The efficient *o*-benzenedisulfonimide catalysed synthesis of benzothiazoles, benzoxazoles and benzimidazoles

Margherita Barbero, Silvano Cadamuro, and Stefano Dughera*

Dipartimento di Chimica dell'Università di Torino, Via Pietro Giuria 7, 10 125 Torino, Italy
E-mail: stefano.dughera@unito.it

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Abstract

o-Benzenedisulfonimide has been used to efficiently catalyse the reaction between 2-amino-thiophenol, 2-aminophenol, *o*-phenylenediamine and various ortho esters (28 examples; average yield 90%) or aldehydes (17 examples; average yield 72%) giving the corresponding benzo-fused azoles in excellent yields. Reaction conditions were very simple. In addition, other carboxylic acid derivatives have been tested and gave good results. The catalyst was easily recovered and reused.

Keywords: Green chemistry, homogeneous catalysis, heterocycles, recyclable catalyst, disulfonimide

Introduction

Benzoxazoles, benzimidazoles, benzothiazoles and their derivatives are important classes of molecules in several field of organic chemistry.[1] In particular, they are a common heterocyclic scaffold in biologically active and medicinally significant compounds[2a] and are found in a large variety of natural products.[2b] Moreover, these groups of heterocyclic compounds exhibit a wide range of pharmacological properties, which include antiviral,[3] antimicrobial,[4] antitumor,[5] antibiotic,[6] antifungal,[7] anticonvulsant,[8] anti-inflammatory activity[9] and many others.[10,11] Their use in the field of advanced materials is also worthy of note.[12]

Because of the number and the significance of their applications, many synthetic methods have been reported for the preparation of these compounds over the years.[1b,1d,2a] In brief, there are two commonly used approaches for their construction, both of which employ 2-aminothio-phenol, 2-aminophenol, or *o*-phenylenediamine as the starting substrates. The first involves the coupling of the appropriate aminoaromatic with a carboxylic derivative under strongly acidic conditions. The second one works via the reaction of the appropriate aminoaromatic with an aldehyde followed by oxidative cyclization of the imine intermediate. However, these methods

often suffer from drawbacks, such as the use of strongly acidic conditions, toxic catalysts (often not recoverable and reusable), and long reaction times, low products yields, troublesome work-up, and the need to use solvents and reagents in large excess.[13]

Therefore, due to the importance of these heterocycles, the literature has provided new, efficient and environmentally benign methods for their preparation over the last few years.[2a,10-14] Moreover, the numerous and important biological applications that exist for benzo derivatives of azoles have been the motivation for renewed efforts in the search for novel derivatives with improved biological activity and diverse applications in the pharmaceutical industry.[11] We have recently reported the use of *o*-benzenedisulfonimide[15a] (**1**; Figure 1) in catalytic amounts as a Brønsted acid in several acid-catalyzed organic reactions under very mild and selective conditions.[15b,c] The catalyst was easily recovered and purified, ready to be used in further reactions, with economic and ecological advantages. Furthermore, **1** has already been advantageously used as a catalyst in the preparation of other important biologically active compounds such as quinolines [15d] and tetrahydroisoquinolines.[15e]

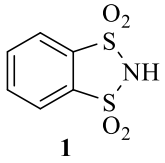

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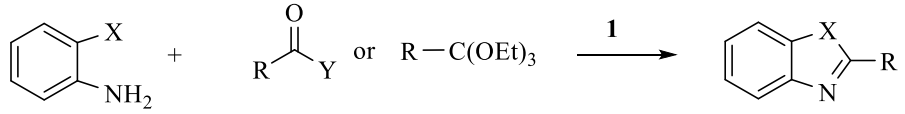
Figure 1. *o*-benzenedisulfonimide (**1**).

Results and Discussion

In this paper we report a comprehensive study of the reactions between 2-aminothiophenol (**2a**), 2-aminophenol (**2b**), *o*-phenylenediamine (**2c**), and some their derivatives. with various carboxylic acid derivatives **3**–**5**, **8** or aldehydes **6** (and ketones **7,** in order to obtain benzothiazolines or benzoxazolines) in the presence of catalytic amounts of **1** to provide benzothiazoles **9**, benzoxazoles **10** and benzimidazoles **11** (Scheme 1).



2a X = SH
2b X = OH
2c X = NH_2

3 Y = OH
4 Y = Cl
5 Y = OCOR
6 Y = H
(**7** Y= Me)

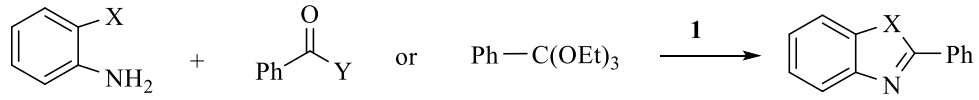
8

9 X = S
10 X = O
11 X = NH

Scheme 1. Reaction between 2-aminoaromatics **2** and carboxylic **3–5** or carbonyl derivatives **6**, **7** catalyzed by **1**.

To begin with, we studied the reaction between **2a** and four carboxylic derivatives, namely benzoic acid (**3a**), benzoyl chloride (**4a**), benzoic anhydride (**5a**) and triethyl orthobenzoate (**8a**) in the presence of catalytic amounts of **1** (5 mol-%) under neat conditions and in equimolar amounts. The results are reported in Table 1. The reaction did not occur with **3a** (Table 1, entry 1) and occurred only in part with **5a** (Table 1, entry 3). However, **4a** (Table 1, entry 2; the formation of the by-product HCl did not impede the progress of the reaction) and **8a** (Table 1, entry 4) gave the target compound 2-phenylbenzothiazole (**9a**) in very good yields. It must be stressed that the presence of a solvent (THF or CH_2Cl_2) slowed the reactions and decreased the yields (Table 1, entry 4, note d).

Table 1. Trial reactions between **2a-c** and various carboxylic derivatives



2a X = SH
2b X = OH
2c X = NH_2

3a Y = OH
4a Y = Cl
5a Y = OCOR

8a

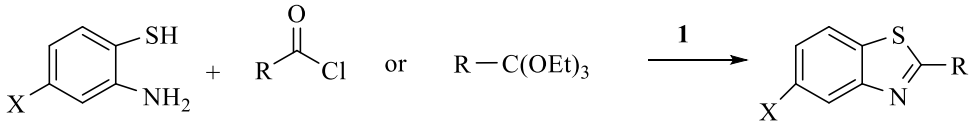
9a X = S
10a X = O
11a X = NH

Entry	Reactant	Temp (°C)	Time (h)	Yield (%) of **9a, 10a, 11a** [a,b]
1	**2a; 3a**	50	24	-
2	**2a; 4a**	50	24	**9a**; [c]
3	**2a; 5a**	50	2	**9a**; 87
4	**2a; 8a**	r.t.	1.5	**9a**; 90[d]
5	**2b;4a**	50	24	[e]
6	**2b;8a**	r.t.	3	**10a**; 93[d]
7	**2c;4a**	50	24	[f]
8	**2c;5a**	50	24	**11a;** 87
9	**2c;8a**	r.t.	3	**11a;** 92[d]

[a] Yields refer to the pure products. [b] Reactants **2a** and **3a–5a**, **8a** were in equimolar amounts (10 mmol). The reactions were carried out in neat conditions and in the precence of 5 mol-% of **1**. [c] After 24 hours, **9a** and several by-products were detected by GC-MS analyses. [d] The reaction did not occur without **1**. In the presence of an organic solvent (THF or CH_2Cl_2) the yields of **9a**, **10a**, **11a** were lower. [e] The main product of the reaction was *N*-(2-hydroxyphenyl)benzamide (**17a**), MS, *m/z* (%) = 213 (25) [M^+], 105 (100), 77(35). Only traces of **10a** were detected on GC-MS analyses, MS, *m/z* (%) = 195 (100) [M^+], 167 (15), 63 (20). On heating to 120 °C the main product was 2-(benzamidophenyl)phenyl benzoate (**18a**), MS, *m/z* (%) = 317 (15) [M^+], 105 (100), 77(12). [f] The sole product of the reaction was *N*-(2-aminophenyl)benzamide (**21a**), MS, *m/z* (%) = 212 (55) [M^+], 194 (100), 105 (100), 77 (35). To detect **21a** it was necessary to treat the crude residue with aqueous NaOH (10%).

When comparing the two reagents, it can be seen that the use of **8a** was certainly preferable because of the formation of EtOH rather than HCl as a by-product. In addition, the reactions with **8a** were carried out at r.t. while it was necessary to heat the reaction to 50 °C when using **4a**. However, a greater variety of acyl chlorides are commercially available. For this reason, it was also decided to study the reaction between **2a** and its derivative **2d** and a selected number of **4** and **8**, both aromatic and aliphatic, (**4**: 7 examples, Table 2, entries 1–7. Average yield 71%. **8**: 8 examples. Table 2, entries 8–15. Average yield 90%) gave the corresponding **9** in excellent yields. Reaction conditions, especially in the presence of **8** were very simple, mild and efficient (Scheme 2, where is also reported the mechanism of the reaction).

Table 2. Reactions between **2a, d** and **4** or **8**



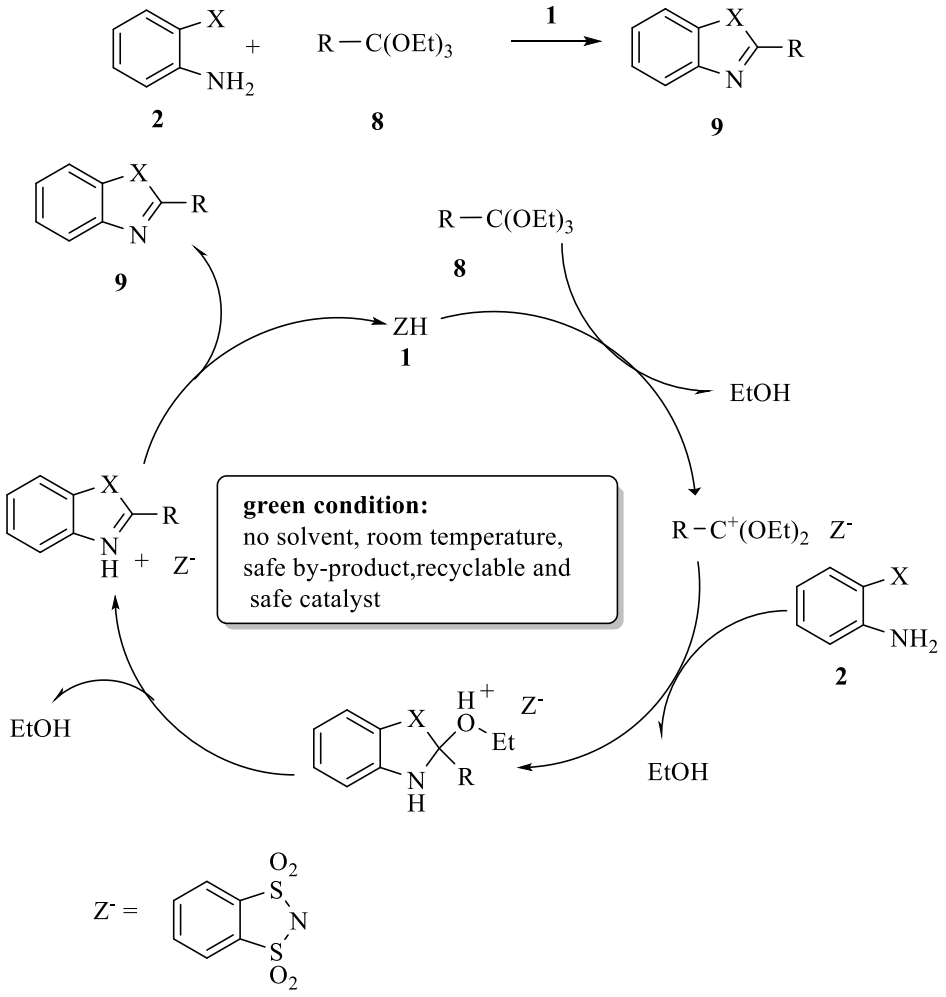
2a X= H
2d X= Cl

4 **8** **9**

Entry	R; reactant **4** or **8**	R; product **9**	Time (h)	Yield (%)[a]
1	Ph; **4a**	Ph; **9a**	2	87[b]
2	4-$MeOC_6H_4$; **4b**	4-$MeOC_6H_4$; **9b**	2.5	83[b]
3	4-ClC_6H_4; **4c**	4-ClC_6H_4; **9c**	2.5	80[b]
4	4-$NO_2C_6H_4$; **4d**	4-$NO_2C_6H_4$; **9d**	3	76[b]
5	Me; **4e**	Me; **9e**	3.5	81[b]
6	*c*-$C_6H_{11;}$ **4f**	*c*-$C_6H_{11;}$ **9f**	2.5	53[b,d]
7	*t*-C_4H_9; **4g**	*t*-C_4H_9; **9g**	3	42[b,d]
8	Ph; **8a**	Ph; **9a**	1.5	90[c]
9	4-$MeOC_6H_4$; **8b**	4-$MeOC_6H_4$; **9b**	1	90[c]
10	4-ClC_6H_4; **8c**	4-ClC_6H_4; **9c**	1	92[c]
11	4-$NO_2C_6H_4$; **8d**	4-$NO_2C_6H_4$; **9d**	1.5	91[c]
12	Me; **8e**	Me; **9e**	3	90[c]
13	$PhCH_2$; **8f**	$PhCH_2$; **9h**	2	90[c]
14	Ph; **8a**[e]	Ph; **9i** (X = Cl)	1.5	90[c]
15	Me; **8e**[e]	Me; **9j** (X = Cl)	2	86[c]

[a] Yields refer to the pure products. [b] Reactants were in equimolar amounts (10 mmol). The reactions were carried out in neat conditions at 50 °C and in the presence of 5 mol-% of **1.** [c] Reactants were in equimolar amounts (10 mmol) in neat conditions. The reactions were carried out in neat conditions at r.t. and in the presence of 5 mol- % of **1**. [d] Products **9f** and **9g** were

purified by flash column chromatography on silica gel, (CH_2Cl_2–MeOH 9.8 : 0.2). [e] The other reactant was **2d.**



Scheme 2. Reaction between **2** and **8**.

When compounds **9** were solid (generally those that have an aromatic group bonded to the benzothiazole ring) (Table 2, entries 1–4 and 8–11,14) the work-up was very easy and convenient. It was sufficient to add H_2O to the crude residue, filter and wash the resulting solid with additional H_2O and a small amount of PE on a Buchner funnel. In other cases (Table 2, entries 5–7, 12, 13, 15) a fast extraction with a small amount of solvent (EtOAc) was necessary.

Furthermore, **1** was recovered in excellent yield (91%) simply by the evaporation of the aqueous washings as reported in the Experimental Section. The recovered **1** was reused as the catalyst in four further consecutive reactions between **2a** and **8a**. The results are listed in Table 3: the reaction time increased over the course of the different reactions, however, the yields of **9a** and the recovery of **1** were always good.

We also performed the reaction between **2a** and **8a** in the presence of 5 mol-% of eight different acid catalysts under neat conditions to compare and contrast them with the catalytic

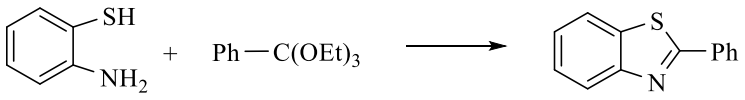
activity of **1** (Table 4). The results showed that only with 2,4-dinitrobenzenesulfonic acid both the reaction time and the yield were similar to that obtained with **1** (Table 4, entry 8). However, it was not easily recovered and reused.

Table 3. Consecutive runs with recovered **1**

Entry	Time (h)	Yield (%) of **9a**[a]	Recovery (%) of **1**[b]
1	1.5	90[c]	91 (100 mg[d])
2	1.5	88	92 (92 mg[e])
3	2	87	87 (80 mg[f])
4	2.5	85	86 (69 mg[g])
5	2.5	84	84 (58 mg)

[a] Yields refer to the pure product. [b] The amount (in mg) of recovered **1** is reported in brackets. [c] The reaction was performed with 10 mmol of **2a** and **8a** and 5 mol-% of **1** (110 mg, 0.5 mmol). [d] Recovered **1** was used as a catalyst in entry 2. [e] Recovered **1** was used as catalyst in entry 3. [f] Recovered **1** was used as a catalyst in entry 4. [g] Recovered **1** was used as a catalyst in entry 5.

Table 4. 2-Phenylbenzothiazole synthesis using other acid catalysts



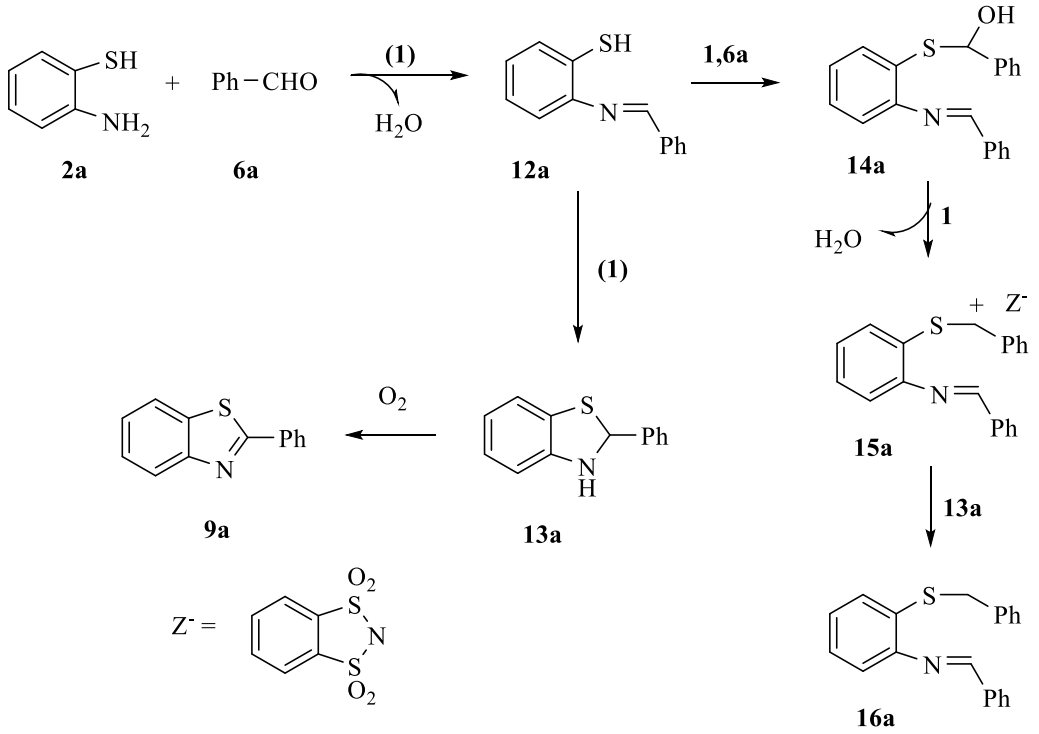
2a **8a** **9a**

Entry	Acid Catalyst	Time (h)	Yield (%) of **5a** [a,b]
1	$AlCl_3$	24	[c]
2	HCl 37%	24	[c]
3	$HBF_4 \cdot Et_2O$ 54%	7	85
4	HCOOH	7	90
5	$MeSO_3H$	5	91
6	NH_2SO_3H	8	84
7	$4\text{-}MeC_6H_4SO_3H$	5	90
8	$2,4\text{-}(NO_2)_2C_6H_3SO_3H$	2	91

[a] Yields refer to the pure products. [b] Reactants **2a** and **8a** were in equimolar amounts (5 mmol). The reactions were carried out in neat conditions at r.t. and in the precence of 5 mol-% of catalysts. [c] After 24 hours the reaction was not complete. GC-MS analyses showed the presence of starting products **2a**.

Aldehydes **6** were also used in place of carboxylic derivatives **4** and **8** (Scheme 3) in order to further explore the synthetic usefulness of **1** in the synthesis of benzothiazoles **9**. In a

preliminary test, benzaldehyde (**6a**) and **2a** were reacted. The reaction was heated to 50 °C in neat conditions and in the presence of catalytic amounts of **1** (5 mol-%). After 1 hour, the GC-MS analyses showed the presence of three products: **9a,** benzothiazoline **13a** (or/and imine **12a**) and a compound which had a mass spectrum compatible with the structure **16a**, shown in Scheme 3. Most probably, **1** favored the nucleophilic attack of the SH group of **12a** towards the carbonyl group of **6a** and then the dehydration of intermediate **14a**. The adduct **15a** furnished **16a,** perhaps due to a hydride transfer from **13a** (Scheme 3).

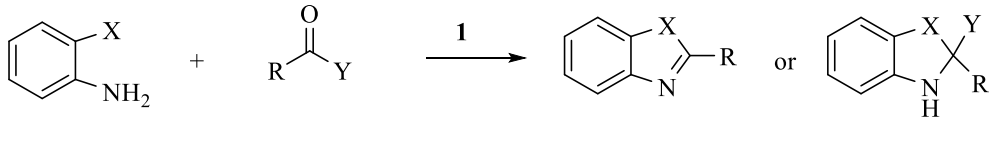


Scheme 3. Reaction between **2a** and **6a**.

After 3 hours, **13a** completely disappeared due to its air oxidation to **9a**. In order to avoid the formation of by-product **16a**, the reaction conditions were modified. In this version, **2a** and **6a** were initially heated to 50 °C in neat conditions. After 1 hour, the GC-MS analyses only showed the presence of **9a** and **13a**. Indeed, the ^{1}H-NMR analyses showed the presence of a *third* compound, namely the imine **12a.** In fact, two singlets could be found among the other peaks; the first (δ_H 6.36) is due to **13a** and the second (δ_H 8.51) is due to **12a.** After about 36 hours of heating to 50 °C, **9a** was obtained as the only product in fairly good yields (73%). After 1 hour of heating (when **2b** is no longer present) the addition of **1** (5 mol-%) allowed us to obtain **9a** in considerably less time (3 hours) and in a higher yield (88%. Table 5, entry 1). Evidently, the protonation of **12a** by **1** greatly facilitated the internal nucleophilic attack of SH group. On these grounds, ten aldehydes **6**, both aliphatic and aromatic, were reacted with **2a** with excellent results (average yield 86%) which are reported in Table 5, (entries 1–10). Therefore, **6** (compounds readily commercially available and easily handled) can also be advantageously used

as an alternative to **4** and **8** in the synthesis of **2**. Benzothiazoline **13c** was easily obtained after reacting **2a** with acetone **7b** (Table 5, entry 12).

Table 5. Reactions between **2a**, **2b**, **2c** and aldehydes **6** or ketones **7**



2a X = SH
2b X = OH
2c X = NH_2

6 Y = H
7 Y = Me

9 X = S
10 X = O
11 X = NH

13 X= S; Y= Me
20 X= O; Y= Me

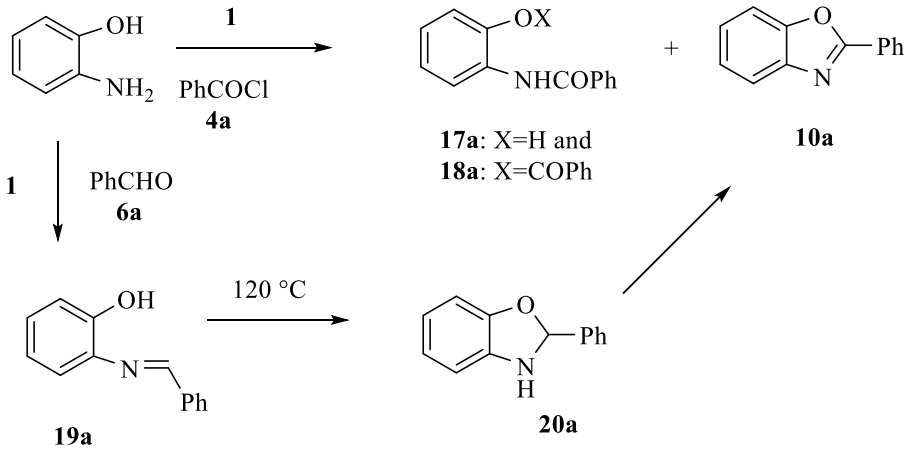
Entry	Reactant **2**	R; reactant **6** or **7**	R; product **9**, **13** or **20**	Time (h)	Yield (%)[a,b]
1	**2a**	Ph; **6a**	Ph; **9a**	3	88
2	**2a**	2-$MeOC_6H_4$; **6b**	2-$MeOC_6H_4$; **9k**	4	84
3	**2a**	3-$MeOC_6H_4$; **6c**	3-$MeOC_6H_4$; **9l**	3.5	84
4	**2a**	4-$MeOC_6H_4$; **6d**	4-$MeOC_6H_4$; **9b**	2.5	87
5	**2a**	4-ClC_6H_4; **6e**	4-ClC_6H_4; **9c**	3.5	90
6	**2a**	4-$NO_2C_6H_4$; **6f**	4-$NO_2C_6H_4$; **9d**	5	91
7	**2a**	2-Indolyl; **6g**	2-Indolyl; **9m**	4.5	83
8	**2a**	$PhCH_2$; **6h**	$PhCH_2$; **9f**	6	85[c]
9	**2a**	*c*-$C_6H_{11;}$ **6i**	*c*-$C_6H_{11;}$ **9g**	8	88
10	**2a**	*t*-C_4H_9; **6j**	*t*-C_4H_9; **9h**	24	86
11	**2a**	Ph; **7a**	Ph; **13b**	48	[d]
12	**2a**	Me; **7b**	Me; **13c**	48	87
13	**2b**	Ph; **6a**	Ph; **10a**	5	63[e,f]
14	**2b**	2-$MeOC_6H_4$; **6b**	2-$MeOC_6H_4$; **10b**	7	63[e]
15	**2b**	3-$MeOC_6H_4$; **6c**	3-$MeOC_6H_4$; **10c**	6	66[e]
16	**2b**	4-$MeOC_6H_4$; **6d**	4-$MeOC_6H_4$; **10d**	4	64[e]
18	**2b**	4-ClC_6H_4; **6e**	4-ClC_6H_4; **10e**	6	60[e]
19	**2b**	4-$NO_2C_6H_4$; **6f**	4-$NO_2C_6H_4$; **10f**	12	47[e]
20	**2b**	$PhCH_2$; **6h**	$PhCH_2$; **10g**	12	-
21	**2b**	Me; **7b**	Me**; 20b**	48	55[g]
22	**2c**	Ph; **6a**	Ph; **11a**	2	[h]

[a] Yields refer to the pure products. [b] Reactants were in equimolar amounts (10 mmol). The reactions were carried out in neat conditions at 50 °C and in the presence of 5 mol-% of **1.** [c] Without **1**, the reaction time was considearbly longer (48 h) and the yield lower (61%). [d] Only traces of **13b** were detected on GC-MS analyses, MS, *m/z* (%) = 227 (45) [M^+], 212 (80), 150 (100). [e] Reactants were in equimolar amounts (10 mmol).The reactions were carried out in neat conditions at 120 °C and in the presence of 5 mol-% of **1.** [f] At 50 °C the sole product was imine

19a. [g] Product **20b** was purified by flash column chromatography on silica gel (CH_2Cl_2). [h] The sole product of the reaction was *N*,*N*-dibenzylidene-*o*-phenylenediamine (**22a**), MS, *m/z* (%) = 284 (100) [M^+], 91 (80).

The use of aldehydes **6** is particularly interesting: H_2O is the only by-product and the oxidation of the intermediate benzothiazolines **13** takes place easily with air.

The next reaction to be examined was the reaction of **2b** with **4a** or **8a** in the presence of 5 mol-% of **1** as a catalyst**,** in order to obtain benzoxazole **10a**. Using the same conditions as described previously for the synthesis of **9a**, the only useful positive results occurred with **8a** (Table 1, entry 6). In fact, **10a** was easily obtained in good yields (93%). When using **4a**, the GC-MS analyses of the reaction mixture showed the presence of amide **17a** as the major product and only traces of **10a** (Scheme 4; Table 1, entry 5). The same result was also obtained when both the reaction temperature and the amount of catalyst (80 °C and 10 mol-% respectively; Table 1, entry 5) were increased. Indeed, under these conditions even the product of diacylation **18a** formed. Evidently, the more weakly nucleophilic OH group was not able to promote the cyclization reaction (Scheme 4).



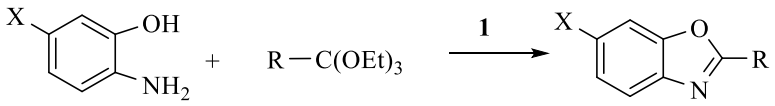
Scheme 4. Reaction between **2b** and **4a** or **6a.**

In the light of this information, the reaction between **2b**, **2e** and **2f** and selected orthoesters **8a**–**f** furnished the corresponding benzoxazoles **10** in excellent yields (Scheme 2; 10 examples. Table 6, entries 1–10. Average yield 89%). The reaction conditions were very simple, mild, efficient and the work-up was very easy and convenient also in this case.**1** was easily recovered in all the reactions.

On the other hand, reacting **6a** with **2b** in the presence of 5 mol-% of **1** at 50 °C, the GC-MS and ^{1}H-NMR (singlet at 8.40 ppm among other peaks) showed the presence of imine **19a** as the only product. No traces of possible benzoxazoline **20a** and target product **10a** were detected (Scheme 4; Table 5, entry 13).However, at 120 °C the oxidative cyclization occurred and **10a**

was obtained with a fairly good yield (61%; Scheme 3; Table 5, entry 13). So, it was possible to obtain benzoxazoles **10** in moderate yield by heating at 120 °C **2b** and aromatic aldehydes **6b**–**f** (6 examples. Table 5, entries 14–19. Average yields 60%). Only tars formed when using aliphatic aldehydes (Table 5, entry 20). Benzoxazoline **20b** was also obtained in moderate yield (Table 5, entry 21).

Table 6. Reactions between **2b, 2e, 2f** and **8**



2b X= H
2e X= Me
2f X =NO_2

8

10

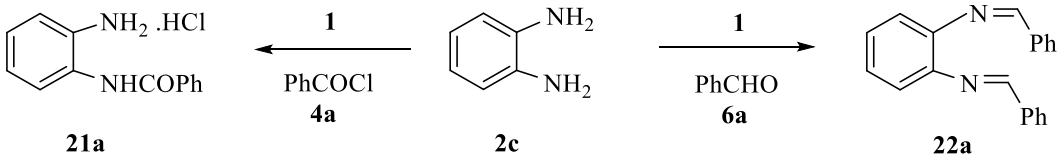
Entry	R; reactant **8**	R; product **10**	Time (h)	Yield (%)[a,b]
1	Ph; **8a**	Ph; **10a**	2	93
2	4-$MeOC_6H_4$; **8b**	4-$MeOC_6H_4$; **10d**	3	90
3	4-ClC_6H_4; **8c**	4-ClC_6H_4; **10e**	3	87
4	4-$NO_2C_6H_4$; **8d**	4-$NO_2C_6H_4$; **10f**	4	90
5	Me; **8e**	Me; **10g**	3	93
6	$PhCH_2$; **8f**	$PhCH_2$; **10h**	3	85
7	Ph; **8a**[c]	Ph; **10i** (X = Me)	3	91
8	Me; **8e**[c]	Me**; 10j** (X = Me)	3	84
9	Ph; **8a**[d]	Ph; **10k** (X = NO_2)	4	87
10	Me; **8e**[d]	Me; **10l** (X = NO_2)	4	85

[a] Yields refer to the pure products. [b] Reactants were in equimolar amounts (10 mmol). The reactions were carried out in neat conditions at r.t. and in the presence of 5 mol-% of **1**. [c] The other reactant was **2e**. [d] The other reactant was **2f**.

Finally, we studied the reaction between **2c** and **4a**, **5a**, **8a** (Table 1, entries 7–9), **6a** (Table 5, entry 22) in the presence of 5 mol-% of **1** as a catalyst in order to obtain benzimidazoles **5.** First of all, due to the formation of HCl and the subsequent protonation of the NH_2 group, the reaction between **2c** and **4a** only allowed the formation of product **21a** (Scheme 5; Table 1, entry 7). Furthermore, the reaction with **6a** does not give positive results: in fact only adduct **22a** was recovered (Scheme 5; Table 5, entry 22).

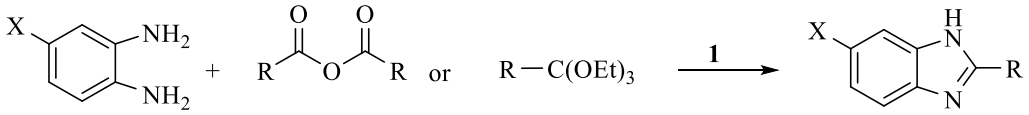
On the other hand, both **5a** and **8a** proved to be excellent reagents for the synthesis of benzimidazoles, in the presence of 5 mol-% of **1** as a catalyst. Therefore, the reaction between **2c**, **2e** and **2f** with selected **5** (8 examples. Table 7, entries 1–8. Average yield, 77%) and **8** (10 examples. Table 7, entries 9–18. Average yield, 91%) furnished the corresponding benzimid-

azoles **11** in very good yields. The reaction conditions were always very simple and efficient and **1** was easily recovered (Scheme 2).



Scheme 5. Reaction between **2c** and **4a** or **6a.**

Table 7. Reactions between **2c**, **2g**, **2h** and **5** or **8**



2c X= H
2g X= Me
2h X = NO_2

5

8

11

Entry	R; reactant **5** or **8**	R; product **11**	Time (h)	Yield (%)[a]
1	Ph; **5a**	Ph; **11a**	6	87[b]
2	4-$MeOC_6H_4$; **5b**	4-$MeOC_6H_4$; **11b**	8	85[c]
3	4-ClC_6H_4; **5c**	4-ClC_6H_4; **11c**	6.5	86[c]
4	4-$NO_2C_6H_4$; **5d**	4-$NO_2C_6H_4$; **11d**	9	87[c]
5	Me; **5e**	Me; **11e**	12	84[b]
6	$PhCH_2$; **5f**	$PhCH_2$; **11f**	15	74[b]
7	*c*-$C_6H_{11;}$ **5g**	*c*-C_6H_{11}; **11g**	18	54[b]
8	*t*-C_4H_9; **5h**	*t*-C_4H_9; **11h**	24	63[b]
9	Ph; **8a**	Ph; **11a**	3	92[d]
10	4-$MeOC_6H_4$; **8b**	4-$MeOC_6H_4$; **11b**	3.5	90[d]
11	4-ClC_6H_4; **8c**	4-ClC_6H_4; **11c**	4	91[d]
12	4-$NO_2C_6H_4$; **8d**	4-$NO_2C_6H_4$; **11d**	5	92[d]
13	Me; **8e**	Me; **11e**	4.5	95[d]
14	$PhCH_2$; **8f**	$PhCH_2$; **11f**	4	91[d]
15	Ph; **8a**[e]	Ph; **11i** (X = Me)	3.5	92[d]
16	Me; **8e**[e]	Me;**11j** (X = Me)	4	89[d]
17	Ph; **8a**[f]	Ph;**11k** (X =NO_2)	6	88[d]
18	Me; **8e**[f]	Me; **11l** (X = NO_2)	5.5	90[d]

[a] Yields refer to the pure products. [b] Reactants were in equimolar amounts (10 mmol). The reactions were carried out in neat conditions at 50 °C and in the presence of 5 mol- % of **1.** [c] Due

to the high mp of **5b–d**, the reaction were carried out in THF at reflux. Lower yields of products **11** were obtained when the same reaction was performed in neat conditions at higher temperature (100 °C). [d] Reactants were in equimolar amounts (10 mmol) in neat conditions. The reactions were carried out in neat conditions at r.t and in the presence of 5 mol- % of **1.** [e] The other reactant was **2e.** [f] The other reactant was **2h**

Conclusions

The Brønsted acid (**1**)-catalyzed synthesis of benzo derivatives of azoles **9**, **10** and **11**, an efficient, mild and simple procedure, is proposed in this paper. We tested various carboxylic acid derivatives and aldehydes as reactant. Undoubtedly the orthoesters **8** are by far the best; in fact, only they gave all three target products **9**, **10**, **11** in easy processes.

The reactions were carried out at r.t., under neat conditions (with the sole exception of oily products. In order to isolate them, a solvent extraction was necessary) and the safe by-product EtOH was easily removed. The high yields obtained are comparable to that reported in the literature.[12,14a,14f]

Moreover, acid catalyst **1** is a safe, non-volatile, non-corrosive Brønsted acid; it was easily recovered at the end of the reactions simply evaporating aqueous washings and it was reused in another four consecutive runs without a significant decrease in catalytic activity. But since only a few of **8** are commercially available, alternatively we employed easily available aldehydes **6** and acyl chlorides **4** to synthesize benzothiazoles **9** and anhydrides **5** to synthesize benzimidazoles **11**.

Experimental Section

General. All the reactions were conducted in open-air flasks. Analytical grade reagents and solvents were used and reactions were monitored by GC, and GC-MS. Petroleum ether (PE) refers to the fraction boiling in the range 40-70 °C. ^{1}H NMR and ^{13}C NMR were recorded on a Brucker Avance 200 spectrometer at 200 and 50 MHz respectively. Mass spectra were recorded on an HP 5989B mass selective detector connected to an HP 5890 GC. Room temperature (r.t.) is 20–25 °C. Melting points were measured on a Stuart Scientific SMP3 apparatus. *o*-Benzene-disulfonimide (**1**) was prepared as reported.[15f] (Now **1** is commercially available from 3B Scientific Corporation.) Ortho esters **8b–d, f** were prepared using the Pinner synthesis.[16] Anhydrides **5b**, **5d**, **5f**, **5g** were prepared by reacting the appropriate acyl chloride with the corresponding sodium salt of the carboxylic acid or reacting the acyl chloride with the corresponding carboxylic acid in the presence of pyridine. All the other reactants were purchased from Sigma-Aldrich or from Alpha-Aesar. Yields of the pure (GC, MS, ^{1}H NMR, ^{13}C NMR) isolated products **9**, **10** and **11** are reported in Tables 2, 5, 6, 7. Structures and purity of the

products **9**, **10**, **11** were confirmed by comparison of their physical and spectral data with those reported in the literature. The physical and spectral data of the obtained products in most cases are in accordance with those reported in the literature. The spectral data of the products **9**, **10**, **11** are reported in the Supplementary Material.

2-Phenylbenzothiazole (9a). Typical procedure for the preparation of benzothiazoles 9 from orthoesters 8 or acyl chlorides 4. In entry 8 (Table 2) *o*-benzenedisulfonimide (1; 5 mol%; 110 mg, 0.5 mmol) was added to a mixture of 2-aminothiophenol (2a, 1.25 g, 10 mmol) and triethyl orthobenzoate (8a, 2.24 g, 10 mmol). The mixture was stirred at r.t. The reaction was monitored by GC and GC-MS until the complete disappearance of starting products (1.5 h). Cold water (20 ml) was added to the reaction mixture, under vigorous stirring. The resulting solid was filtered on a Büchner funnel and washed with additional cold water (2 × 5 ml) and small amount of PE (5 ml). It was virtually pure (GC, MS, ^{1}H NMR, ^{13}C NMR) title compound **9a**, a pale yellow solid; yield: 90% (1.90 g). The oily benzothiazoles **9e–h** were recovered extracting with EtOAc the crude residue.

The aqueous washings were collected and evaporated under reduced pressure. After the removal of H_2O, virtually pure (^{1}H NMR) *o*-benzenedisulfonimide (**1**) was recovered (100 mg, 91% yield). The recovered **1** was employed in another four catalytic cycles under the conditions described above, reacting with **2a** and **8a**; Table 3 reported the yields of **9a** and the yields of recovered **1**. Spectral data on the products are presented as Supplementary Data.

2-Phenylbenzothiazole (9a). Typical procedure for the preparation of benzothiazoles 9 from aldehydes 6. In entry 1 (Table 5) a mixture of 2-aminothiophenol (**2a**, 1.25 g, 10 mmol) and benzaldehyde (**6a**, 1.06 g, 10 mmol) was stirred at 50 °C. After 1 hour, GC and GC-MS analyses showed the presence of two peaks: the first was **9a**, MS, *m/z* (%) = 211 (100) [M^+], 108 (25) and the second may have been **12a** or **13a**, MS, *m/z* (%) = 213 (70) [M^+], 212 (100), 136 (50). However, the ^{1}H-NMR (200 MHz, $CDCl_3$) analyses most probably showed the presence of both. In fact, among others, two distinct singlets were clearly visible, the first (δ_H 6.36, H-2) due to **13a**; the second (δ_H 8.51, HC=N) due to **12a**. At this point, *o*-benzenedisulfonimide (**1**; 5 mol-%; 110 mg, 0.5 mmol) was added to the reaction mixture. After 3 hours, the intermediates **12a** and **13a** disappeared. Cold H_2O (20 ml) was added to the reaction mixture, under vigorous stirring. The resulting solid was filtered on a Büchner funnel and washed with additional cold water (2 × 5 ml) and small amount of PE (5 ml). It was the virtually pure (GC, MS, ^{1}H NMR, ^{13}C NMR) title compound **9a**, a pale yellow solid; yield: 88% (1.85 g). The aqueous washings were collected and evaporated under reduced pressure. After the removal of H_2O, virtually pure (^{1}H NMR) o-benzenedisulfonimide (**1**) was recovered (91 mg, 83% yield). The reaction also completed without adding **1**. However, the reaction time was longer (36 h) and the yield lower (73%; 1.54 g). On the other hand, adding **1** to a mixture of **2a** and **11a** from the beginning of the reaction, after 1 h GC and GC-MS showed three peaks: **9a**, **12a** or **13a** and adduct **16a**, MS, *m/z* = 303 (85) [M^+], 226 (75), 212 (90), 91 (100). Continuing the stirring at 50 °C, after 3 h only **9a** and **16a** were detected.

2-Phenylbenzothiazole (**9a**). Pale yellow solid; mp 116–117 °C (EtOH; lit.[17] 115–116 °C). Yield: 90% (1.90 g) from **2a** and **8a**; 87% (1.84g) from **2a** and **4a**; 88% (1.87g) from **2a** and **6a**.
2-(4-Methoxyphenyl)benzothiazole (**9b**). Pale yellow solid; mp 126–127 °C (EtOH; lit.[18] 127–128 °C). Yield: 90% (2.18 g) from **2a** and **8b**; 83% (2.00 g) from **2a** and **4b**; 87% (2.10 g) from **2a** and **6d**.
2-(4-Chlorophenyl)benzothiazole (**9c**). Pale yellow solid; mp 116–117 °C (EtOH; lit.[19] 111.5–112.5 °C). Yield: 92% (2.27 g) from **2a** and **8c**; 80% (1.95 g) from **2a** and **4c**; 90% (2.21 g) from **2a** and **6e**.
2-(4-Nitrophenyl)benzothiazole (**9d**).Yellow solid; mp 224–226 °C (EtOH; lit.[20] 226–228 °C). Yield: 91% (2.34 g) from **2a** and **8d**; 76% (1.95 g) from **2a** and **4d**; 91% (2.34 g) from **2a** and **6f**.
2-Methylbenzothiazole (**9e**).Pale yellow oil.[21] Yield: 90% (1.34 g) from **2a** and **8e**; 81% (1.19 g) from **2a** and **4e**.
2-Benzylbenzothiazole (**9f**). Pale yellow oil.[22] Yield: 90% (2.02 g) from **2a** and **8f**; 85% (1.91 g) from **2a** and **6h**.
2-Cyclohexylbenzothiazole (**9g**)**.** Pale yellow oil.[23] Yield: 53% (1.15 g) from **2a** and **4f**; 88% (1.92 g) from **2a** and **6i**.
2-*t*-Butylbenzothiazole (**9h**)**.** Pale yellow oil.[24] Yield: 42% (0.80 g) from **2a** and **4g**; 86% (1.66 g) from **2a** and **6j**.
5-Chloro-2-phenylbenzothiazole (**9i**).Pale brown solid; mp 136–138 °C (EtOH; lit.[25] 138–139 °C). Yield: 90% (2.21 g) from **2d** and **8a**.
5-Chloro-2-methylbenzothiazole (**9j**).Pale brown solid; mp 66–68 °C (EtOH; lit.[26]68–69 °C). Yield: 86% (1.57 g) from **2d** and **8e**.
2-(2-Methoxyphenyl)benzothiazole (**9k**).Pale yellow solid; mp104–105 °C (EtOH; lit.[27] 95–98 °C). Yield: 84% (2.04 g) from **2a** and **6b**.
2-(3-Methoxyphenyl)benzothiazole (**9l**).Pale yellow solid; mp 80–81 °C (EtOH; lit.[19] 81.5–82 °C). Yield: 84% (2.04 g) from **2a** and **6c**.
2-(2-Indolyl)benzothiazole (**9m**).Brown solid; mp168–170 °C (EtOH; lit.[28] 144–146 °C). Yield: 83% (2.06 g) from **2a** and **6g**.
2,2-Dimethylbenzothiazoline (**13c**).Waxy grey solid (mp lit.[29] 44–45 °C). Yield: 87% (1.44 g) from **2a** and **7b**.
2-Phenylbenzoxazole (10a). Typical procedure for the preparation of benzoxazoles from aldehydes 6. According to the procedure described above, in entry 13 (Table 5) *o*-benzenedisulfonimide (**1**; 5 mol-%; 110 mg, 0.5 mmol) was added to a mixture of 2-aminophenol (**2b**, 1.09 g, 10 mmol) and benzaldehyde (**6a**, 1.06 g, 10 mmol). The mixture was stirred at 50 °C. After 24 hour, GC, MS and ^{1}H NMR analyses showed the presence of the immine **19a**. ^{1}H NMR (200 MHz, $CDCl_3$): δ_H 8.64 (s, 1H, HC=N), 7.89–7.85 (m, 2H), 7.45–7.45 (m, 3H), 7.28–7.11 (m, 2H), 6.99–6.85 (m, 2H), 4.84 (br s, 1H); MS, *m/z* (%) = 197 (100) [M^+], 196 (100), 120 (100). On the other hand, heating at 120 °C for 5 hours we obtained the title compound **10a** in fairly good yield (1.22 g; 63%).

2-Phenylbenzoxazole (**10a**). Grey solid; mp 103–104 °C (EtOH; lit.[30] 102–103 °C). Yield: 93% (1.82 g) from **2b** and **8a**; 63% (1.22 g) from **2b** and **6a.**
2-(2-Methoxyphenyl)benzoxazole (**10b**). Pale yellow solid; mp 56–57 °C (EtOH; lit.[31] 53–55 °C). Yield: 63% (1.42 g) from **2b** and **6b**.
2-(3-Methoxyphenyl)benzoxazole (**10c**). Pale yellow solid; mp 73–74 °C (EtOH; lit.[31] 71.3–73.8 °C). Yield: 66% (1.48 g) from **2b** and **6c**.
2-(4-Methoxyphenyl)benzoxazole (**10d**). Pale yellow solid; mp 103–104 °C (EtOH; lit.[32] 100–102 °C). Yield: 90% (2.02 g) from **2b** and **8b**; 64% (1.44 g) from **2b** and **6d**.
2-(4-Chlorophenyl)benzoxazole (**10e**). Pale yellow solid; mp 153–154 °C (EtOH; lit.[32] 150–152 °C). Yield: 87% (2.00 g) from **2b** and **8c**; 60% (1.37 g) from **2b** and **6e**.
2-(4-Nitrophenyl)benzoxazole (**10f**). Yellow solid; mp 271–273 °C (EtOH; lit.[32] 270–272 °C).Yield: 90% (2.15 g) from **2b** and **8d**; 47% (1.13 g) from **2b** and **6f.**
2-Methylbenzoxazole (**10g**). Pale yellow oil.[33] Yield: 93% (1.24 g) from **2b** and **8e**.
2-Benzylbenzoxazole (**10h**).Pale yellow oil.[31] Yield: 85% (1.77 g) from **2b** and **8f**.
6-Methyl-2-phenylbenzoxazole (**10i**). Pale brown solid; mp 104–105 °C (EtOH; lit.[33] 99–102 °C). Yield: 91% (1.90 g) from **2e** and **8a.**
2,6-Dimethylbenzoxazole (**10j**). Pale yellow oil.[33] Yield: 84% (1.23 g) from **2e** and **8e**.
6-Nitro-2-phenylbenzoxazole (**10k**). Pale yellow solid; mp 142–143 °C (EtOH; lit.[34] 138–142 °C).Yield: 87% (2.08 g) from **2f** and **8a**.
2-Methyl-6-nitrobenzoxazole (**10l**).Pale yellow solid; mp 171–172 °C (EtOH; lit.[34] 170–173 °C).Yield: 85% (1.52 g) from **2f** and **8e**.
2,2-Dimethylbenzoxazoline (**20b**).Pale yellow oil.[35] Yield: 55% (0.82 g) from **2b** and **7b**.
2-Phenylbenzimidazole (11a). Typical procedure for the preparation of benzimidazole from orthoesters 8 or anhydrides 5. According to the procedure described above, in entry 8 (Table 7) *o*-benzenedisulfonimide (**1**; 5 mol-%; 110 mg, 0.5 mmol) was added to a mixture of *o*-phenylenediamine (**2c**, 1.11 g, 10 mmol) and triethyl orthobenzoate (**10a**, 2.24 g, 10 mmol). The mixture was stirred at r.t. The reaction was monitored by GC and GC-MS until the complete disappearance of starting products (3 h). With the same work-up as described above, the virtually pure (GC, MS, ^{1}H NMR, ^{13}C NMR) title compound **11a** was obtained; pale grey solid; yield: 93% (1.70 g). The aqueous washings were collected and evaporated under reduced pressure. After the removal of H_2O, virtually pure (^{1}H NMR) *o*-benzenedisulfonimide (**1**) was recovered (90 mg, 82 % yield).
This procedure was also applied, practically unchanged, using the anhydrides (**5**). However, in order to eliminate the by-product carboxylic acid, the resulting solid was filtered on a Büchner funnel and washed with aqueous NaOH (10%) (2 × 5 ml) and small amount of PE (5 ml). In this case, in order to recover **1,** the aqueous layer was passed through a column of Dowex 50X8 ion exchange resin; elution was with H_2O. After removal of H_2O virtually pure (^{1}H NMR) *o*-benzenedisulfonimide (**1**) was recovered.
2-Phenylbenzimidazole (**11a**). Pale brown solid; mp 293–294 °C (EtOH; lit.[36] 292–294 °C).Yield: 92% (1.79 g) from **2c** and **8a**; 87% (1.68 g) from **2c** and **5a.**

2-(4-Methoxyphenyl)benzimidazole (**11b**). Pale yellow solid; mp 223–225 °C (EtOH; lit.[36] 222–225 °C).Yield: 90% (2.01 g) from **2c** and **8b**; 85% (1.90 g) from **2c** and **5b**.
2-(4-Chlorophenyl)benzimidazole (**11c**). Pale yellow solid; mp 294–295 °C (EtOH; lit.[37] 292–293 °C). Yield: 91% (2.08 g) from **2c** and **8c**; 86% (1.95 g) from **2c** and **5c.**
2-(4-Nitrophenyl)benzimidazole (**11d**).Yellow solid; mp 264–265 °C (EtOH; lit.[36] 259–260 °C).Yield: 92% (2.20 g) from **2c** and **8d**; 87% (2.07 g) from **2c** and **5d.**
2-Methylbenzimidazole (**11e**).Pale yellow solid; mp 175–176 °C (EtOH; lit.[38] 172–174 °C). Yield: 95% (1.25 g) from **2c** and **8e**; 84% (1.11 g) from **2c** and **5e.**
2-Benzylbenzimidazole (**11f**). Pale yellow solid; mp 179–180 °C (EtOH; lit.[39] 175 °C).Yield: 91% (1.90 g) from **2c** and **8f**; 74% (1.55 g) from **2c** and **5f.**
2-Cyclohexylbenzimidazole (**11g**). Pale yellow solid; mp 280–282 °C (EtOH; lit.[25] mp >265 °C). Yield: 54% (1.12 g) from **2c** and **5g.**
2-*t*-Butylbenzimidazole (**11h**). Pale yellow solid; mp >300 °C (EtOH; lit.[36] 303–306 °C).Yield: 63% (1.11 g) from **2c** and **5h.**
5-Methyl-2-phenylbenzimidazole (**11i**). Pale brown solid; mp 244–246 °C (EtOH; lit.[40] 243–245 °C). Yield: 92% (1.91 g) from **2h** and **5a**.
2,5-Dimethylbenzimidazole (**11j**). Pale grey solid; mp 205–206 °C (EtOH; lit.[41] 203–204 °C). Yield: 89% (1.30 g) from **2h** and **5e**.
5-Nitro-2-phenylbenzimidazole (**11k**). Pale brown solid; mp 212–213 °C (EtOH; lit.[40] 208–210 °C). Yield: 88% (2.11 g) from **2g** and **5a**.
2-Methyl-5-nitrobenzimidazole (**11l**).Pale brown solid; mp 216–218 °C (EtOH; lit.[38] 218–220 °C). Yield: 90% (1.59 g) from **2g** and **5e.**

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References

1. Katritzky, A. R.; Lagowski, J. M. In *Comprehensive Heterocyclic Chemistry*; Potts, K. T. Ed.; Pergamon: Oxford, 1984; Vol. 5, Chap. 4.01, pp 1–38 and Chap. 4.02, pp 39–110. (b) Potts, K. T. In *Comprehensive Heterocyclic Chemistry*; Potts, K. T. Editor; Pergamon: Oxford 1984**,** Vol. 5, Chap. 4.03, pp 111–166. (c) Chen C.; Chen, Y.-J. *Tetrahedron Lett*. **2004**, *45*, 113. (d) Evindar, G.; Batey, A. R. *J. Org. Chem*. **2006**, *71*, 1802 and references cited therein.
2. (a) Wen, X.; El Bakali, J.; Deprez-Poulain, R.; Deprez, B. *Tetrahedron Lett.* **2012**, *53*, 2440 and references cited therein. (b) Chaney, M. O.; Demarco P. V.; Jones, N. D.; Occolowitz, J. L. J. *J. Am. Chem. Soc*. **1974**, *96*, 1932.

3. (a) Porcari A. R.; Devivar R.V.; Kucera, L. S.; Drach, J. C.; Townsend, L. B. *J. Med. Chem.* **1998**, *41*, 1252. (b) Song, X.; Vig, B. S.; Lorenzi, P. L.; Drach, J.C.; Townsend, L. B.; Amidon, G. L. *J. Med. Chem.* **2005**, *48*, 1274.
4. Yildiz-Oren, I.; Yalcin, I.; Aki-Sener, E.; Ucarturk, N. *Eur. J. Med. Chem*. **2004**, *39***,** 291.
5. (a) Kumar, D.; Jacob, M. R; Reynolds, M. B.; Kerwin, S. M. *Bioorg. Med. Chem.* **2002**, *10*, 3997. (b) Huang, S. T.; Hsei, I. J.; Chen, C. *Bioorg. Med. Chem*. **2006**, *14*, 6106.
6. Evans, D. A.; Sacks, C. E.; Kleschick, W. A.; Taber, T. R. *J. Am. Chem. Soc.* **1979,** *101*, 6789.
7. Yamato, M. *Yakugaku Zasshi* **1992**, *112*, 81.
8. Benazzouz, A.; Boraud, T.; Dubèdat, P., Boireau, A.; Stutzmann, J.-M.; Gross, C. *Eur. J. Pharmacol.* **1995**, *284*, 299.
9. Mader, M.; de Dios, A.; Shih, C.; Anderson, B. D. *Bioorg. Med. Chem. Lett*. **2008**, *18*, 179.
10. Raghavendra, G. M.; Ramesha, A. B.; Revanna, C. N.; Nandeesh, K. N.; Mantelingu, K.; Rangappa, K. S. *Tetrahedron Lett.* **2011**, *52*, 5571.
11. Facchinetti, V.; Reis, R. D.; Gomes, C. R. B.; Vasconcelos, T. R. A. *Mini-Rev. Org. Chem.* **2012**, *9*, 44.
12. Liu, J.; Liu, Q.; Xu, W.; Wang, W. *Chin. J. Chem.* **2011**, *29*, 1739.
13. Hojati, S. F.; Maleki, B.; Beykzadeh, Z. *Monatsh. Chem.* **2011**, *142*, 87.
14. For other examples of papers of the last two years see: (a) Karami, B.; Ghashghaee, V.; Khodabakhshi, S. *Catal. Commun.* **2012**, *20*, 71. (b) Zhang, L.-J.; Xia, J.; Zhou Y.-Q.; Wang, H.; Wang, S. W. *Synth. Commun.* **2012**, *42*, 328. (c) Eshghi, H.; Rahimizadeh, M.; Shiri, A.; Sedaghat, P. *Bull. Korean Chem. Soc.* **2012**, *33*, 515. (d) Deng, H.; Li, Z.; Ke, F.; Zhou, X. *Chem. Eur. J.* **2012**, *18*, 4840. (e) Khurana, J. M.; Sneha; Vij, K. *Synth. Commun.* **2012**, *42*, 2606. (f) Aridoss, G.; Laali K. K. *Eur. J. Org. Chem*. **2011**, 2827. (f) Maleki, B.; Azarifar, D.; Hojati S. F.;Veisi, H.; Gholizadeh, M.; Salehabadi, H.; Khodaverdian Moghadam, M. *J. Heterocyclic Chem*. **2011**, *48*, 449. (g) Riadi, Y.; Mamouni, R.; Azzalou, R.; El Haddad, M.; Routier, S.; Guillaumet, G.; Lazar, S. *Tetrahedron Lett.* **2011,** *52*, 3492.
15. (a) Barbero, M.; Bazzi, S.; Cadamuro, S.; Dughera, S. *Curr. Org. Chem.* **2011**, *15*, 576. (b) Barbero, M.; Cadamuro, S.; Dughera, S.; Magistris, C.; Venturello, P. *Org. Biomol. Chem.* **2011**, *9*, 8393. (c) Barbero, M.; Cadamuro, S.; Ghigo, G.; Dughera, S. *Org. Biomol. Chem.* **2012**, *10*, 4058. (d) Barbero, M.; Bazzi, S.; Cadamuro, S.; Dughera, S. *Tetrahedron Lett.* **2010**, *51*, 2342. (e) Barbero, M.; Bazzi, S.; Cadamuro, S.; Dughera, S. *Tetrahedron Lett.* **2010**, *51*, 6356. (f) Barbero, M.; Crisma, M.; Degani, I.; Fochi, R.; Perracino, P. *Synthesis* **1998**, 1171.
16. (a) Hunter, M. J.; Ludwig, M. L. *J. Am. Chem. Soc.* **1962**, *84*, 3491. (b) Brooker, L.G. S.; White, F. L. *J. Am. Chem. Soc.* **1935**, *57*, 2480.
17. Osuka, A.; Uno, Y.; Horiuchi, H.; Suzuki, H. *Synthesis* **1984**, 145.
18. Melzig, L.; Metzger, A.; Knöchel, P. *Chem. Eur. J.* **2011**, *17*, 2948.
19. Inamoto, K.; Hasegawa, C.; Hiroya, K.; Doi, T. *Org. Lett.* **2008**, *10*, 5147.
20. Chakraborti, A. K.; Rudrawar, S.; Kaur, G.; Sharma, L. *Synlett* **2004**, 1533.

21. Itoh, T.; Mase, T. *Org. Lett.* **2007**, *9*, 3687.
22. Mukai, T.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2010**, *12*, 1360.
23. Wang, Z.; Tang, R.; Xiao, Q. *Chin. J. Chem*. **2011**, *29*, 314.
24. Prasad, D. J. C.; Sekar, G. *Org. Lett.* **2011**, *13*, 1008.
25. Lim, H.-J.; Myung, D.; Lee, I. Y. C.; Jung, M. H. *J. Comb. Chem*. **2008**, *10*, 501.
26. Huang, X.; Tang, J. *Tetrahedron* **2003**, *59*, 4851.
27. Organ, M. G.; Hadi, M. A.; Avola, S.; Dubovyk, I.; Hadei, N.; Nasielski, J.; O'Brien, C. J.; Valente C. *Chem. Eur. J*. **2007**, *13*, 150.
28. Qin, X.; Cong, X.; Zhao, D.; You, J.; Lan, J. *Chem. Commun*., **2011**, *47*, 5611.
29. Kodomari, M.; Satoh, A.; Nakano, R.; Aoyama, T. *Synth. Commun*. **2007**, *37*, 3329.
30. Marsden, S. P.; McGonagle, A. E.; McKeever-Abbas, B. *Org. Lett.* **2008**, *10*, 2589.
31. Ackermann, L.; Barfűsser, S.; Pospech, J. *Org. Lett*. **2010**, *12* , 724.
32. Kidwai, M.; Bansal, V.; Saxena, A.; Aerry, S.; Mozumdar, S. *Tetrahedron Lett.* **2006,** *47*, 8049.
33. Lee, J. J.; Kim, J.; Jun, J. M.; Lee, B. M; Kim, B. H. *Tetrahedron* **2009,** *65*, 8821.
34. Wei1,C.-X.; Guan, L. P.; Jia, J. H.; Chai, K. Y.; Quan, Z.-S. *Arch. Pharm. Res.* **2009**, *32*, 23.
35. Erker, T. *Liebigs Ann. Chem.* **1989**, *6*, 601.
36. Kim, Y.; Kumar, M. R.; Park, N.; Heo, Y.; Lee, S. *J. Org. Chem*. **2011**, *76*, 9577.
37. Sharghi, H.; Beyzavi, M. H.; Doroodmand, M. M. *Eur. J. Org. Chem*. **2008**, 4126.
38. Yang, D.; Fu, H.; Hu, L.; Jiang, Y.; Zhao, Y. *J. Org. Chem*. **2008**, *73*, 7841.
39. Blacker, J.; Farah, M. M.; Hall, M. I.; Marsden, S. P.; Saidi, O.; Williams, J. M. J. *Org. Lett.* **2009**, *11*, 2039.
40. Adharvana Chari, A; Shobha, M. D.; Sasaki, T. *Tetrahedron Lett.* **2011**, *52*, 5575.
41. Kim, Ja.; Kim, Je.; Lee, H.; Lee, B. M; Kim, B. H. *Tetrahedron* **2011,** *67*, 8027.

