

Synthesis of Highly Substituted Imidazoles Using Brønsted Acidic Ionic Liquid, Triphenyl(propyl-3-sulphonyl)phosphonium Toluenesulfonate, as Reusable Catalyst

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Brønsted acidic ionic liquid, triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate, has been used as an efficient and reusable catalyst for the one-pot synthesis of 2,4,5-trisubstituted and 1,2,4,5-tetrasubstituted imidazoles under solvent-free conditions in excellent yields.

Keywords: Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate, 2,4,5-Trisubstituted imidazoles, 1,2,4,5-Tetrasubstituted imidazoles, Solvent-free, Ionic liquid

INTRODUCTION

Multi-component reactions (MCRs) are powerful tools in generating products in organic and medicinal chemistry for their high degree of atom economy and application in the diversity-oriented convergent synthesis of complex organic molecules from simple and readily available substrates in a single synthetic operation [1,2].

Imidazoles are an important class of heterocycles being the core fragment of different natural products and biological systems [3]. Compounds containing imidazole moiety have many pharmacological properties and play important roles in biochemical processes [4]. Substituted imidazoles can be used as light-sensitive materials in photography and are known as inhibitors, fungicides and herbicides [5], plant growth regulators and therapeutic agents [6].

Ionic liquid (IL) technology offers a new and environmentally benign approach toward modern synthetic chemistry. Ionic liquids have interesting advantages such as

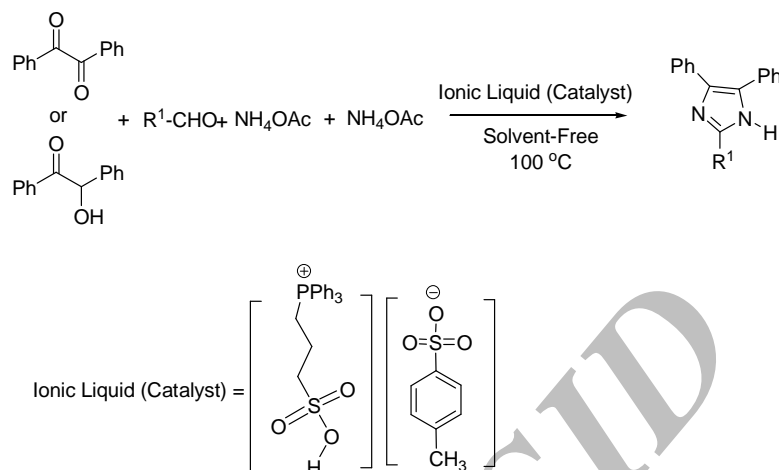
extremely low vapor pressure, excellent thermal stability, reusability, talent to dissolves many organic and inorganic substrates [7]. Ionic liquids have been successfully employed as solvents and catalyst for a variety of reactions [8-11], which promises widespread applications in industry and organic synthesis.

In continuation of our effort to develop Lewis and Brønsted acid catalyzed synthetic methodologies [8,12], we report herein, a simple synthesis of 2,4,5-trisubstituted (Scheme 1) and 1,2,4,5-tetrasubstituted imidazoles (Scheme 2) in high yields using Brønsted acidic ionic liquid, triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate, as a catalyst for the first time.

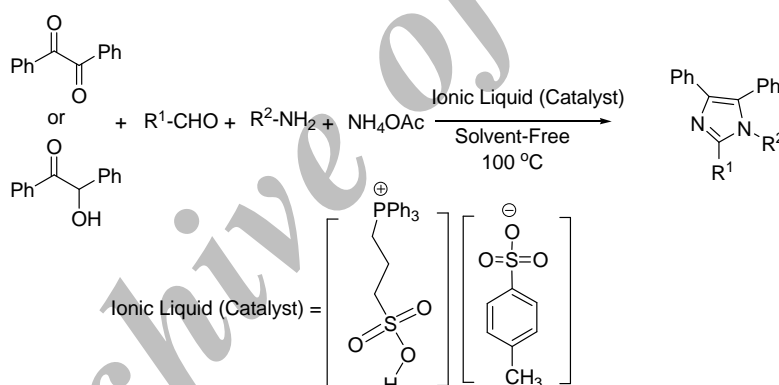
EXPERIMENTAL

All reagents were purchased from Merck and Aldrich and used without further purification. All yields refer to isolated products after purification. Products were characterized by comparison with authentic samples and by spectroscopy data (IR, ¹H NMR and ¹³C NMR spectra). The NMR spectra were

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Scheme 1. Pseudo four-component reaction between benzil or benzoin, benzaldehydes, and ammonium acetate at 100 °C in the presence of triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate as ionic liquid.



Scheme 2. Four-component of benzil or benzoin, benzaldehydes, anilines, and ammonium acetate using triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate as catalyst at 100 °C

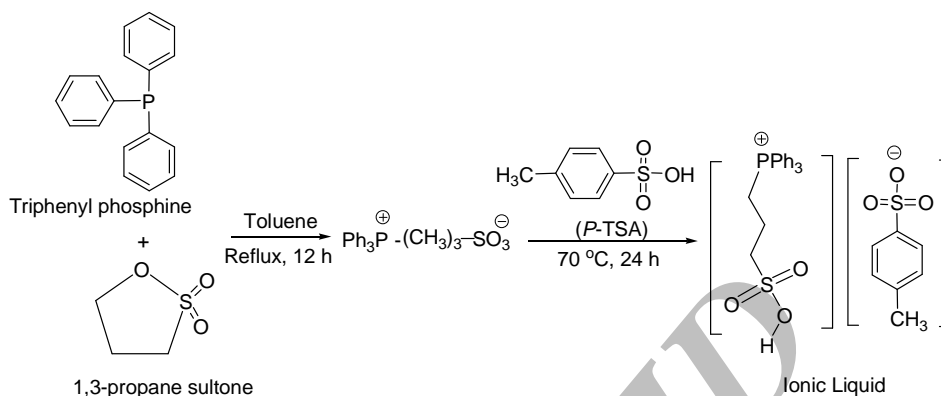
recorded on a Bruker Avance DPX 500 MHz instrument. The spectra were measured in DMSO-*d*₆ relative to TMS (0.00 ppm). FT-IR spectra were recorded on a JASCO FT-IR 460 plus spectrophotometer. Mass spectra were recorded on an Agilent technologies 5973 network mass selective detector (MSD) operating at an ionization potential of 70 eV. TLC was performed on silica-gel Poly Gram SIL G/UV 254 plates.

Preparation of Triphenyl(propyl-3-sulphonyl)phosphonium Toluenesulfonate as Ionic Liquid [13]

Triphenylphosphine and 1,3-propane sultone are combined in equimolar quantities in toluene and brought to reflux for 12

h. Then, a white precipitate forms which is isolated by filtration and dried. Analysis of the solid revealed it to be the desired zwitterion, formed in quantitative yield. The desired zwitterion was of sufficient purity to be used without any further purification. Conversion to the ionic liquid is accomplished by combining equimolar quantities of *p*-TSA hydrate and the zwitterion and heating to 70 °C for 24 h, during which, the solids liquefy resulting in the formation of triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate (Scheme 3). The IL phase was then washed repeatedly with toluene and ether to remove non-ionic residues, and dried in vacuo. The product was formed quantitatively and in high

Synthesis of Highly Substituted Imidazoles Using Brønsted Acidic Ionic Liquid



Scheme 3. Preparation of triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate as ionic liquid

purity as assessed by NMR spectroscopy. Spectral data: ^1H NMR (300 MHz, D_2O): $\delta = 7.66\text{--}7.60$ (m, 3H), $7.53\text{--}7.44$ (m, 14H), 7.06 (d, $J = 8.0$, 2H), $3.31\text{--}3.21$ (m, 2H), 2.89 (t, $J = 6.9$, 2H), 2.11 (s, 3H), $1.97\text{--}1.80$ (m, 2H) ppm; ^{13}C NMR (75.5 MHz, D_2O): $\delta = 142.21$, 139.75 , 135.29 , 135.25 , 133.47 , 133.34 , 130.40 , 130.23 , 129.42 , 125.44 , 118.13 , 116.98 , 50.55 , 50.33 , 20.58 , 20.04 , 17.94 ppm.

General Procedure for Preparation of 2,4,5-Trisubstituted Imidazoles

Benzil or benzoin (1 mmol), aldehyde (1 mmol), and ammonium acetate (4 mmol) were added to triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate (0.09 g, 0.2 mmol) at $100\text{ }^{\circ}\text{C}$ for the appropriate time reported in Table 1. After completion of the reaction which was monitored by TLC, the mixture was washed with water, and the solid product purified by recrystallization from ethanol. All of the desired product(s) were characterized by comparison of their physical data with those of known compounds. Some characterization data for selected known products are given below.

2-(4-Methoxyphenyl)-4,5-diphenylimidazole (Table 1, Entry 4). ^1H NMR ($\text{DMSO-}d_6$, 500 MHz): $\delta = 12.48$ (s, 1H), 8.00 (dt, $J = 8.80$ Hz, 2.0 Hz, 2H), 7.51 (d, $J = 7.2$ Hz, 4H), 7.35 (t, $J = 7.2$ Hz, 4H), 7.27 (t, $J = 7.2$ Hz, 2H), 7.04 (dt, $J = 8.8$ Hz, 2.0 Hz, 2H), 3.80 (s, 3H) ppm; ^{13}C NMR ($\text{DMSO-}d_6$, 125 MHz): $\delta = 55.2$, 114.1 , 122.9 , 126.7 , 127.0 , 127.7 , 128.4 , 145.6 , 159.4 ppm; IR (KBr, cm^{-1}): 3400 , 3060 , 1611 , 1490 , 1179 , 1028 , 830 , 761 .

2-(2,4-Dichlorophenyl)-4,5-diphenylimidazole (Table 1,

Entry 18). ^1H NMR ($\text{DMSO-}d_6$, 500 MHz): $\delta = 12.8$ (s, 1H), 7.80 (d, $J = 8.4$ Hz), 7.81 (s, 1H), $7.61\text{--}7.22$ (m, 12H) ppm; ^{13}C NMR ($\text{DMSO-}d_6$, 125 MHz): $\delta = 126.7$, 127.2 , 127.4 , 127.9 , 128.2 , 128.3 , 128.7 , 128.8 , 129.6 , 130.6 , 132.4 , 132.6 , 133.9 , 134.8 , 137.1 , 142.4 ppm; IR (KBr, cm^{-1}): 3427 , 3068 , 1593 , 824 , 767 .


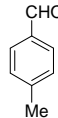
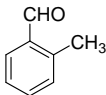
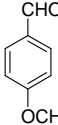
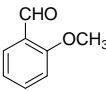
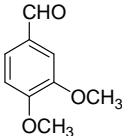
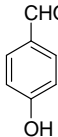

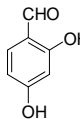
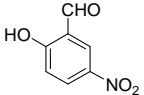
For recycling of the catalyst, after washing solid products with water completely, the water containing ionic liquid (IL is soluble in water) was evaporated under reduced pressure and the ionic liquid was recovered and reused.

General Procedure for Preparation of 1,2,4,5-Tetrasubstituted Imidazoles

Benzil or benzoin (1 mmol), aldehyde (1 mmol), amine (1 mmol), and ammonium acetate (1 mmol) were added to triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate (0.09 g, 0.2 mmol) at $100\text{ }^{\circ}\text{C}$ for the appropriate time reported in Table 2. After completion of the reaction which was monitored by TLC, the mixture washed with water, the solid product purified by recrystallization from ethanol. All of the desired product(s) were characterized by comparison of their physical data with those of known compounds. Some characterization data for selected known products are given below.

1,4,5-Triphenyl-2-P-tolyl-1H-imidazole (Table 2, Entry 6). ^1H NMR ($\text{DMSO-}d_6$, 500 MHz): $\delta = 2.26$ (s, 3H), 7.08 (d, $J = 8.0$ Hz, 2H), $7.16\text{--}7.18$ (m, 1H), $7.22\text{--}7.25$ (m, 6H), $7.26\text{--}7.28$ (m, 5H), $7.31\text{--}7.32$ (m, 3H), 7.50 (d, $J = 8.0$ Hz, 2H) ppm; ^{13}C NMR ($\text{DMSO-}d_6$, 125 MHz): $\delta = 21.5$, 127.2 , 128.4 ,

Table 1. Synthesis of 2,4,5-Trisubstituted Imidazoles *via* a One-Pot Pseudo Four Component Condensation Reaction in the Presence of Triphenyl(propyl-3-sulphonyl)phosphonium Toluenesulfonate as Brønsted Acidic Ionic Liquid (0.09 g, 0.2 mmol) under Solvent-Free Conditions at 100 °C

Entry	R ¹ -CHO	Reaction time (h)		Yield (%)		M.P. (°C)	
		Benzil	Benzoin	Benzil	Benzoin	Found	Reported [Ref.]
1		1	1.5	95	90	270	269 [19]
2		1.5	2	85	80	233-236	232-235 [20]
3		1.5	2.5	87	80	203-206	205-207 [21]
4		2	3	80	76	231-233	230-232 [21]
5		2	2.5	72	78	210	210-210.5 [21]
6		2	3.5	80	85	217-220	216-218 [22]
7		1	2.5	90	93	233	233 [19]
8		1	1.5	94	97	204-207	205 [23]
9		1	1.5	98	95	270-273	272 [17]
10		1	2	95	96	261-263	260.5-262 [24]

Synthesis of Highly Substituted Imidazoles Using Brønsted Acidic Ionic Liquid

Table 1. Continued


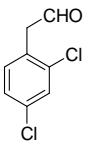

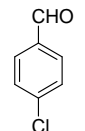
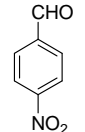
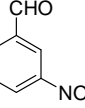
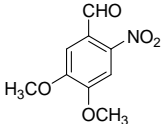
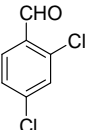

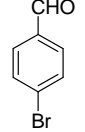
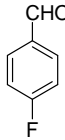
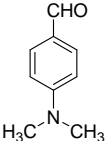
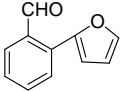
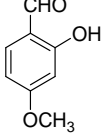
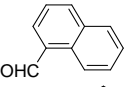
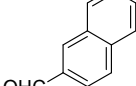
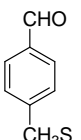
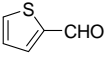
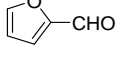
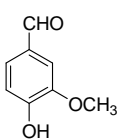
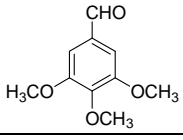
11		1	1.5	92	98	287-289	285-287 [18,25]
12		1	1.5	97	98	176-178	176.5-177 [26]
13		1	1.5	94	90	196-198	195-197 [27]
14		1	1.5	95	97	263	262-264 [21]
15		1	1.5	97	95	242-243	241-242 [18]
16		1	2	92	95	>265	>260 [18]
17		1.5	2.5	90	89	269-271	270 [17]
18		1	1.5	89	90	176-178	176.5-177 [26]
19		1.5	2	87	93	200-202	201-202 [28]
20		1	1.5	92	96	261-263	261.5-263.5 [21]

Table 1. Continued

21		1.5	2	95	89	189-191	189-190 [27]
22		2	3	92	92	256-258	257-258 [27]
23		1	2	88	95	202-204	202-203 [28]
24		2	2.5	94	98	242-243	243 [17]
25		1.5	2	89	92	290-292	291.5-292 [21]
26		1	2	85	95	242-243	241-242 [29]
27		1.5	2	96	98	243-244	242-244 [30]
28		2	3	92	90	260-262	260-261 [27]
29		1.5	2	90	94	200-201	200-201 [27]
30		1.5	2	89	90	199	197 [31]
31		2	3	84	80	261-262	261 [17]

^aYields refer to isolated pure products. The known products were characterized and compare their physical properties (M.P., ¹H NMR, ¹³C NMR and FT-IR) with authentic samples.

Synthesis of Highly Substituted Imidazoles Using Brønsted Acidic Ionic Liquid

Table 2. Synthesis of 1,2,4,5-Tetrasubstituted Imidazoles *via* a One-Pot Four Component Condensation Reaction in the Presence of Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate as Brønsted Acidic Ionic Liquid (0.09 g, 0.2 mmol) under Solvent-Free Conditions at 100 °C







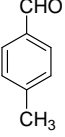

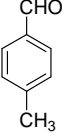

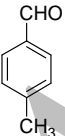

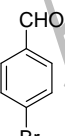
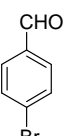

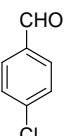
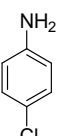
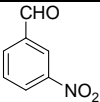
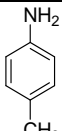
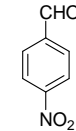
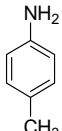
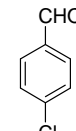
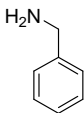
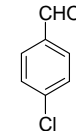
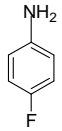
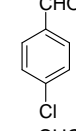
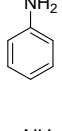
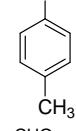
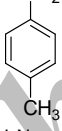
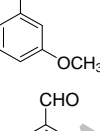
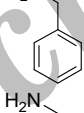
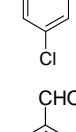
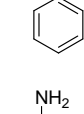
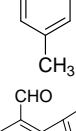

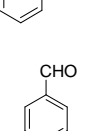
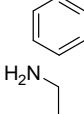

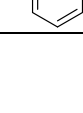
Entry	R ¹ -CHO	R ² -NH ₂	Reaction time (min)		Yield (%)		M.P. (°C)	
			Benzil	Benzoin	Benzil	Benzoin	Found	Reported [Ref.]
1			35	40	89	87	215-217	218 [32]
2			30	45	88	83	161-163	158-160 [32]
3		CH ₃ NH ₂	40	50	90	85	212-214	208-211 [33]
4		C ₂ H ₅ NH ₂	45	55	80	89	121-123	124-126 [33]
5			45	60	85	80	156-157	151-153 [33]
6			40	55	78	85	192-193	189 [32]
7			30	35	96	98	164-165	165-166 [32]
8		CH ₃ NH ₂	30	40	95	89	197-198	201-202 [32]
9			25	35	87	93	174-177	170-172 [34]
10			15	25	98	96	189-202	187-189 [33]

Table 2. Continued

11			30	35	92	89	152-154	149-151 [33]
12			25	30	95	90	222-225	219-220 [33]
13			20	25	89	93	160-162	156-158 [33]
14			15	20	95	97	198-200	196-197 [33]
15			20	25	92	85	167-169	163-165 [34]
16			45	50	85	78	192-194	188-191 [33]
17			45	60	87	90	132-135	128-130 [34]
18			30	35	93	95	149-152	146-148 [34]
19			55	60	87	82	164-167	164 [34]
20			20	25	89	92	156-158	156-157 [34]
21			20	30	92	97	135-137	134-135 [34]

Synthesis of Highly Substituted Imidazoles Using Brønsted Acidic Ionic Liquid

Table 2. Continued

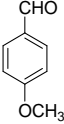
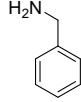
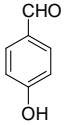
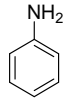

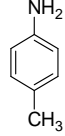
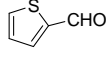
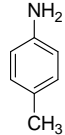
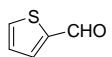
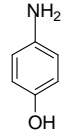
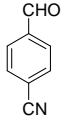
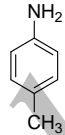


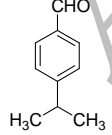
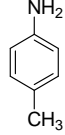
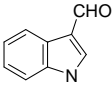
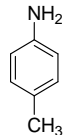
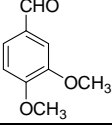
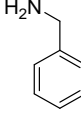
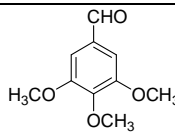
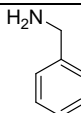

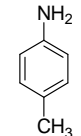
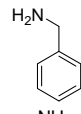
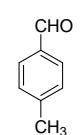
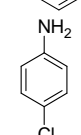

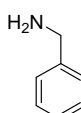
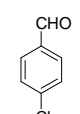
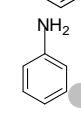
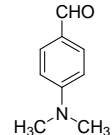
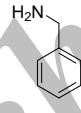
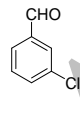
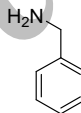
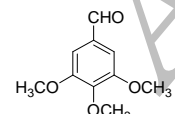

22			40	45	80	85	155-158	157-160 [35]
23			20	25	92	96	283-286	280-281 [36]
24			30	40	95	92	227-230	226-228 [37]
25			30	40	90	95	203-205	199-202 [38]
26			30	35	89	87	294-297	289-290 [38]
27			30	45	90	92	205-207	198-201 [38]
28			45	50	95	92	227-229	230-232 [37]
29			45	60	89	87	214-216	215-217 [38]
30			35	45	82	89	219-221	218-220 [38]
31			45	60	75	78	188-190	185-187 [37]

Table 2. Continued

32			50	60	72	76	188-190	184-186 [34]
33			30	40	85	89	250-253	248-251 [37]
34	$\text{CH}_3\text{CH}_2\text{CHO}$		50	60	80	87	100-104	104-105 [34]
35			25	30	92	92	162-165	165-167 [33]
36			25	35	90	85	145-147	140-142 [34]
37			20	30	87	85	154-155	150-152 [34]
38			25	40	85	86	180-182	183-185 [37]
39			25	30	92	92	140-141	144-146 [37]
40			50	60	89	83	117-119	112-115 [33]

^aYields refer to isolated pure products. The known products were characterized and compare their physical properties (M.P., ¹H NMR, ¹³C NMR and FT-IR) with authentic samples.

128.9, 129.0, 129.2, 129.50, 129.58, 129.6, 129.9, 131.3, 131.9, 132.0, 135.3, 137.60, 137, 63, 138.6, 147.0 ppm; IR (KBr, cm^{-1}): 2935, 1590, 1577, 1492.

1,2-Bis(4-chlorophenyl)-4,5-diphenyl-1H-imidazole (Table 2, Entry 10). ¹H NMR (DMSO-*d*₆, 500 MHz): δ =

7.17-7.19 (m, 1H), 7.23-7.25 (m, 4H), 7.29-7.32 (m, 5H), 7.38-7.42 (m, 6H), 7.50 (d, *J* = 7.0 Hz, 2H) ppm; ¹³C NMR (DMSO-*d*₆, 125 MHz): δ = 127.2, 127.4, 129.44, 129.49, 129.9, 130.1, 130.8, 130.9, 131.3, 132.0, 132.3, 134.1, 134.3, 135.0, 136.2, 145.8 ppm; IR (KBr, cm^{-1}): 2987, 1596, 1499,

1411.

For recycling the catalyst, after washing solid products with water completely, the water containing ionic liquid (IL is soluble in water) was evaporated under reduce pressure and ionic liquid was recovered and reused.

RESULTS AND DISCUSSION

Owing to the versatile biological activities of substituted imidazoles, numerous classical methods for the synthesis of these compounds have been reported [3-6]. In a typical procedure, benzil or benzoin, aldehydes, amines, and ammonium acetate are condensed in the presence of strong protic acid such as H_3PO_4 [14], H_2SO_4 [15], HOAc [16a] as well as organocatalysis in HOAc [16b] under reflux condition. These homogeneous catalysts present limitations due to the use of corrosive reagents and the necessity of neutralization of the strong acid media. In addition, the synthesis of these heterocycles in polar organic solvents such as ethanol, methanol, acetic acid, DMF and DMSO lead to complex isolation and recovery procedures.

In the optimization reactions, the condensation reaction of benzil or benzoin (1 mmol), aldehyde (1 mmol), and ammonium acetate (4 mmol) in the presence of ionic liquid, triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate (0.09 g, 0.2 mmol), as catalyst was found to be suitable and produced 2,4,5-trisubstituted imidazoles under solvent-free conditions at 100 °C (Scheme 1, Table 1).

Stoichiometric amount of ammonium acetate for the preparation of 2,4,5-trisubstituted imidazoles is 2. Although we can prepare 2,4,5-trisubstituted imidazoles using two equivalents of ammonium acetate but we observed in our experiments and other published papers, that if we use inexpensive and available ammonium acetate more than two equivalents, the reaction will show better results. Thus, excess of ammonium acetate was found to be advantageous and hence the molar ratio of benzil or benzoin to ammonium acetate was kept at 1:4.

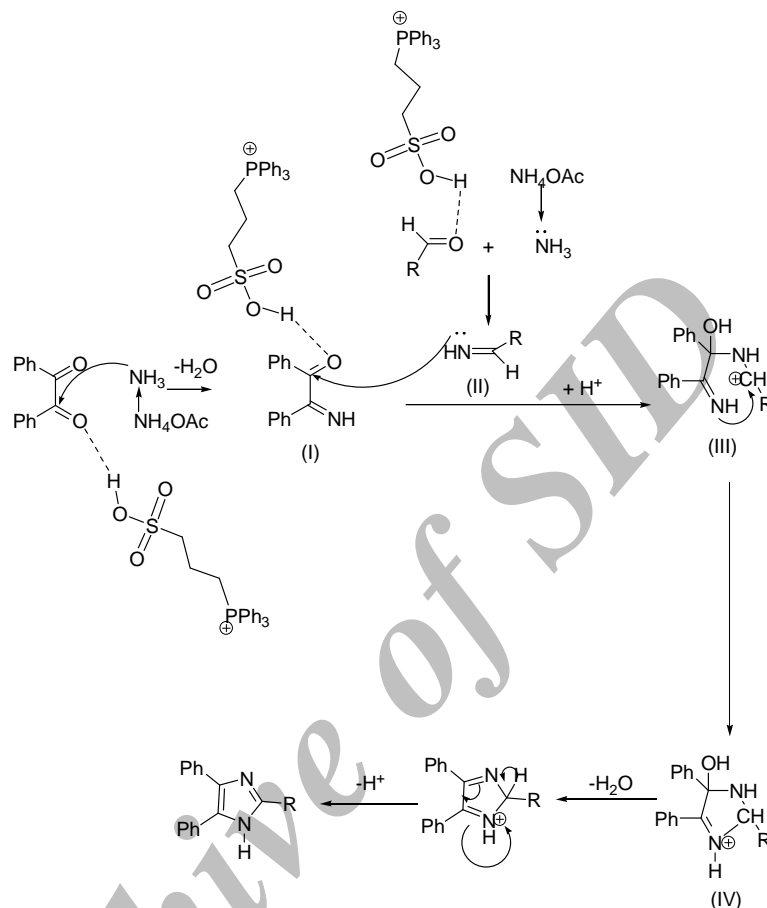
The efficiency and versatility of the ionic liquid as catalyst for the preparation 2,4,5-trisubstituted imidazoles was demonstrated by the wide range of substituted and structurally divers aldehydes to synthesis the corresponding products in high to excellent yields (Table 1). The presence of electron

donating groups on the aromatic aldehyde resulted in the corresponding products in low yields and the reaction was sluggish, however the presence of electron-withdrawing groups afforded the corresponding 2,4,5-trisubstituted imidazoles in shorter reaction time with higher yields. Also, benzil in comparison with benzoin give corresponding products in shorter reaction time rather than benzoin but there was no effect in the yield of corresponding 2,4,5-trisubstituted imidazoles.

Next, as part of our program aimed to develop useful new synthetic methods based on the use of mentioned ionic liquid as a catalyst, we have studied the four-component one-pot synthesis of 1,2,4,5-tetrasubstituted imidazoles by condensing benzil or benzoin (1 mmol), aldehyde (1 mmol), amine (1 mmol), and ammonium acetate (1 mmol) using a catalytic amount of triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate (0.09 g, 0.2 mmol) under solvent-free conditions at 100 °C (Scheme 2, Table 2).

According to the literature [39], the proposed mechanism for the reaction using ionic liquid as catalyst is described for the preparation of 2,4,5-trisubstituted imidazoles from the reaction of benzil, aldehyde and ammonium acetate in Scheme 4. Hydrogen bonding can occur between the solute (benzil) and the cationic component ($\text{ph}_3\text{P}^+(\text{CH}_2)_3\text{SO}_3\text{H}$) of ionic liquid. Brønsted acidic ionic liquid, triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate can activate the carbonyl groups of benzil and aldehydes to decrease the energy of transition state. Then nucleophilic attack of the nitrogen of ammonia obtained from NH_4OAc on the activated carbonyl group, resulted in formation of aryl aldimine(I) and α -imino ketone(II), and it followed by the nucleophilic attack of the *in situ* generated imine to carbonyl of aryl aldimine giving the intermediate(III). Their subsequent intramolecular interaction leads to cyclization and eventually to the formation of intermediate(IV) which dehydrates to the 2,4,5-trisubstituted imidazoles.

To show the merit of the present work in comparison with the reported results in the literature, we compared the obtained results of using triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate with some of the reported catalysts in the synthesis of 2,4,5-trisubstituted and 1,2,4,5-tetrasubstituted imidazoles. As shown in Table 3, 4, this ionic liquid can act as a suitable catalyst with respect to reaction times and yields of



Scheme 4. Suggested mechanism for preparation of 2,4,5-trisubstituted imidazoles

Table 3. Comparison of the Efficiency of Various Catalysts with Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate in the Synthesis of 2,4,5-Tri-substituted Imidazoles^a

Entry	Catalyst	Conditions	Time (min)	Yield (%)	Ref.
1	InCl ₃ .3H ₂ O	MeOH/R.T	492	76	[40]
2	KH ₂ PO ₄	Reflux EtOH	60	89	[41]
3	Yb(OPf) ₃	C ₁₀ F ₁₈ /80 °C	360	80	[42]
4	Zr(acac) ₄	Reflux EtOH	120	95	[43]
5	L-proline	Methanol/60 °C	9 h	87	[23]
6	[Hbim]BF ₄	100 °C	60	94	[19]
8	NiCl ₂ . 6H ₂ O/Al ₂ O ₃	Reflux ethanol	90	89	[44]
	triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate	100 °C	60	98	Present work

^aBased on the preparation of 2-(4-nitrophenyl)-4,5-diphenyl-1*H*-imidazole (Table 1, entry 15).

Table 4. Comparison of the Efficiency of Various Catalysts with Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate in the Synthesis of 1,2,4,5-Tetrasubstituted Imidazoles^a

Entry	Catalyst	Condition	Time (min)	Yield (%)	Ref.
1	BF ₃ /SiO ₂	140 °C	120	92	[42]
2	SiO ₂	CH ₂ Cl ₂ /R.T	120	90	[45]
3	NaHSO ₄ /SiO ₂	140 °C	120	92	[33]
4	InCl ₃ .3H ₂ O	140 °C	440	79	[40]
5	L-proline	Methanol/R.T	9 h	88	[23]
6	AlCl ₃	Methanol/60 °C	120	53	[42]
7	MgCl ₂	140 °C	120	50	[42]
8	SnCl ₄	140 °C	120	60	[32]
9	K ₅ CoW ₁₂ O ₄₀ .3H ₂ O	140 °C	120	95	[37]
10	Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate	100 °C	30	98	Present work

^aBased on the preparation of 1-benzyl-4,5-diphenyl-2-*p*-tolyl-1*H*-imidazole (Table 2, entry 7).

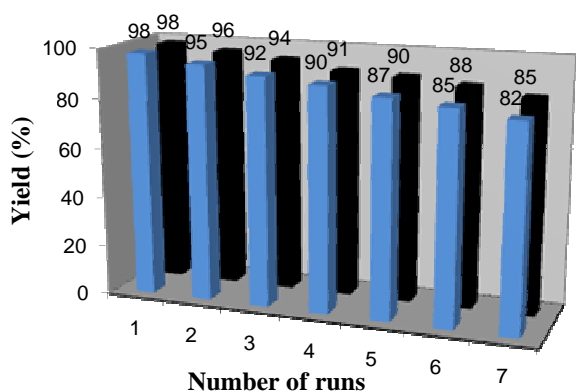


Fig. 1. The recycling of the triphenyl(propyl-3-sulphonyl) phosphonium toluenesulfonate as Brønsted acidic ionic liquid under solvent-free conditions: (blue) product yield, %; (black) recycling catalyst yield, %.

the products.

We also investigated the recycling of the catalyst under solvent-free conditions in the reaction of 4-methylbenzaldehyde, benzyl amine, benzil, and ammonium acetate (Table 2, Entry 7). After completion of the reaction, water was added and the precipitated was filtered off for

separation of the crude product. After washing the solid products with water completely, the water containing ionic liquid (IL is soluble in water) was evaporated under reduced pressure and the ionic liquid was recovered and reused. The recovered catalyst was reused in seven runs without any loss of its activities (Fig. 1). We also calculated the turnover frequency (TOF) to discuss the activity of the catalyst. The substrate conversion percentage to the product was 100% and TOF obtained 10 h⁻¹.

CONCLUSIONS

Triphenyl(propyl-3-sulphonyl)phosphonium toluenesulfonate efficiently catalyzes the condensation reaction of benzil or benzoin, aldehydes, amines and ammonium acetate in a four-component reaction and affords the corresponding 1,2,4,5-tetrasubstituted imidazoles in high yields. Also this recyclable catalyst has been used for preparation of 2,4,5-trisubstituted imidazoles by one-pot condensation of benzil or benzoin, aldehydes and ammonium acetate in excellent yields under solvent-free and conventional heating conditions. The recovered ionic liquid was reused for seven cycles without loss of its activities.

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