Hz). The ^{1}H NMR spectrum of this compound was identical with that of commercial compound.

2-(1,1-Dimethylethyl)benzimidazole (11h). mp > 300°C (EtOH) (lit.,[21] 331-333°C). ^{1}H NMR (MeOH-d_4) δ: 1.47 (9H, s), 7.17 (2H, dd, *J*=5.8, 3.2 Hz), 7.50 (2H, br s). ^{13}C-NMR (MeOH- d_4) δ: 29.7, 34.4, 123.0, 164.0. Anal. Calcd for $C_{11}H_{14}N_2$: C, 75.82; H, 8.10; N, 16.08. Found: C, 75.77; H, 8.26; N, 16.04.

1-Benzyl-2-phenylbenzimidazole (12a). oil; ^{1}H NMR($CDCl_3$) δ: 5.46 (2H, s), 7.11 (2H, d, *J*=7.6 Hz), 7.19-7.37 (6H, m), 7.43-7.50 (3H, m), 7.69 (2H, d, *J*=7.6 Hz), 7.87 (1H, d, *J*=8.0 Hz). ^{13}C-NMR($CDCl_3$) δ: 48.40, 110.53, 119.97, 122.70, 123.06, 125.98, 127.78, 128.75, 129.06, 129.27, 129.93, 130.04, 136.04, 136.38, 143.13, 154.17. HRMS (FAB): Calcd for $C_{20}H_{17}N_2$ $(M+H)^+$: 285.1392. Found 285.1380.

1-(4-Chlorophenyl)methyl-2-(4-chlorophenyl)benzimidazole (12b). mp 139.7-140.1°C (hexane). ^{1}H NMR ($CDCl_3$) δ: 5.40 (2H, s), 7.02 (2H, d, *J*=8.6 Hz), 7.20 (1H, d, *J*=7.7 Hz), 7.25-7.34 (4H, m), 7.44 (2H, d, *J*=8.8 Hz), 7.59 (2H, d, *J*=8.6 Hz), 7.87 (1H, d, *J*=7.7 Hz). ^{13}C NMR ($CDCl_3$) δ: 47.7, 110.1, 120.1, 122.9, 123.3, 127.1, 128.3, 129.0, 129.2, 130.3, 133.7, 134.5, 135.8, 136.2, 143.0, 152.7. FAB-MS: 353 $(M+H)^+$. Anal. Calcd for $C_{20}H_{14}N_2Cl_2$: C, 68.00; H, 3.99; N, 7.93. Found: C, 67.86; H, 3.76; N, 7.83.

1-(1-Naphthylmethyl)-2-(1-naphthyl)benzimidazole (12c). oil; ^{1}H NMR ($CDCl_3$) δ: 5.72 (2H, s), 6.83 (1H, dd, *J*=7.1, 0.9 Hz), 7.20-7.29 (3H, m), 7.35-7.57 (7H, m), 7.73 (2H, d, *J*=8.2 Hz), 7.84-7.92 (3H, m), 7.99 (2H, d, *J*=7.7 Hz). ^{13}C NMR ($CDCl_3$) δ: 46.1, 110.8, 120.3, 122.1, 122.7, 123.1, 123.6, 124.8, 125.4, 125.6, 126.0, 126.4, 126.5, 127.2, 127.4, 128.17, 128.21, 128.3, 129.0, 130.2, 130.4, 131.2, 132.3, 133.6, 133.7, 135.4, 143.4, 153.1. HRMS (FAB): Calcd for $C_{28}H_{21}N_2$ $(M+H)^+$: 385.1705. Found 385.1702.

1-(4-Methylphenyl)methyl-2-(4-methylphenyl)benzimidazole (12d). mp 128-129°C (AcOEt/hexane). ^{1}H NMR ($CDCl_3$) δ: 2.31 (3H, s), 2.38 (3H, s), 5.38 (2H, s), 6.98 (2H, d, *J*=7.9 Hz), 7.11 (2H, d, *J*=7.9 Hz), 7.16-7.30 (5H, m), 7.58 (2H, d, *J*=8.1 Hz), 7.85 (1H, d, *J*=7.9 Hz). ^{13}C-NMR ($CDCl_3$) δ: 21.05, 21.40, 48.21, 110.52, 119.69, 122.66, 122.92, 125.87, 126.90, 129.17, 129.45, 129.69, 133.34, 135.96, 137.47, 140.15, 142.75, 154.17. Anal. Calcd for $C_{22}H_{20}N_2$: C, 84.58; H, 6.45; N, 8.97. Found: C, 84.69; H, 6.48; N, 8.97.

1-Methylbenzimidazole (12f). oil; ^{1}H NMR ($CDCl_3$) δ: 3.79 (3H, s), 7.25-7.40 (3H, m), 7.78 (1H, dd, *J*=8.4, 1.2 Hz), 7.85 (1H, s). The ^{1}H NMR spectrum of this compound was identical with that of the commercial compound.

1-Ethyl-2-methylbenzimidazole (12g). oil; ^{1}H NMR ($CDCl_3$) δ: 1.41 (3H, t, *J*=7.4 Hz), 2.61 (3H, s), 4.16 (2H, q, *J*=7.4 Hz), 7.22-7.26 (2H, m), 7.32 (1H, dd, *J*=6.1, 1.5 Hz), 7.68 (1H, dd, *J*=6.8, 2.2 Hz). ^{13}C NMR ($CDCl_3$) δ: 13.57, 14.79, 38.36, 108.85, 118.88, 121.65, 121.84, 134.55, 142.49, 150.97. HRMS (FAB): Calcd for $C_{10}H_{13}N_2$ $(M+H)^+$: 161.1079. Found 161.1069.

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